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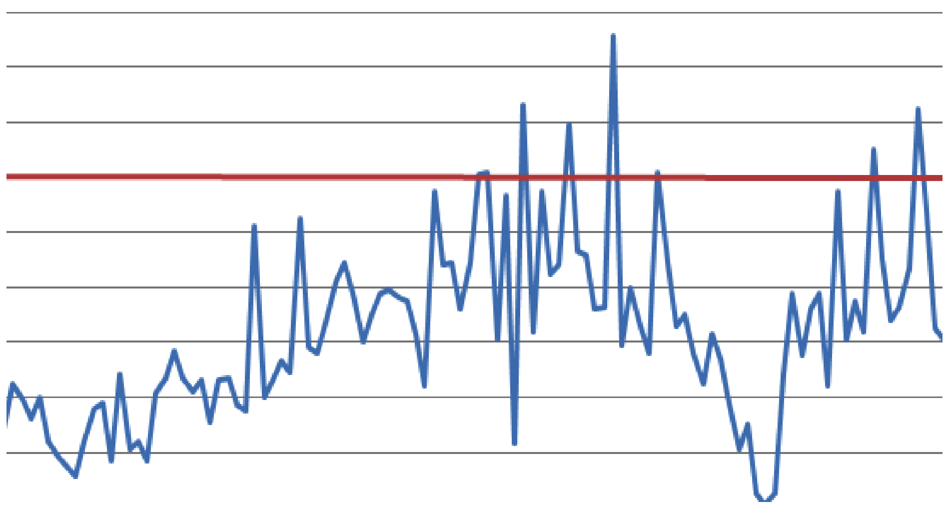

Lean Capacity Planning

- planning for maximising customer value

Master of Science Thesis in Supply Chain Management

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Abstract

The importance of capacity planning has increased since many companies have reduced their inventories of finished goods to decrease unnecessary tied-up capital. At the same time, these companies want to have the possibility to respond to fluctuations in demand. The fluctuations that previously were absorbed by the inventories have now been transferred upstream to the production sites. As a result of this transfer, high performance of the capacity planning is essential and problems have to be mitigated. Many companies believe in lean as an approach to improve processes and thereby gain competitive advantage. However, it is unclear if lean can be an approach to mitigate problems in a capacity planning process. With this background, the purpose of this thesis is to investigate how companies can apply lean principles in their capacity planning process.

This thesis was conducted as a case study at Nobel Biocare. Three research questions were formulated. The first question concerns the identifying of problems in the capacity planning process. In order to answer this question, 11 interviews were conducted at Nobel Biocare. Research question two investigates how lean principles can be used to mitigate the identified problems in the capacity planning process. Inspiration from three reference companies that have implemented lean principles in their capacity planning process were used as input to answer this question. The last research question was formulated to assess how the solutions could be applied into a model. A structure of the capacity planning process was used as a basis for categorising the solutions into three parts; preconditions for planning, planning hierarchy and planning cycle.

The result of this thesis is that 17 problems were identified in Nobel Biocare's capacity planning process. 13 out of these 17 problems could be mitigated with the use of lean principles. The conclusion is that companies will become more customer-focused by applying lean principles in their capacity planning processes. The findings of this analysis have been summarised in a model called the lean capacity planning process. Based on this model recommendations to Nobel Biocare have been given.

The thesis's contribution to theory is a starting point for closing the gap of how lean principles and capacity planning can be combined. By following the model, lean capacity planning process, companies can improve their capacity planning process and thereby increase competitiveness.

Keywords: *Capacity planning, lean, lean principles, lean planning*

Foreword

This Master of Science thesis was conducted during the spring of 2013 within the Master Degree Programme Supply Chain Management at Chalmers University of Technology in Gothenburg, Sweden. The thesis was carried out as a case study at Nobel Biocare.

First, we would like to thank Fredrik Helgesson at Nobel Biocare for giving us the opportunity to conduct this thesis at the company. We would like to give a special thanks to our supervisor Andreas Liljeskog at Nobel Biocare, who has given us great support, input and continuous feedback during the entire time. As a part of the study, we have conducted several interviews at Nobel Biocare. All of these interviewees have given us support and helpful input. Therefore we would like to thank the interviewees at the two production sites and at the supply chain department.

Further, we want to thank Paulina Myrelid who has served as our supervisor at Chalmers. Your support, knowledge within the subject and clear guidelines have been very valuable throughout this thesis.

Finally, the three reference companies gave us invaluable inspiration to the result of this thesis. We therefore want to thank Thomas Nilsson and Hans-Jörgen Abrahamsson at Autoliv, Sven Kjellström at Emerson and Lars Hansson at Parker for their input.

This spring has given us valuable knowledge and insights into the capacity planning process and lean principles as well as the combination of these two. We are grateful for this experience!

Gothenburg, May 2013

Anna Linné Carl-Johan Ekhall

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List of Definitions

In this section important definitions are presented.

- Available capacity: $Capacity_{available}\ [hours] = Resources_{mach\frac{ines}{operators}}\ [units] *$ Conversion factor $\left[h\frac{ours}{unit}\right] - Losses\ [hours]$
- Capacity utilisation accuracy:
  Capacity utilisation accuracy = $(1 - \left|\frac{actual\ cap.utilisation - planned\ cap.utilisation}{actual\ cap.utilisation}\right|) \times$ 100
- Capacity utilisation:
  $Capacity\ utilisation\ [\%] = \frac{Produced\ volume}{Nominal\ capacity}$
- Conversion factor, available capacity:
  The number of available hour a certain machine/operator corresponds to.
- Conversion factor, requirements of capacity:
  The time each SKU requires for processing
- Customer:
  The term customer in this thesis is referred as both internal and external stakeholders.
- Delivery lead-time:
  The time between an order is received at the production site and the delivery can take place at the customer.
- Forecast accuracy:
  $Forecast\ accuracy\ [\%] = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{Forecast\ demand - Actual\ demand}{Actual\ demand}\right| \times 100$
- Inventory turns:
  $Inventory\ turns = \frac{Cost\ of\ goods\ sold}{Tied-up\ capital}$
- Perceived customer value:
  $Perceived\ customer\ value = \ Total\ customer\ value - Total\ customer\ cost$
- Requirements for capacity (principal formula):
  $Capacity_{Required,SKU}\ [hours] = \ Volume_{SKU}\ [units] * Conversion\ factor\ [hours/unit] * \ (1 + scrap\ rate_{SKU})\ [\%] \ + \ Setup\ time\ [hours]$
- Scrap rate:
  $Scrap\ rate\ [\%] = \frac{Number\ of\ scrapped\ products}{Total\ produced\ products}$
  The scrap rate corresponds to an additional volume that needs to be produced (Chiu et al, 2004)

1 Introduction

This chapter begins with the theoretical background for this thesis. A brief background to the case company and its situation is also presented. These backgrounds result in the purpose and related research questions of this thesis. A section of the scope and limitations is also provided as well as an outline for the rest of the thesis.

1.1 Theoretical background

Many companies have implemented lean on their way to operational excellence (Grimson & Pyke, 2007). The focus in lean is to maximize customer value with minimal resources. For many companies, this approach has lead to reduced inventory levels and shortened lead times (Christopher, 2005). The lean principles are used in organisations to identify and minimise waste within operations. In the case of inventory, unnecessary tied-up capital can be regarded as waste. Companies that have a culture of reflecting on and identifying waste in their organisation have the opportunity to continuously improve their processes (Liker & Meier, 2006). Continuous improvements are important for companies to stay competitive in a changing environment. This is one of the benefits that companies believe in as a result of implementing lean in their organisations.

Companies have also realised the importance of responding faster to fluctuations in demand to stay competitive (Grimson & Pyke, 2007). The trend of becoming lean and the focus on having minimal inventories have increased the importance of having available capacity in production (Christopher, 2005). The fluctuations that previously were managed by inventories have been transferred upstream to production creating capacity imbalances. The different alternatives to manage capacity imbalances are related to costs (Bakke & Hellberg, 1993). These costs should not be exceeded by the costs for having inventory. For companies with low inventory it is essential to choose the right alternative for balancing capacity. The right alternative meets the customer demand and is the most cost efficient. There is also a time-dimension when changing capacity. The rule of thumb is that changes in capacity are more limited on a short term compared to on a long term (Vollmann et al, 2005). This requires companies to plan capacity ahead and to have a higher focus on the challenges in the capacity planning.

As mentioned, lean is regarded as an approach for many companies to stay competitive. In the same companies, the importance of capacity planning has increased. It is thus interesting to investigate how lean affects the capacity planning process. There exist a gap in current literature of how lean principles can be applied in a company's capacity planning process. Lenders et al (2011) briefly investigated the possibility of using lean principles for planning purposes but this needs to be further investigated.

1.2 Case company background

Many companies use lean principles to maximise customer value with minimal use of resources. One of these companies is Nobel Biocare, which is the case company of this thesis. Nobel Biocare is one of the largest producers of dental implants in terms of market share with sales of 581 million euro.

Nobel Biocare has identified decreasing margins within the last five years as a result of increased competition. This has made them focusing on cutting costs in their operations. Many different projects were conducted at Nobel Biocare between 2008-2010 to become more cost-efficient. The most important outcome from these projects was reduced inventory of finished goods for Implant systems by 50%. Although the inventory was reduced, the service level targets were maintained. This increased the pressure on production to handle fluctuations in demand instead of manage them by inventory. Accordingly, a capacity planning process was set up and a responsible Global Capacity Planner was employed in January 2011. The capacity planning process is thus relatively new at Nobel Biocare and there are problems that harm the performance of it, e.g. low accuracy of the capacity data and inefficient meetings.

The company has realised that one of the approaches to become more cost efficient is the use of lean principles. Some of the lean principles used at the company today are pull-based production and continuous improvements at the production sites. There has not been any implementation of lean principles in the capacity planning process. However, Nobel Biocare believes that there exist a potential for implementing lean principles to overcome the problems in the capacity planning process.

1.3 Purpose

The purpose of this thesis is to investigate how companies can apply lean principles in their capacity planning process.

1.4 Research questions

To fulfil the purpose three research questions (RQs) will be answered. The answer to each question creates the preconditions to answer the following question in a descending order.

RQ1) What problems can be identified in a company's capacity planning process and its related context?

RQ2) How can lean principles be applied as potential solutions to the identified problems?

RQ3) How can the solutions be applied in the capacity planning process by incorporating them into a model?

1.5 Scope and limitations

The scope covers how lean principles can be applied to solve problems in Nobel Biocare's capacity planning process and its related context. Although demand management and material planning affect the capacity planning these processes are not investigated in depth. The primary data collection about the case company will only be conducted in Gothenburg (Supply Chain department), Stockholm (Procera production site) and Karlskoga (Implant Systems production site). The thesis is excluded from the practical implementation of the proposed solutions as well as from following-up the results of the implementation at Nobel Biocare. Moreover, it only covers the capacity planning of in-house manufactured products.

Nobel Biocare has three planning levels in its capacity planning process. These three planning levels correspond to sales and operation planning, master production schedule and order planning. In theory a fourth planning level is described, execution and control (Jonsson & Mattsson, 2009). This fourth level will not be included in this thesis.

There exist several methods for calculating capacity. All of these methods will not be included in the thesis. Only the method used at Nobel Biocare will be described due to the scope of this thesis.

1.6 Outline

The first chapter is the introduction, with the aim of creating an understanding of the relevance of the thesis topic. The aim also includes discussing the problem investigated in this thesis as well as purpose, research questions and delimitations of the thesis. The second chapter is frame of references, which present relevant literature. This literature includes two main topics, capacity planning and lean. Next chapter is the methodology, followed by the empirical findings. The latter describes Nobel Biocare´s capacity planning process and its context as well as three reference companies. The fifth chapter is the analysis. Here an analysis is done regarding the empirical findings together with the frame of references. This chapter is followed by the discussion, which includes a critical reflection on the method used. The results of the analysis are also discussed here. Finally, the conclusions of the thesis are presented.

2 Frame of reference

This frame of reference provides the theoretical foundation needed to understand this thesis and has supported the collection of empirical data and conduction of analyses. In relation to the research questions, the two general topics of this thesis are capacity planning and lean. The objectives of capacity planning and the concept capacity imbalances are presented to be able to identify problems. The structure of the capacity planning process is described. The three parts; preconditions for planning, planning hierarchy and planning cycles are important to understand. Finally, lean principles are explained, since they are applied as solutions to mitigate these identified problems.

2.1 Capacity planning

In this section different aspects of capacity planning are described. These aspects have been chosen according to their relevance to this thesis.

2.1.1 Objectives of the capacity planning process

The primary objective of capacity planning is to guarantee that production plans become feasible to execute (Tenhiälä, 2011). It is reached by estimating the requirements for capacity far enough into the future to be able to match with available capacity (Vollmann et al, 2005). Another objective is achieved on short-term, namely execution. Vollmann et al. (2005) emphasise that risks that can alter the capacity plan should be mitigated to guarantee a flawless execution of the capacity plan.

If companies fail to manage these objectives, capacity imbalances will appear (Jonsson & Mattsson, 2009). Avoiding capacity imbalances are important since production resources available for adding value are associated with costs, regardless if the resources are used or not. On one hand, if the available capacity exceeds the requirements this will lead to overcapacity and thereby low resource utilisation. On the other hand, if a manufacturer lacks capacity it cannot meet the demand from customers and thereby experience loss of income. Hence, capacity planning has a substantial impact on companies' financial bottom lines (Vollmann et al, 2005).

Capacity imbalances usually appear due to unpredicted fluctuations in demand. These can be a result of changed market conditions e.g. changed competition, raw material shortage or regulatory changes. Increasing or decreasing the stock for make-to-stock (MTS) products can absorb some of the fluctuations. However, many companies have decreased their inventories lately to decrease tied-up capital. As a result of this trend, the fluctuations are handled by production capacity to a larger extent than before. For make-to-order (MTO) products, the lead-times could possibly be shortened or prolonged. (Christopher, 2005)

Companies want to utilise their existing capacity as much as possible to get return on their investments (Christopher, 2005). There exists two main strategies for capacity utilisation: *level*- and *chase strategy* (Jonsson & Mattsson, 2009), see Figure 1. Level strategy means that the capacity is equally utilised over time and the stock or delivery time is changing as the demand fluctuates. This results in a steady production volume per time period. The main advantage is that costly capacity changes such as overtime and subcontracting are avoided while the largest downside is tied-up capital in inventory. The opposite strategy is chase strategy where the capacity utilisation is determined by the demand. The corresponding advantages and disadvantages are opposite those for the level strategy. Since many companies have reduced their inventories, it is hard for them to follow the level strategy on long-term. It is therefore common to combine the two strategies. The chosen strategy influence companies' decisions regarding how to cope with capacity imbalances, e.g. the choice of inventory levels, lot sizing and overtime usage.

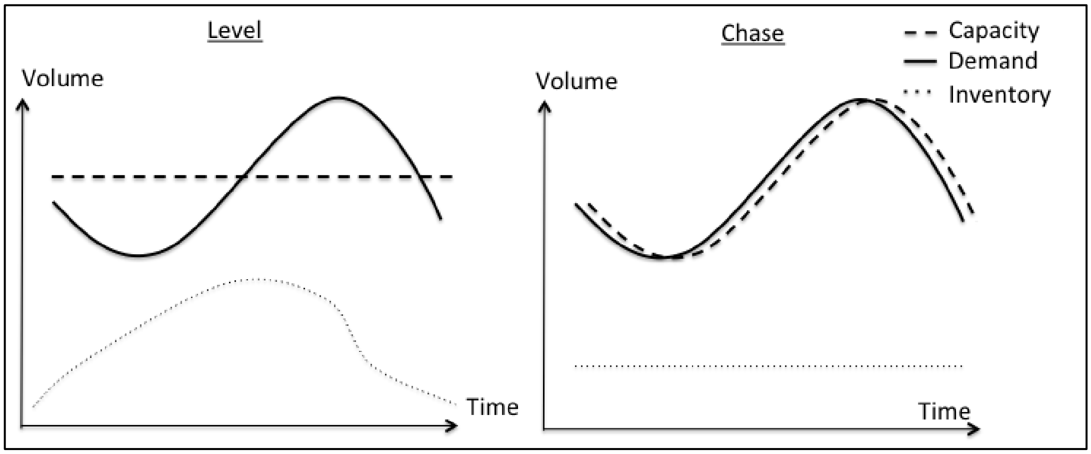

Figure 1 - Level strategy and chase strategy (adopted from Jonsson & Mattsson, 2009)

2.1.2 Structure of the capacity planning process

The capacity planning process can be divided into three distinguishable parts; *preconditions for planning*, *planning hierarchy* and *planning cycles*. These three parts have been identified from (Jonsson & Mattsson, 2009) and (Vollmann et al, 2005). These three parts can be seen as important steps to follow when developing a capacity planning process. The three process steps are illustrated in Figure 2. First, it is important to assess the preconditions for planning since they determine the possibilities and limitations to balance capacity. Second, since capacity imbalances appear on different time-horizons it is important to define a planning hierarchy that suits the preconditions for planning. Third, the capacity planning executed at the different planning levels is repeated in a fixed frequency and can be described as cycles. When the preconditions for planning are assessed and the planning hierarchy is defined, companies need to design their planning cycles. All the three stages should be developed in a way that maximizes the performance of the capacity planning. The three parts of the capacity planning process are explained further below.

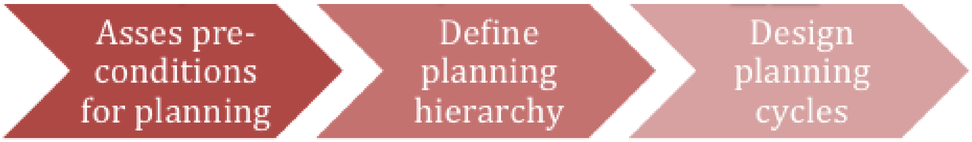

Figure 2 - Structure of the theoretical framework

2.1.3 Preconditions for planning

Different aspects of a company's context are important to consider when planning capacity. Some of these aspects are *manufacturing approach, production, market and demand, people, lean* and *ERP-system.* These six preconditions will be explained further since they are relevant for this thesis.

The manufacturing approach affects what opportunities and limitations that exist in the capacity planning. The planning for MTS and MTO has different characteristics. For instance, the MTS production has a higher possibility to level out the production since an inventory of finished goods exist. Since MTO production is based on real customer demand, fewer options exist. The lead-time also affects the planning environment. A shorter lead-time requires a faster responsiveness than having longer lead-times. (Jonsson & Mattsson, 2009)

The production layout is affecting the complexity of the planning. The layout is dependent on the processes of a company (Tenhiälä, 2011). The processes might require a certain production layout to achieve a feasible and efficient production. The production layout determines the number of planning points (Olhager & Rudberg, 2002). The concept of planning points means that a manufacturing resource or a set of manufacturing resources can be regarded as one entity from a planning point of view. These resources can be a work-centre or a work cell. The degree of flow orientation and routing complexity together with the number of manufacturing operations are all affecting the number of planning points. If the machines in a production are planned individually, each of them can be seen as a planning point. The numbers of planning points can be reduced e.g. with the use of cellular manufacturing instead of single resources. Cellular manufacturing means that several operations are linked together in a continuous flow. This leads to that the entire cell can be seen as one planning point regardless of the number of operations within it. Fewer planning points implies less resources to consider in the planning.

Vollmann et al. (2005) stress the importance to understand the market requirements and demand when planning capacity. This includes the understanding of customers' behaviour. Understanding the demand is crucial for capacity planners to be able to make decisions that benefit customers. The fluctuations in demand and related inventory are two factors that determine how much capacity that is needed in production. If the capacity planners are aware of these two factors, they will be able to plan more efficiently.

All organisations consist of people. The capacity planning process involves many people from different functions. Tyler (2003) argues that it is essential that these people trust each other in order to collaborate in the creation of customer value. Van Weele (2010) writes that trust is a result of two factors, competence and trustworthiness. First, building competence is about developing people´s skills, experience and creativity. Second, having strict ethical principles and procedures generates trustworthiness. Related to trust, in many companies there exist information asymmetry (Clarkson et al., 2007). Information asymmetry means that the information in a given situation between two parties is not the same. One of the parties has greater informational awareness to effectively participate in this situation compared to the other party. Information asymmetry can lead to opportunistic behaviour (Dawson et al., 2011). Depending on the departments, different performance targets have been established. It is important to understand these different objectives when conducting planning, since there can be a conflict of interest. Jonsson and Mattsson (2009) emphases that the top management has to prioritise the performance targets that support the company's strategy and competitiveness. These targets should be the basis for the KPIs that the planning strives for.

Today many companies are committed to lean. It is therefore important to assess what lean principles these companies believe in and reflect upon how they affect the planning environment. If companies want to implement lean principles in their processes, they need to have a clearly stated lean philosophy. The philosophy is working as the basis for all other lean principles. It is essential to have one clear stated philosophy in order to benefit from the other lean principles. This philosophy should be shared throughout the entire organisation in order to achieve outstanding results. The key to success of implemented lean principles in processes is rather how people use the principles than the process itself. (Liker & Meier, 2006)

ERP-systems provide powerful tools that can support the capacity planner (Kappauf, 2011). If the ERP-system should be used for planning it is important to understand the opportunities and limitations of the system. It is also important to be aware of the available master data in the ERP-system (Jonsson & Mattsson, 2009). Implementing ERP for capacity planning is often related to an investment and it is important that the benefits outweigh the costs for it.

2.1.4 Planning hierarchy

Capacity planning is about making decisions regarding future actions to avoid capacity imbalances. These decisions may concern the next few hours or days but they can also relate to actions that are six months or one year ahead. These different situations differ not only regarding the time horizon but also the level of detail of information behind the decisions. The challenges regarding these two planning parameters, time and detail, can be handled by the use of a hierarchical structure of planning levels, see Figure 3. This hierarchical structure contains three levels of capacity planning. The first planning level is sales and operations planning (S&OP), which has the longest time-horizon and low level of details. The second level is master production scheduling (MPS). Finally, order planning is the level with shortest time-horizon and high level of details. The chosen time-horizon and detail-level in these levels should be chosen dependent on the decisions made at the different levels. Some decisions, e.g. recruitments and investments, take long time to implement and therefore need to be made with a long time-horizon. (Jonsson & Mattsson, 2009)

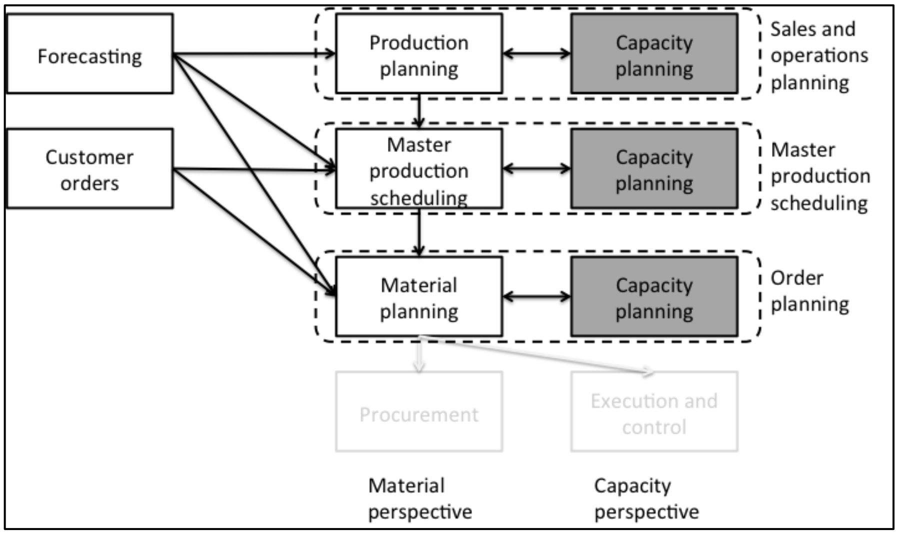

Figure 3 - Planning hierarchy (adopted from Jonsson & Mattsson (2009))

The planning levels need to be integrated. In order for the functions of the different planning levels to work efficiently, two conditions must be fulfilled. The first one is that decisions at one level need to consider the limits of the level above. The second condition is that the decisions at one level can be transferred to subordinate levels. If these conditions are not fulfilled, decisions become meaningless due to they are being replaced by later decisions at a lower level or they cannot be implemented. (Jonsson & Mattsson, 2009)

2.1.5 Planning cycle

The planning cycle below is developed from Jonsson & Mattsson (2009) description of capacity planning at different planning levels. The capacity planning is conducted in parallel with material planning. The capacity planning cycle includes five steps: production plan, capacity requirements, meetings, actions and capacity plan, see Figure 4. The capacity planning per se is the second and fifth step but the three other steps are necessary as input or as supporting steps.

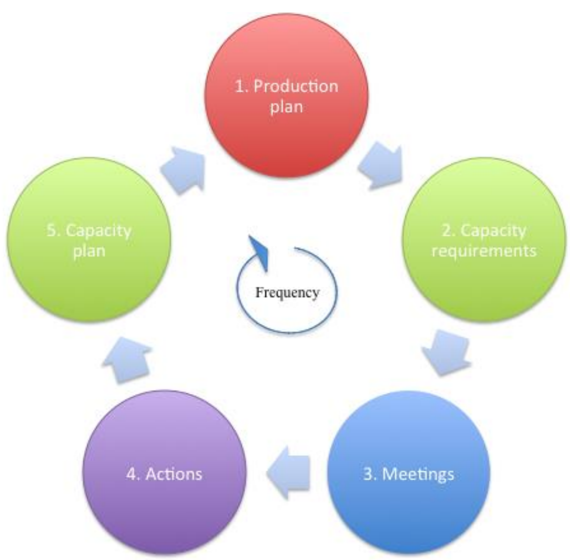

Figure 4 - The capacity planning cycle

1. Production plan - The first two steps according to Jonsson & Mattsson (2009) model is to forecast future demand and to develop a delivery plan. For MTS products this delivery plan takes inventory into account. The quantities that need to be produced to fill-up the inventory are summarized in a production plan. The production plan can contain both forecasts and real customer orders depending on the planning level. The production plan is used as input for the capacity calculations conducted in the next step.

2. Capacity requirements - The next step of the planning cycle is to translate the production plan into capacity requirements. The required capacity is compared with the available capacity to identify capacity imbalances. This implies calculations that can be conducted with the use of different capacity planning methods. The methods are different with regards to how many aspects the calculations take into consideration. Companies need to find the method that best suits their planning environment (Tenhiälä, 2011). Rough-Cut Capacity Planning (RCCP) is a common method used by many companies, especially on long-term (Jonsson & Mattsson, 2009).

In RCCP the demanded volume is multiplied with the historical capacity requirement per volume-unit and stock-keeping unit (SKU), i.e. conversion factors. In addition, scrap rates and setup times can be taken into consideration. The latter leads to a fixed additional amount of time. The setup time is a specific share of the total required time and this share decreases if the lot-size is increased, see Figure 5. See List of definitions for the formulas to calculate required capacity and available capacity. The result from the former is required hours per SKU. These capacity requirements per SKU are added up to assess the aggregated requirements for capacity per period. (Jonsson & Mattsson, 2009)

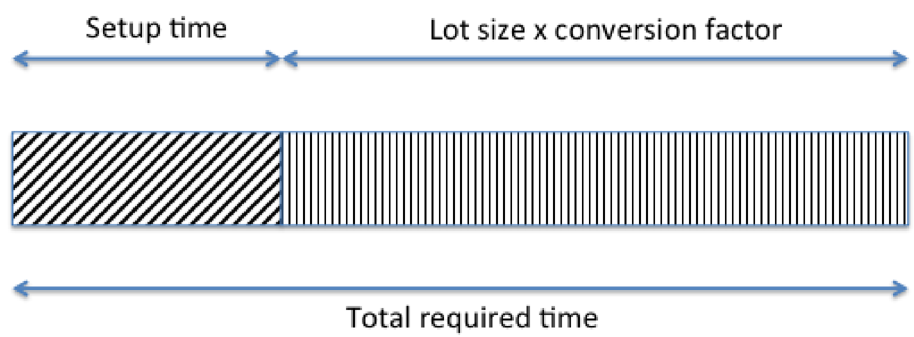

Figure 5 - Setup time and run time as constituents to the total required time

3. Meetings - The third step in the planning cycle is to have a meeting with the involved stakeholders. Alternative actions to mitigate the identified capacity imbalances are discussed during these meetings. The actions can be to use overtime to adjust capacity or to postpone orders to change the delivery- and production plan. The goal is to come to an agreement regarding the best action to implement.

4. Actions – After the meeting the decided actions are implemented. There is a time-dimension in capacity planning and the rule of thumb is that actions to change capacity are more limited on a short-term compared to long-term (Vollmann et al, 2005). This implies that different actions are possible depending on what planning level the decision is made. On long-term, it is generally possible to completely adapt the available capacity to the required capacity. However, financial limitations always exists and costs for increasing capacity have to be justified against the potential loss of income, which can be the case when orders are postponed. On mid-term and short-term the possibilities are fewer. Jonsson & Mattsson (2009) summarised the different actions to balance the capacity on mid-and short-term. See Table 1.

Table 1 - Summary of different actions by Jonsson & Mattsson (2009)

Type of alternative	Mid-term	Short-term
Increase/decrease capacity	Hire/fire personnel New machines Number of shifts Sub-contracting	Sub-contracting Extra shifts
Increase/decrease capacity need	Change master production schedule Increase/decrease inventory	
Reallocate capacity	Reallocate personnel between work-centers	Reallocate personnel between work-centers
Adjust capacity		Overtime Postpone maintenance
Reallocate capacity requirements	Make-to-anticipation inventory Change delivery lead-time	Earlier/postpone order start Change order quantities Alternative work-centers Overlapping/order splitting

5. *Capacity plan* – The fifth step includes that the actions taken are taken into consideration into a capacity plan. The plan should be provided to all the employees that are affected by it. In relation to the primary objective of capacity planning, the capacity plan and related production plan should now be feasible to execute.

2.1.6 KPIs in capacity planning

Key performance indicators (KPIs) are used to measure companies’ performance (Bongsug, 2009). KPIs are also essential to measure the performance of the capacity planning process. The role of KPIs is to provide feedback for continuous learning and development. Companies can by monitoring KPIs reveal the gap between plan and execution and identify and make correcting actions to potential problems. KPIs can serve as an early warning system. It is difficult to design strategic operational processes transparently without the use of relevant KPIs. In order to gain success in the use of performance metrics it is necessary to determine organisational infrastructure regarding roles and responsibilities. This is something that many companies have little understanding for.

There exist a large number of KPIs mainly used for production, distribution and inventory systems (Popova & Sharpanskykh, 2010). The selection is a critical step for the design and evaluation of a system. It is important for companies to determine the relevant indicators, how they relate to the company´s goals and how they depend on the performed activities. One of the KPIs that is affected by the capacity is lead-time from customer order to delivery. The lead-time together with inventory levels determines what service level that can be offered to customers. It is common that companies do not consider the impact of capacity levelling on lead-time performance in their capacity planning models. It is especially important to consider these impacts in make-to-order environments since customer orders arrive randomly. Companies with a high variety of products have long lead-time due to insufficient capacity, which create queuing delays at the machines. The inventory levels are usually limited by targets on inventory turns. The inventory should be turned over a number of times per year to avoid high levels of tied-up capital. A KPI that measures the performance of the capacity planning per se is capacity utilisation. The goal is to maximise the capacity utilisation to increase the return on investments. However, a high level of utilisation can create longer lead-time for the products and at the same time high levels of inventory. Finally, a KPI that affects the capacity planning indirect is forecast accuracy (Jonsson & Mattsson, 2009). The forecast accuracy determines the accuracy of the production plan, which is the basis for the capacity requirements.

2.2 Lean

The definition of customer value has been changed from the notion that value is something created by the seller towards that value is determined by the customers, referred to as perceived value (Setijono & Dahlgaard, 2008). The components of a high customer value include low price, quick response, great service and high quality. These are similar to what can be referred to as value added, i.e. higher quality for products or services, lower cost and faster delivery and have been discussed within manufacturing companies as lean production. Lean is often associated with the improvement of organisational performance regarding reduced manufacturing lead-time, reduced inventory, increased flexibility, increased quality and overall improved customer satisfaction (Worley & Doorlen, 2006).

Customers that are now demanding more specialised products have made companies move away from mass-production toward more differentiated production in order to meet customer demand (Mileham et al., 1999). Companies need to compete on product differentiation, product quality, price, delivery performance and time for development so that they can introduce new and improved products to the market. The previous mass manufacturing is not competitive enough and has, among others, lead companies to adopt production systems that are based on lean principles (Christopher, 2005). This means an approach toward total improvement by involvement of all personnel and a more process-oriented way of thinking.

The focus of lean is value. Many organisations see the creation of value equal to cost reduction. Value is linked to the customers and it is those who decide what can be perceived as waste. Customer value will increase if the waste is reduced regarding internal activities and associated costs are reduced. When lean is used, short delivery cycle times or smaller delivery batches to the customer can be achieved, which also create value without any adding of costs. (Hines et al., 2004)

Hines et al. (2004) argue that lean exists at two levels, the strategic and operational levels. The strategic level contains the customer-centred thinking and involves everyone at the company, whereas the operational level does not. This has created a misunderstanding for the use of lean and many companies have their major focus on lean implementation on the shop floor level, without considering lean thinking. In order to implement the right tools and strategies to create customer value it is crucial to understand lean.

2.2.1 Lean principles

Lean can be divided into four aspects denoted as the 4P model: *Philosophy*, *Process*, *People* and *Problem solving* (Liker & Meier, 2006). Each aspect involves a number of principles that have managerial consequences for companies adopting them, in total 14 principles. These four aspects of lean encompass 14 principles are elaborated below.

First, a stringent lean philosophy sets the foundation for all other principles (Liker & Meier, 2006). The focus in a lean philosophy is long-term profitability. This implies that it can be necessary to create waste and make investments in the short-term to get high-quality lean processes to save money and reduce waste in the long-term. This leads to the first lean principle.

Lean principle 1. *"Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals"(Liker & Meier, 2006, p. 8)*

This is a principle that should be shared with everyone at the company and it should be the starting point for every decision. The objective is to maximize value for the customers, and other stakeholders in the long run.

The second aspect is process, which emphasises the fact that the right process will produce the right results. Process involves lean principles 2-8.

Lean principle 2. *"Create a continuous process flow to bring problems to the surface" (Liker & Meier, 2006, p. 9)*

Problems are brought up to the surface by creating a continuous process flow where waiting times in operations are eliminated. It is not only about material flows in production; this can also be applied to project management or business development. People and processes are linked together in workflows and this lead to great opportunities to identify areas of improvements in any process.

Lean principle 3. *"Use pull systems to avoid overproduction" (Liker & Meier, 2006, p. 9)*

Traditionally, holding inventory has been seen as the only strategy to always have high product availability. However, inventory is not only tying up capital, it also increases the risk to produce too much or even products that customers do not request. The lean approach is instead to create a value-chain that only initiates value-creation if there exists a "pull" signal that is derived from customer demand. If these signals are incorporated in a company's supply chain the need of inventory is reduced dramatically. However, it requires relatively stable demand and this is emphasised in the fourth principle.

Lean principle 4. *"Level out the workload (work like the tortoise, not the hare)" (Liker & Meier, 2006, p. 9)*

Customer demand varies both in volume and time due to market dynamics. Hence, it is necessary for companies to actively balance the workload, especially if continuous flows are desired and pull systems are used. If the workload is uneven over time, waste will be generated and standardisation will be impossible. Lean encompasses a number of techniques for companies to actively balance the workload to the degree possible, usually referred to as *Heijunka*.

Lean principle 5. *"Build a culture of stopping to fix problems, to get quality right the first time." (Liker & Meier, 2006, p. 10)*

It should be possible to stop any workflow directly when problems are identified. The long-term benefits with this principle are almost always worth the negative short-term productivity.

Lean principle 6. *"Standardised tasks and processes are the foundation for continuous improvement and employee empowerment." (Liker & Meier, 2006, p. 10)*

Tasks and processes should be standardised in order to have predictable outcomes. It should not be confused with rigidity and lack of room for improvements. Improvements are easier to identify in standardised processes and have a stronger effect when they are implemented. It is also a way to steepen the learning curve for new employees.

Standardisation is an on-going activity of identifying problems, establishing effective methods and defining how these methods should be performed (Liker & Meier, 2006). This cannot only be done at the shop floor. Many managers are spending their time with fire fights, which have created the perception that their work is widely varied from day-to-day and standardised work cannot be done on a management level. Emiliani (2008) argue that the use of standardised work at a management level can provide many of the benefits being proven at shop-floor level. Standards can be used for processes such as decisions making in order to become more efficient and less costly.

Lean principle 7. *"Use visual control so no problems are hidden." (Liker & Meier, 2006, p. 10)*

People are visual creatures meaning that we use our eyesight to make sure that we have control over situations. This applies to any type of work. Lean is suggesting that, if possible, every work process should be visualised with physical objects, e.g. flip charts or post-it notes. With this approach it becomes clear to anyone if problems occur in a process.

Lean principle 8. *"Use only reliable, thoroughly tested technology that serves your people and process." (Liker & Meier, 2006, p. 11)*

People should not be slaves of technology. In contrast, people should only apply technology to processes if it is needed and improves the outcome of the processes. Before a new technology is implemented it needs to be fully investigated and proven beneficial.

Third, companies can obtain great value by developing their people and partners. The people aspect encompasses Lean principles 9-11.

Lean principle 9. *"Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others." (Liker & Meier, 2006, p. 11)*

Lean regards the development of leaders as a slow-growing process where context-specific knowledge, lean commitment and the ability to teach lean are key factors to success.

Lean principle 10. *"Develop exceptional people and teams who follow your company's philosophy." (Liker & Meier, 2006, p. 12)*

Shared company culture and values are prerequisites for a long-lasting organisation with people and teams that achieve outstanding results. It is the management's duty to create this culture and convince every employee that this is the way to work. The key to success is rather the people who uses the lean tools and how they use them.

Lean principle 11. *"Respect your extended network of partners and suppliers by challenging them and helping them improve." (Liker & Meier, 2006, p. 12)*

This principle is the way the company should approach its partners and suppliers, which is outside the scope of this study.

Fourth, a lean organisation should continuously work with root problem solving. This means that problems should not be solved for the moment but a close investigation should be done to thoroughly understand the root cause for the problem to occur. This is what the final lean-principles (12-14) facilitate.

Lean principle 12. *"Go and see for yourself to thoroughly understand the situation." (Liker & Meier, 2006, p. 13)*

This principle emphasises the importance of deeply analysing the causes behind problems by actually going to the source, before solutions are developed. Hence, the reliance on secondary data and experience is rather low compared to primary data collected by the problem solver.

Lean principle 13. *"Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly." (Liker & Meier, 2006, p. 13)*

When problems and root causes to these are identified, lean illuminates the importance to take time to explore all potential solutions. In this way it is easier to reach consensus in decisions and rapidly implement them.

Lean principle 14. *"Become a learning organisation through relentless reflection and continuous improvement." (Liker & Meier, 2006, p. 13)*

Continuous improvements, *kaizen*, are the constant development of standardised processes. It includes the practice of asking "Why?" five times whenever processes deviate from the normal. The problem-solving follows a standardised procedure called Plan-Do-Check-Act, which leads to a learning organisation.

2.2.2 Lean planning

Many of the lean principles are implemented at the operational level on the shop-floor level, which makes many people believe this is the only area for lean practices (Hines et al., 2004). However, the central role of value creation and waste elimination of lean makes it useful for any business process. Planning is one process that has a high potential to become more effective and efficient by adopting lean principles into it (Lenders et al, 2011).

Lean planning emphasises the importance of being customer-centric and value-driven in the process. It implies that big efforts are made to understand demand and supply to identify how value is created for customers. (Lenders et al, 2011)

Lenders et al. (2011) defines 8 key principles that can be used to for planners to become lean:

Lean planning principle A. One single forecast should be shared and used throughout the entire organisation

Lean planning principle B. The required data should have high accuracy and the right level of aggregation.

Lean planning principle C. Roles and responsibilities in the planning process should be defined.

Lean planning principle D. Risks in the planning process should be mitigated as much as possible.

Lean planning principle E. Alert systems should exist to indicate deviations from the plan

Lean planning principle F. Bottom-up feedback about e.g. actual demand and actual capacity utilisation to be able to improve the planning accuracy

Lean planning principle G. Visual presentation of data for review meetings and reporting purposes

Lean planning principle H. Organisation-wide focus and effort on continuous improvements.

3 Methodology

How this thesis was conducted is presented and motivated in this chapter. In the end of this chapter, the reliability and validity of the study are assessed.

3.1 Research strategy

This thesis followed an inductive research strategy. It was inductive since theoretical implications were the outcome of the study and generalizable conclusions can be drawn from it (Bryman & Bell, 2011). The purpose was not to test existing theory, as it is in a deductive study (Bryman & Bell, 2011), but to generate new theory.

The lean capacity planning process does not conflict with existing theory, it is rather a new and alternative approach to capacity planning. The goal was to close a gap in current literature how lean principles can be applied in capacity planning. To reach this goal an inductive research strategy was required.

3.2 Research approach

This thesis has mainly been conducted in the context of Nobel Biocare. Nobel Biocare was chosen as case company since it has lately reduced inventory and set up a capacity planning process. In addition, three reference companies have been used to find solutions to the problems identified at Nobel Biocare. These were chosen based on their lean commitment. The study is thus considered as a case study. A case study includes a detailed and intensive study in the specific setting (Bryman & Bell, 2011). It is an approach that is useful when the investigation of a phenomenon is hard to conduct outside its particular environment. It is also an adequate approach for areas where gaps exists in current literature (Ghauri & Grønhaug, 2005). The approach to use multiple cases also encourages the researchers to consider what is unique and what is common across the cases (Bryman & Bell, 2011).

The research questions of this thesis represent gaps in current literature, the case study approach was therefore well suited. The capacity planning process and problems within it are difficult to investigate outside a specific case company. They are considerably affected by the preconditions in the specific planning environment. The confidence to the conducted interviews and the access to internal reports are also increased significantly when the thesis was studied within a specific case company. Furthermore, there exist a gap in literature how lean principles can be applied in the capacity planning process. Hence, it was applicable to include reference companies as external cases where lean principles are applied in practice. The reference companies were chosen with considerations to their lean commitment and how they have applied lean in their planning processes. The multi-case approach also illuminates how different contexts affect the applicability of the lean principles.

The main drawback of the case study is that it becomes bounded to a specific situation or system (Bryman & Bell, 2011). In this thesis, the specific case is the capacity planning process at Nobel Biocare. However, some of the identified problems and solutions are transferable to other cases. One of these is low capacity utilisation at companies with low inventories. These companies need available capacity to cope with imbalances.

The thesis is rather qualitative than quantitative in its approach. The qualitative approach aims to generate new theory and is thus suitable when complementing existing theory (Bryman & Bell, 2011). There exists a gap in theory regarding how lean principles can be used in a capacity planning process. The results of this thesis will contribute to some of the missing theory within this gap. In addition, quantitative data was used to support arguments in the analysis. This data was collected from Nobel Biocare.

3.3 Research process

The research process can be divided in 6 different steps, see Figure 6.

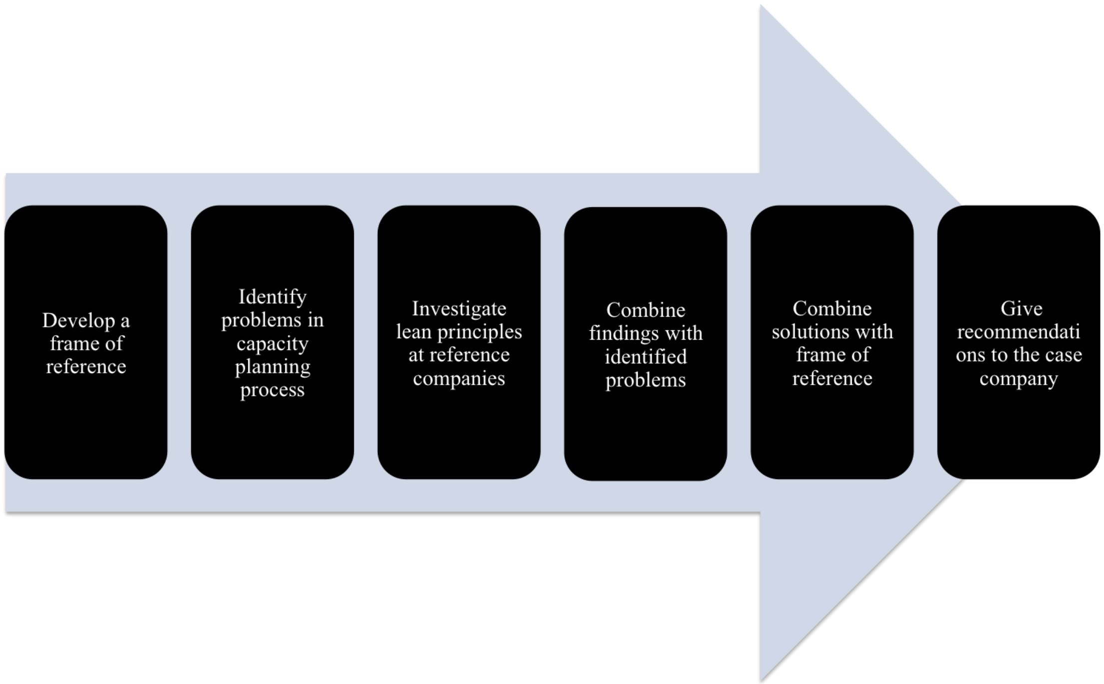

Figure 6 - Research process

1. Develop a frame of reference

The first step in this research process was to make a literature review. This was done to create an understanding and insight into the topic of this thesis. The literature was mainly collected from published research databases. For this study the databases used are focusing on supply chain, operations and production. Examples of these databases are Emerald and ScienceDirect accessed through Chalmers library. The main keywords that have been used when searching are; capacity planning, lean and integration between planning levels. The findings of this literature review were conducted into a frame of references. The frame of reference was developed and structured around two theoretical subjects: capacity planning and lean. The frame of reference was used as a basis for the development of an interview guide. It was important to base the interviews on theory in order to ask relevant questions.

2. Identify problems in Nobel Biocare's capacity planning process

The second step was to conduct interviews with key persons at Nobel Biocare. These interviewed persons are described in Appendix 1. The interviews were used to map the current capacity planning process at Nobel Biocare. The mapping made it possible to identify problems in the process. These problems were identified by the personnel at the company and by the researchers.

3. Investigate lean principles at reference companies

Three companies were chosen as reference companies. One interview was held with each of the companies. This was done to use input from other companies regarding how to apply lean principles in the capacity planning process.

4. Combine findings with identified problems

The findings from the reference companies were combined with the identified problems at Nobel Biocare. This approach was chosen to investigate if the lean principles used at the reference companies could solve the identified problems.

5. Combine solutions with frame of reference

The elaborated solutions were combined with the frame of reference created earlier. This was done to show where in the capacity planning process the solutions were applicable. This resulted in a model, called the lean planning process. The goal with this model was to show how lean principles can be incorporated in any capacity planning process, not only Nobel Biocare's.

6. Give recommendations to the case company

Since the problems that were identified in this study were derived from one case company, the developed model was applied in theory on the same company. This resulted in an improved capacity planning process at Nobel Biocare. The identified problems were combined with lean principles and methods on how to use these.

3.4 Data collection

The methods used to collect the primary and secondary data is presented in this section.

Primary data

Primary data is data collected by the researchers for the purpose of the particular study (Ghauri & Grønhaug, 2005), In this thesis, primary data was collected via interviews at Nobel Biocare and the three reference companies; Autoliv, Emerson and Parker.

Knowledge about Nobel Biocare was obtained through semi-structured interviews with employees at the Supply Chain and Production departments of the firm. The purpose of the interviews was to collect data regarding the capacity planning process, to be able to answer the research questions. All of the interviews were held with open lines of communication. After each interview the researchers compiled the collected data. This was done right after the interviews in order to make sure the information was fresh.

In total, 11 interviews were held at Nobel Biocare. See Appendix 1 for list of interviewees and Appendix 3 for interview guides. The interviewees that were chosen are involved in the capacity planning process. Data from the Supply Chain department were collected at Nobel Biocare in Gothenburg, while data from the production sites were collected for Procera in Stockholm and Implant Systems in Karlskoga. It was important to pay a visit to the two production sites since they are heavily involved in the capacity planning process but separated geographically from the Supply Chain department. All 11 interviewees contributed to the holistic picture of Nobel Biocare's capacity planning process and its context as well as problems within it.

One interview was held with each reference company. The interviews were mainly done by phone due to geographical distance. See Appendix 2 for interviewees at these companies. These interviews provided an overview over the reference companies' capacity planning processes and how lean principles were applied. The overview was deep enough to be able to adopt solutions from these processes and elaborate them according to identified problems at Nobel Biocare. The interview guides for the interviews can be found in Appendix 3.

Secondary data

Secondary data is relevant data that have been collected for other purposes than the particular study (Ghauri & Grønhaug, 2005). Secondary data was collected from internal documents at Nobel Biocare. These were mainly collected from presentations that described the capacity planning and its context. An advantage with the chosen method is that secondary analysis offers the researchers to access good-quality data for a tiny fraction of the resources involved in carrying out a data collection by themselves (Bryman & Bell, 2011).

3.5 Data analysis

There has been an overlap between the data collection and the data analysis during the entire project. This approach gives flexibility regarding adjustments in collected data and what is needed in the analysis (Eisenhardt, 1989). To be able to answer the first research question, literature about production planning, capacity planning and organisational performance was reviewed. This literature review was used to create relevant interview guides that were used when interviewing employees at Nobel Biocare. From these interviews problems in the capacity planning process were identified. In connection with research question 2, literature was reviewed regarding lean and lean in planning. This literature review was used to create relevant interview guides for the interviews with the reference companies. The outcome of these interviews was used one-by-one as inspiration to find lean principles that mitigate the identified problems. Finally, research question three was answered when literature about the capacity planning process was reviewed. A summary of the theoretical- and empirical evidences per research question is showed in Table 2.

Table 2 - Theoretical- and empirical evidence per research question

Research question	Theoretical evidence	Empirical evidence
1. What problems can be identified in a company's capacity planning process and its related context?	Literature about planning in general Literature about capacity planning Literature about organisational performance	Interviews with employees from different relevant departments within Nobel Biocare regarding identified problems Internal presentations about different scenarios for insufficient capacity
2. How can lean principles be applied as potential solutions to the identified problems?	Literature regarding lean principles in general Literature regarding lean principles in planning	Interviews with reference companies regarding their implementations of lean principles
3. How can the solutions be applied in the capacity planning process by incorporating them into a model?	Literature about capacity planning process	

3.6 Reliability and validity

It is important to evaluate research by discussing the two factors reliability and validity. These concepts measure the wider potential and the quality of the research. Reliability is referring to the question if the results of a study are repeatable (Bryman & Bell, 2011). During the interviews topics were discussed, that were not included in the interview guide due to semi-structured interview technic. Another factor that affects the repeatable of the study are personal judgements. It is not certain that other researchers share the same judgements as the researchers of this thesis. However, the researchers have had open lines of communication and discussed the personal judgements during the whole process.

The reliability of the study is increased due to the fact that there always has been more than one representative of the researchers during the interviews. When using several persons, these can complement each other on the information said during the interviews. This has also lead to the fact that the authors agree to what have been said.

Validity is referring to the integrity of the conclusions that are generated from a research (Bryman & Bell, 2011). This can be divided into two questions. The first referring to if the conclusions can be generalised beyond the specific research context. The second is a question if the conclusion that incorporates a causal relationship between two variables holds. This thesis gives the study validity for the specific case since the case company´s context have been used. Parts of the findings in this thesis can be generalised for companies and industries active in other environment than the case company. Companies that operate under similar preconditions will find the result more applicable than companies with different preconditions.

4 Empirical findings

This chapter is a description of the empirical data collected from the case company Nobel Biocare and three reference companies; Autoliv, Emerson and Parker.

4.1 Case company, Nobel Biocare

Nobel Biocare is the case company of this thesis and its capacity planning process is described in depth to provide the reader with information relevant for the analysis.

4.1.1 Interviewees at Nobel Biocare

The global planning functions interviewed in Gothenburg were: Global Capacity Planner, Global Demand Planning Manager, Global Supply Planning Manager and Global Operations Project Manager.

The production functions that were interviewed at Implant Systems and Procera were: Plant Managers, Production Managers, Logistics Manager (only Procera), Production Planning Manager (only Implant Systems) and Production Controller (only Implant Systems)

4.1.2 Nobel Biocare's context

There are several key aspects of Nobel Biocare's business context that are important to emphasise and consider when describing its capacity planning. These key aspects are chosen due to its impact on the capacity planning: The aspects are listed below:

- *Product portfolio*
- *Production*
- *Customer base*
- *Locations and abilities*

Product portfolio

Simplified, the product portfolio can be divided into two different categories: Procera and Implant Systems.

Procera are individualised dental prosthetics, i.e. crowns and bridges. Procera is MTO-products that are distributed directly to customers. Accordingly, no inventory of finished goods exists for Procera. Many new products are launched every year and the assortment is growing steadily.

Implant Systems are surgical products: dental implants and abutments. Implant Systems are MTS-products. These products are distributed globally via two central warehouses and several local warehouses. The complete assortment for Implant Systems consists of approximate 2900 SKUs where 1800 are produced in-house. The assortment has been growing every year as a result of new product launches. Only from 2008 to 2012 it grew by 390 new SKUs. This trend is illustrated in Figure 7.

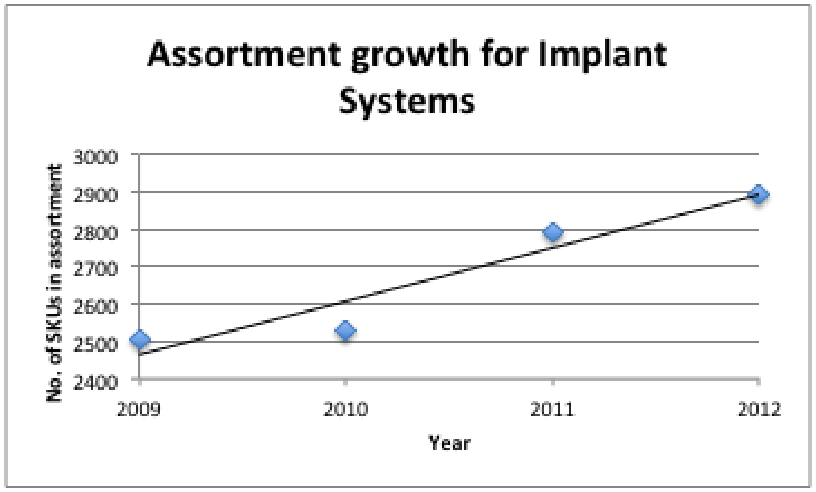

Figure 7 - Assortment trend for Implant Systems

Production of Procera products

The Procera factory has a delivery lead time of 24 hours and every product is customized. This means that the actual production is always triggered by a real customer order received earliest 24 hours before delivery.

The production layout that exists at the Procera plant in Stockholm today is based on product groups. This means that certain work-centres can produce certain product groups. The number of machines is 53 organised in 15 work-centres. The machines are mainly CNC machines. Due to the many product launches every year there has not been a structured way of arranging new machines and processes. Therefore, new machines are not arranged to fit together with existing ones in the most efficient way. The production is also located at different floors of the facility. These aspects create a complex production layout.

Production of Implant Systems products

The order-cycle time is also 24 hours for Implant Systems products. In contrast to Procera, these produts are distributed via warehouses and the order-cycle time is measured from the local warehouse to the customer. The customer orders pulls demand from up-stream entities in the supply chain; from customer to local warehouse, from local warehouse to central warehouse and finally, from central warehouse to production, see Figure 8.

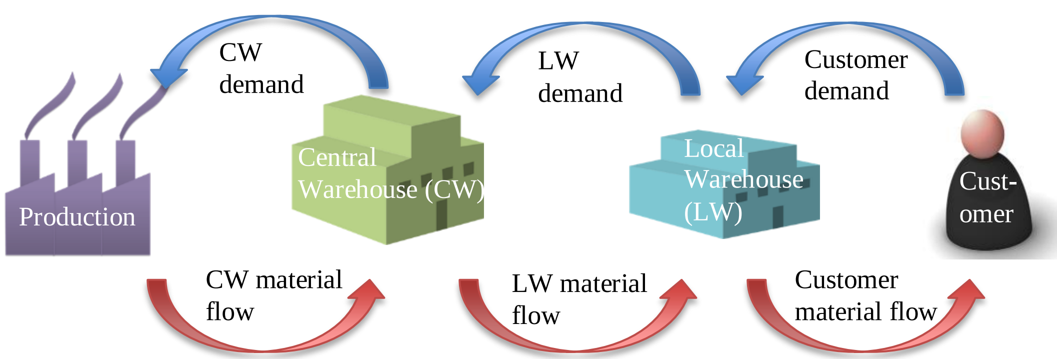

Figure 8 - Pull-based supply chain at Implant Systems

The Implant Systems plant in Karlskoga is responsible for the inventory levels at the two central warehouses. Defined re-order points in the ERP-system trigger the demand from the central warehouse to the production. This demand is translated into production orders.

The production layout at Implant systems is arranged in cells or single machines. There are 61 machines in total, organised in 12 work-centres. 1 of these work-centres consists of 3 cells that are connected to one robot each. Each cell contains 3 machines and is dedicated to a special product group.

The production flow contains five steps. The first step of manufacturing is kitting, where the load carrier is prepared and sent down to machining. The second step machining is done in cells or in a single machine. Third, a conveyor-belt consolidates all cells and machines to a cleaning station. Fourth, dentals implants are thereafter coated with a special Ti-coating. Fifth, the products are packed in a cleanroom.

Customer base
The size of the customer base is between 75 000-100 000 unique customers. The amount of customers and the fact that the knowledge about logistics is low among dentists makes it hard to influence the buying behaviour. Many customers demand 24 hours delivery and it is perceived that few customers understand what this implies for Nobel Biocare in terms of service level and corresponding inventory levels. The required order-cycle time is a standard in the whole industry and it is thus a competitive disadvantage to deviate from this.

To influence the customers behaviour Nobel Biocare are currently implementing a service called Differentiated Delivery Service, DDS at the Procera plant. DDS will give the opportunity for customers to choose delivery service prior to delivery. The different service levels will be controlled with pricing where faster delivery will cost more than slower, i.e. cost-to-serve. The predicted outcome of this project in the Procera case is that many customers will accept a delivery-time of 2-5 days instead of 24 hours. DDS will thereby facilitate the production planning at Procera plants since it gives a wider time-window to schedule orders. It will be easier to level out the workload and avoid capacity imbalances caused by short-term fluctuations in demand.

Locations and abilities
Nobel Biocare has several locations for producing and distributing Procera and Implant Systems products. Procera delivers directly to customers and the production sites are located in Stockholm (Sweden), Mahwah (US), Quebec (Canada) and Chiba (Japan). The production sites for Implant Systems are located in Karlskoga (Sweden) and Yorba Linda (US). Implant Systems products are distributed via central warehouses located in Belfeld (Netherlands) and Yorba Linda (US) and later local warehouses before they reach the customers. All production sites and central warehouses are indicated on the world-map showed in Figure 9.

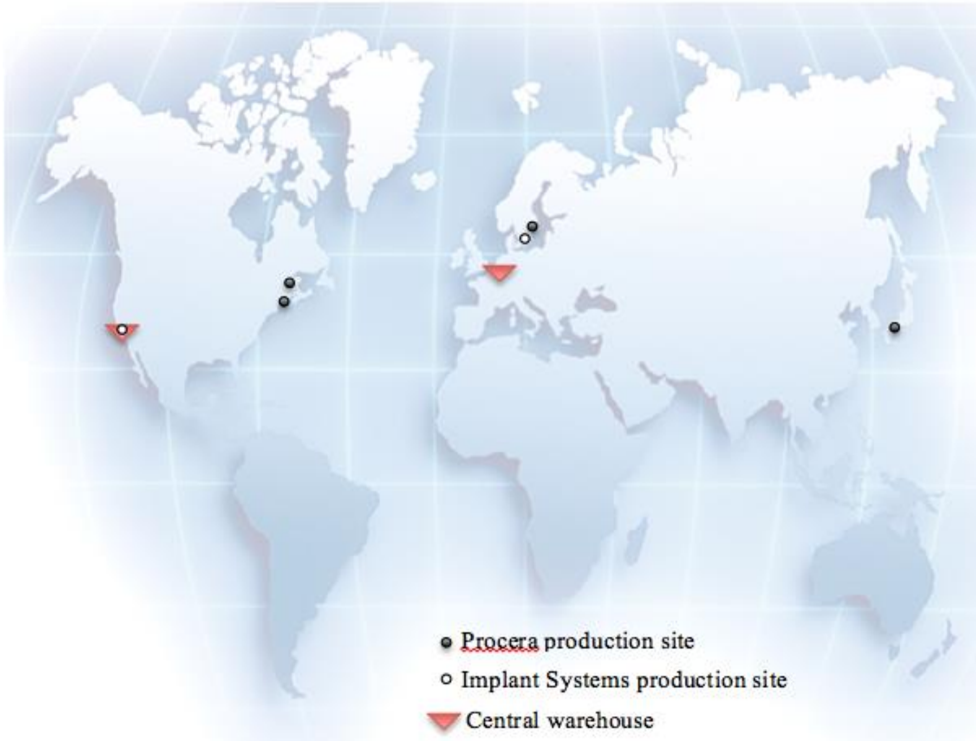

Figure 9 - Nobel Biocare's production sites and central warehouses around the world

4.1.3 Planning levels used at Nobel Biocare

Nobel Biocare has up to three capacity planning levels. See Figure 10. The capacity planning at Implant Systems is separated from the capacity planning at Procera. At Implant Systems three planning levels are used: long-term, mid-term and short-term level. At Procera two planning levels are used: long-term and short-term. Procera does not have any mid-term planning. The explanation to this is that the forecast about future demand does not change until a customer order is received at Procera, which happens in the short-term perspective.

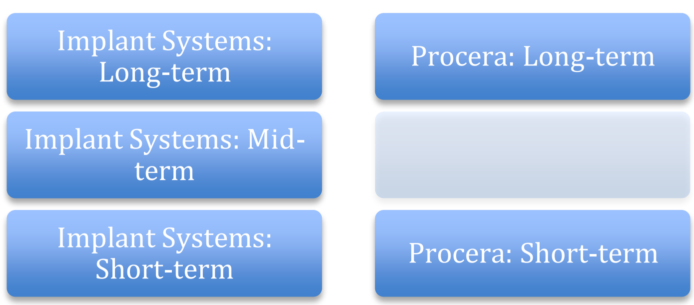

Figure 10 - Planning levels at Nobel Biocare

Procera uses Excel to plan personnel at all planning levels. The managers at production site have not perceived any advantages for using the ERP-system, SAP for this purpose. However, the supply chain department sees benefits from the use of SAP instead of Excel to plan capacity at Procera.

Long-term

The planning horizon used in the long-term planning is 12 months. Nobel Biocare normally makes decisions that take up to 7 months to implement. The planning objects at this level are work-centres including both machines and personnel at the different production sites. One work-centre corresponds to one planning point. The decisions that need to be taken at this planning level are related to machine investments, recruitments, competence development and in some cases volume levelling. The Global Capacity Planner is responsible for calculating and presenting the capacity data for the different stakeholders at this planning level. However, it is the production sites' responsibility that capacity is available on long-term. The long-term plan is updated every month.

Mid-term

The planning horizon is normally 12 weeks in the mid-term planning. However, in many cases a longer time-horizon is used. The planning object can be, as for the higher level, work-centres but also product groups are used. The decision-making at this level includes decisions regarding existing resources. These decisions include machine maintenance, shift planning and changes of allocation regarding existing resources. This means that necessary machines and personnel can be allocated between the different production plants to manage imbalances. The Production Planning Manager at Implant Systems is responsible for calculating and presenting the capacity data for the management team at the production site. The Global Capacity Planner has provided the tool for doing these calculations (Excel spreadsheet). The mid-term plan is updated every week.

Short-term

The time-horizon at this planning level is about 1 week. The planning objects are production orders, which correspond to lots at Implant Systems and single products at Procera. Order scheduling and prioritisation of orders are the two main decisions that are made at this level. The team leaders at the shop floor take these decisions. The short-term plan is updated every day.

4.1.4 Nobel Biocare's capacity planning process

The long-term planning is conducted centralised by the Global Capacity Planner every month. It includes all production sites within the business unit, i.e. one long-term plan for Implant Systems and another for Procera. It is initiated by the supply chain department (located in Gothenburg) and involves the different production sites. The mid-term and short-term planning are conducted locally at the different production sites.

Long-term planning cycle (Procera & Implant systems)

The long-term planning can be illustrated as a monthly planning cycle, see Figure 11. Although the long-term plan is separated for Procera and Implant Systems, the process is conducted similarly.

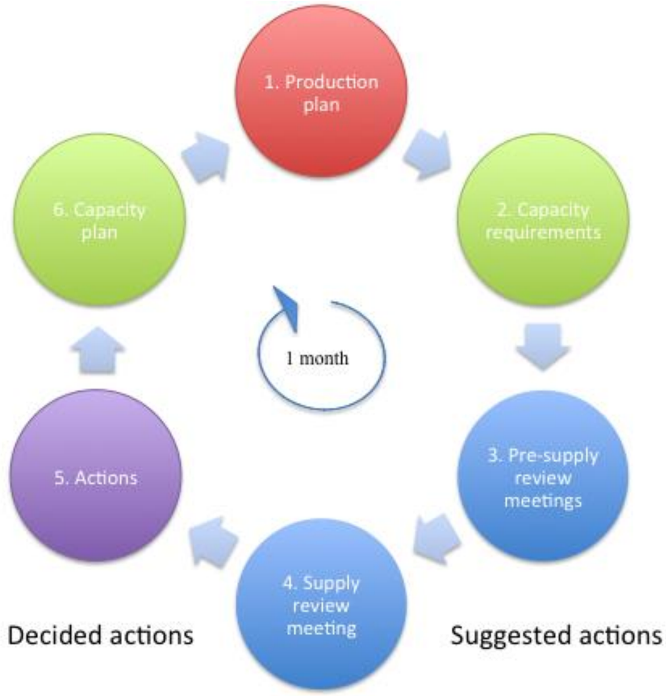

Figure 11 - Global planning cycle

1.Production plan

The Global Demand Planning Manager is responsible for the demand planning process for the entire product portfolio. 15 local demand planners do forecasts for the markets they are responsible for. The Global Demand Planning Manager then merges these 15 demand plans into one global demand plan every month. This demand plan is then released to the ERP-system. This monthly plan is fixed one month ahead and forecast changes only affects the next month's demand plan. The global demand plan is the basis for the production plan. For Implant Systems, the production plan is calculated by subtracting the central warehouses' inventories and goods in transit. The demand plan is equal to the production plan for Procera due to its MTO setting.

2. Capacity requirements

The Global Capacity Planner converts the production plan for each production site into requirements of capacity for the upcoming 12 months. This is done with the capacity method Rough-Cut Capacity Planning (RCCP). It is done in Excel besides of machine capacity at Implant Systems where SAP is used instead. The Global Capacity Planner also estimates available capacity. Available capacity is compared with the requirements of capacity in order to identify upcoming capacity imbalances. The latter is also done in Excel.

Unforeseen peaks in demand, insufficient available capacity or inaccurate planning can cause capacity imbalances. Insufficient available capacity can be caused by unplanned machine maintenances or absent operators. One of the reasons for inaccurate planning is that the forecast accuracy on the demand plan is around 80%. The production plants need to be able to adjust capacity accordingly with ±20% compared to the plan. At Implant systems, only the machining process is included in the capacity plan. Cleaning, coating and packing are manually and locally planned.

Moreover, the requirements for capacity and available capacity that are estimated by the Global Capacity Planner are not fully accurate when they are disaggregated to weekly and daily requirements. The actual available capacity is usually lower than estimated due to losses that is not taken into account in the long-term calculations. Historically, this has lead to an actual capacity of 10% more than what is included in the budget.

3. Pre-supply review meeting

In order to prepare each production site for the required capacity the next 12 months, a pre supply review meeting is held. In total two pre-supply review meetings are held every month. The attendants should be Global Capacity Planner, Production Managers, Plant Managers and Production Planning Managers (Implant Systems). The objective of the meetings is to come up with alternative actions for mitigating capacity imbalances, which are decided on the supply review meeting. It is desirable that the Plant Managers attend these meetings, since they are decision-makers. Unfortunately, this is not always the case today.

4. Supply review meeting

Supply review are global meetings held with each business unit. Two supply review meetings are therefore held every month, one meeting for Procera and another for Implant Systems. The attendants on these meetings are the Head of Supply Chain, Global Demand Planning Manager, Global Supply Planning Manager, Global Capacity Planner, Plant Managers, Production Planning Manager (Implant Systems) and Product Managers (Procera). During supply review meetings the data is presented in tables and charts made in Excel. If decisions are made that alter the demand or capacity, data is changed in SAP and Excel after the meeting.

The objective of the supply reviews is to take decisions on actions to mitigate capacity imbalances that have been identified since the last meeting was held. Different KPIs are also reviewed during this meeting. The goal is to decide actions that lead to a feasible production plan the next 12 months.

5. Actions

Actions to mitigate capacity imbalances are implemented locally at the different production sites. After the supply review meeting internal meetings are held on the production sites before actions are taken. Since the productions sites are limited by their budget, some of the actions previously decided are not applicable in reality. This can lead to deviations between the decided actions at the supply review meeting and real actions.

Actions at Procera

The policy of delivery within 24 hours and peaks in demand can cause situations when orders become late. This does not mean limited total capacity but rather insufficient capacity on short-term. These late orders can only be solved during the weekends since this is the only time where no new orders are released to the shop floor.

If there is a short-term absence, operators can be relocated if necessary. There are also opportunities to bring in temporary workforce or increase the number of shifts to adjust available capacity. However, overtime is the most common action to solve personnel capacity issues and the team leaders take this decision. On a short-term perspective it is possible to make changes in shifts within a two-week period.

Actions at Implants systems
Implant Systems can recruit and discard people to adjust personnel capacity on long-term. In theory, Implant Systems can use temporary personnel to adjust capacity on short-term. However, the skill level required to operate in the production is very high and the training usually takes 3 months. Instead, Implant Systems use night shifts as a first action. If this is not applicable overtime is used to adjust capacity on a short-term.

Implant Systems can acquire machines to increase machine capacity. Machine investments take at least 7-9 months to order, receive and validate. Machine capacity is hard to adjust on a short-term since the processes are specific for Nobel Biocare's purpose and therefore many machines are customized. This rules out subcontracting as an alternative to increase machine capacity on a short-term. Regulations also make it hard to adjust machine capacity on short-term since many processes need to be registered.

6. Capacity plan
The capacity plan is the final step in the planning cycle. The actions implemented at the production sites lead to changes in available capacity. These changes are reported to the Global Capacity Planner, who takes these changed figures into consideration in the long-term capacity plan. Since the long-term planning cycle takes place every month, this capacity plan is updated every month.

Mid-term planning cycle (Implant systems)
At Implant Systems a weekly production planning is done to make mid-term capacity adjustments. The Production Planning Manager calculates requirements for capacity in an Excel template based on the production plan from SAP. The result is required capacity per week. This is also disaggregated per day for the nearest future. It is the responsibility of the Production Manager to take decisions regarding personnel according to the requirements for capacity. If changes are necessary to meet the capacity requirements, these changes are reported to the Global Capacity Planner during the pre-supply review meeting every month. The changes should only affect 12 weeks ahead but sometimes more long-term decisions are made at the production sites. The demand that was forecasted in beginning of the week changes during the week because of sales. The production plan thereby changes on a daily basis. In the end of the week an evaluation of these changes are done. The fluctuations in demand create deviations from planned production and actual production.

Short-term planning (Procera & Implant systems)
The short-term planning is the daily order planning. This process is different at the two business units since Procera is MTO and Implant Systems is MTS. Hence, these are explained separately.

Procera
The first step after the customer orders are received is CAM-processing. When this is done the orders are released to the shop floor as production orders. When orders are registered in SAP no considerations are taken to available capacity. The production orders are scheduled based on a

first-in-first-out (FIFO) approach. There exist no optimisation regarding set-up times, lot-sizing etc. in the production.

Implant systems
An order planner releases all the orders that have been received before noon to the shop floor the same day. Some production orders have higher priority than others. This prioritisation is based on product-segment and current stock-level. The production orders are scheduled to different work-centres depending on product group and current queues. The priority rules are configured in SAP while the allocation is done manually by the use of Excel.

4.1.5 KPIs in capacity planning

Different KPIs are used to evaluate the performance of the operations at Nobel Biocare. These KPIs affect the capacity planning in different ways. Some KPIs are global and affect the entire organisation while others are only measured locally at the different production sites. There are also internal KPIs to measure the demand and capacity planning performance. A summary of the different KPIs that affect the capacity planning is showed in Table 3. The definitions of these can be found in the List of Definitions. The KPIs are chosen depending on what strategy Nobel Biocare has for the current year. The KPI targets are derived from the budgets the same year.

Table 3 - KPIs used to measure performance at Nobel Biocare

KPI	Current level in March 2013	Target 2013	Comments
Service level (Implant Systems)	90,4 %	99,2 %	Full orders from order to requested delivery
Inventory turns	6,5	6,5	Finished products and direct material
Capacity utilisation (Procera)	38 %	60 %	Machine capacity: measured as average machine utilisation based on a 3shift for a 12 months period.
Capacity utilisation (Implant Systems)	61 %	75 %	See above
Forecast accuracy (Procera)	85 %	80 %	Measured as 1 – Error. Error = Sum of forecast-volume-weighted ArtNo errors. ArtNo error equals absolute value of (Actual Sales – Forecast) / Forecast
Forecast accuracy (Implant Systems)	82 %	80 %	See above

4.1.6 Lean

The lean commitment at Nobel Biocare today is limited. No lean philosophy exists and the managers define lean in many different ways. Continuous improvements is a lean principle that the interviewees believe in but it is not implemented in all processes. Different lean principles have also been implemented at the shop floor at Procera and the Implant Systems production sites, respectively.

Definitions used at Nobel Biocare
The managers at Nobel Biocare define lean in different ways. The different definitions are:

- "The cornerstone in lean is to identify customer value and to deliver this to the customers. Regardless if the customer is internal or external to the company. It is important to continuously analysing its own processes and eliminate those things that not contribute to the value for the customers, which can be seen as waste."

- "Lean can be seen as structured way of common sense and the implementation of this. It is desirable that everyone is working towards the same goal. When working with lean it is important to remember that it is the customer demand that is in focus. "

- "Lean is that it is a structure for order. The concept of lean includes many tools that can be used to gain order. Many things that are done at the plant are lean but not labelled lean."

- "Lean is it as a way of eliminating all waste. If it is possible to automate operations this should be done, since unnecessary steps can be eliminated. Some waste is necessary to be able to deliver. The goal is not to work faster but more efficiently. An important aspect of lean is to standardise. The use of standardisation creates a best way of working without being afraid of changes. The best way of working is achieved by continually finding new ways of working."

Continuous improvements
Lean principle 14 (Liker & Meier, 2006), continuous improvements, is used today at Nobel Biocare. The idea is to encourage employees to identify areas of improvements and suggest solutions. The number of suggestions is measured every month. However, there is a desire to incorporate continuous improvements in administrative processes such as the capacity planning process.

Procera factory
The last couple of years many lean-oriented projects have been implemented in the Procera factory. Lean principle 3 (Liker & Meier, 2006), pull-production, is used at the shop floor. Kanban-cards are used as pull-signals for material.

Implant systems
Implant systems have implemented several lean principles. Some of these include continuous improvements and reducing the set-up times in production. An on-going project is also to visualise information via flat-screens on the shop floor. The information is about e.g. backlog-situation, KPIs and absence. The goal is to be able to break down and visualise goals per team and day. Implant Systems has a bottom-up approach to implement lean and many responsibilities are the operators'.

4.2 Reference companies

In addition to the case company Nobel Biocare, empirical data from three reference companies have been collected. These companies are presented below.

4.2.1 Autoliv

Autoliv is the world's largest automotive safety supplier with sales to all the leading car manufacturers in the world. The company is vertically integrated and many products are produced in-house. Autoliv was chosen as a reference company because of its strong lean commitment and their manufacturing setting.

Interviewees at Autoliv

- Acting Logistics Manager
- AMC (Autoliv Manufacturing Center) Manager

Capacity planning at Autoliv
Autoliv produces airbags for cars in cellular production layouts. The airbags are MTO-products since every airbag is customised to a specific brand and car model and only produced on real demand. Only spare parts are produced to stock (MTS). The service level is 100% since Autoliv is committed to produce every order in time.

The demand is derived from the manufacturing of cars. Customers share their forecasts several times per year. Autoliv uses these forecasts as input for their demand planning. The long-term demand plan is updated every quarter. The capacity planning is mostly conducted to secure sufficient personnel capacity since contracts with customers regulate the variations in required machine capacity. A significant part of Autoliv's workforce is temporarily. This is used as flexible mechanism to adjust capacity.

The next planning level is the short-term planning conducted every second week. The input for this planning is a production plan, based on forecasted volumes and real customer orders. The production plan is downloaded from Autoliv's ERP-system M3. Before it is downloaded it has been levelled in another application called ALS (Autoliv Levelling System). ALS conducts a finite scheduling for the proposed production plan that is levelled. The production plan is then discussed during so called contract meetings. The capacity-related outcomes from this meeting are number of shifts, planned overtime and takt-time for the upcoming two weeks.

Lean impact on capacity planning at Autoliv
In its MTO setting, Autoliv needs to have materials and capacity when call-offs from customers occur. From a lean perspective, the production should take place with minimal amount of resources to create maximum value. This implies minimal inventory levels for materials and exact required capacity. However, with such short time-horizon (down to 48 hours) these decisions have to be taken on forecasted data. This requires that the forecast accuracy is high, which requires close collaboration with customers. It also requires that suppliers can have fast delivery and thus close collaboration also exists up-stream in the supply chain.

Autoliv always tries to minimise the needed planning points by aspiring for continuous flows and avoiding buffer inventory. This facilitates the continuous capacity planning, both on long-term and short-term.

In the short-term planning, lean is applied in different ways. A significant effect is the levelling of capacity. The approach to level out production every second week facilitates the ability to have a takt-time and pull-systems (kanban). A result of using lean principles is the view on people and teams in the short-term planning. The responsibility to plan materials and shifts on a short-term is delegated to team-leaders. This is possible because of the strong commitment to the lean philosophy, which is shared by everyone.

Lean has also lead to a problem-solving approach. Every capacity related problem is drilled down to its root cause before solutions are elaborated. Moreover, all possible solutions are discussed before decisions are made. The decisions are made in consensus.

Another thing that is related to both lean and capacity planning is the use of visible planning at Autoliv. Heijunka boards are used at every production cell that shows the expected production output every 30 minutes. In this way it becomes easy for every operator to see if he/she works according to the takt-time. It also works as a signal system between production and logistics.

4.2.2 Emerson Process Management

Emerson Process Management is a part of Emerson. They deliver a complete program of products and services within the process automation. Emerson has production for both MTS and MTO. The orders that are produced MTS have a delivery lead-time within 48 hours. This would not be possible if the products were not in stock. The products that are produced MTO have a lead-time of maximum 5 days.

Interviewees at Emerson Process Management

- Manufacturing manager

Capacity Planning at Emerson Process Management

Emerson capacity planning is based on the global S&OP planning. This S&OP is done on a global basis for all of the different markets. The manufacturing managers get the demand from this plan on a monthly basis. The demand plan is done with a time horizon of 12 months and this is turned into a daily takt-time for the production. The manufacturing manager is responsible for the capacity planning on long-term, while team leaders are responsible for the short-term capacity planning on a daily basis. The manufacturing manager has no influence on the demand plan. Instead he needs to adjust available capacity in order to meet the demand. The team leaders use the same data to plan the short-term capacity planning as the manufacturing manager.

When Emerson Process Management has capacity imbalances these are solved by increasing the lead-time to customers. When discovering an increase in demand for more capacity investments regarding machines are done. Investment decisions involve the manufacturing manager, production technology and top management. The capacity planning regarding personnel is based on orders planned for production.

The team leaders of each shift determine available capacity for that shift. This is working as the basis for the order-planning department, which place orders according to this capacity.

Lean impact on capacity planning at Emerson Process Management

The capacity planning process is affected by lean principles due to the desire of using one-piece flow to the largest extent possible. The planning on a daily basis is also affected by lean principles. Other business units at Emerson have a planning basis of weeks where one order is handled at a time.

Emerson levelled out their production by planning orders according to available capacity. The available capacity can be seen on screens at the order department. This is a way of creating visualisation of the available capacity. Orders are placed where there is capacity available according to these screens.

4.2.3 Parker

Parker is the world leader in motion and control technologies and systems used in mobile, industrial and aerospace application areas. Parker's production site in Borås belongs to the business unit Hydraulics and the division Mobile Controls. The products are produced in an MTO-setting with a lead-time of 15 days. The products are planned, produced and assembled in lines dedicated to specific product families. Few resources are shared with other lines and Parker applies FIFO for these resources.

Interviewees at Parker

- The Division Lean Manager

Capacity planning at Parker

The capacity planning at Parker can be divided into a monthly, a weekly and a daily planning. The monthly planning can be divided into seven steps. First, a production plan with a one-year horizon is assessed. Second, the production plan is calculated to corresponding machine- and labour hours to assess the requirements for capacity. Third, a data collection meeting is held. The purpose of this meeting is to share the requirements for capacity to the production managers so they can estimate the corresponding available capacity for the time period. Fourth, a data confirmation meeting is held. This meeting occur to confirm the calculated requirements for capacity and available capacity. Fifth, a third meeting is arranged to make decisions regarding capacity imbalances. The previous two meetings are the foundation to be able to make these decisions on accurate data. Sixth, a final meeting is held to follow-up the decisions made at the previous meeting, to make sure that actions have been realised. Another reason is for controlling purpose to update the financial figures. Finally, the outcome of the meeting is a feasible capacity plan that meets customer demand. Continuous improvements are applied in this last step. The capacity plan is followed up afterwards to evaluate how accurate it was. Actions are taken if the accuracy has a negative trend and the problems behind this are assessed.

The weekly planning consists of meetings where production managers update their data, confirm it and make short-term decisions to adjust capacity. If these decisions deviate on a monthly basis, these are brought up in the monthly planning to adjust figures. The daily planning occurs per shift and is a confirmation check that the shift will be able to produce what is expected according to the customer orders.

Parker uses temporary personnel to be able to adjust personnel capacity on short-term. The permanent personnel are also trained to be able to be re-allocated to different work-stations. When it comes to machine capacity Parker almost always have a back-up to every resource to avoid production stop when machine failures occur. Parker sees these flexibility mechanisms as key success factors to have a capacity planning that can be adjusted on short-term.

Lean impact on capacity planning at Parker

Parker regards the impact from incorporating lean principles in the capacity planning as strong. Many of the preconditions for planning are simplified by implementing lean at the shop-floor. By striving for process flows as well as understanding and controlling the bottlenecks the planning points are reduced dramatically compared to e.g. a functional layout. Moreover, by standardising the work and having personnel that can be re-allocated the flexibility increases when it comes to capacity adjustments. Visual control is also used to communicate both to operators and managers how well according to plans the production is going. A culture of continuous improvements helps to prevent problems in the future instead of always "fighting fires".

The capacity planning process itself is also benefits from many lean principles. It is standardised, which is a foundation for continuous improvements. Parker is very demand-driven in its planning due to its MTO-setting. When it comes to decision-making Parker uses a "go-slow" approach. Three meetings are held every month to reach consensus in decisions. This enables Parker to find root-causes to problems and evaluate every alternative for action before decisions are made. The final follow-up meeting also enables a forum for continuous improvements and a reconnection to financial functions at the company.

5 Analysis

The three research questions will be analysed in this chapter. The first section is based on the first research question regarding what problems can be identified in a capacity planning process. The second part of this analysis chapter is related to research questions two, how lean principles can be applied to mitigate the identified problems. Finally, in order to answer research question three, the solutions are analysed regarding how these can be incorporated in a model.

5.1 Identified problem areas at Nobel Biocare

Problem areas that were identified in Nobel Biocare's capacity planning process are described in this section. The problem areas were discussed during interviews with employees at Nobel Biocare. The different problem areas were: *lack of lean philosophy, lack of trust to the presented capacity data, lack of personal trust, low average capacity utilisation, decision conflict with KPI targets, inefficient meetings, different opinions regarding SAP* and *overlapping planning levels.*

5.1.1 Lack of lean philosophy

Nobel Biocare is missing one clear definition of lean. This makes the view at the company on lean fragmented. This also leads to the personnel not knowing the purpose of lean principles, which leads to different opinions regarding these.

5.1.2 Lack of trust to the presented capacity data

Based on Nobel Biocare’s situation the accuracy of the capacity planning, estimating the conversion factors and the presentation of capacity data are three critical issues. It is the responsible capacity planner’s task to identify potential capacity imbalances based on capacity data and communicate these findings to affected stakeholders. The latter is important to consider since some affected stakeholders belong to other functions in the company, e.g. production. At Nobel Biocare, these functions are also separated geographically. The presentation of the imbalances is therefore essential since stakeholders' lack of physical interaction. The goal for the Global Capacity Planner is to, by working together with production management, identify capacity imbalances and propose decisions to resolve these. An issue at Nobel Biocare is the resistance to base decisions on capacity data instead of personal judgments. In a planning environment with volatile demand and short lead times it is perceived uncertain to make decisions on capacity data that is based on forecasts and assumptions. One reason behind the mistrust of the capacity data can be related to the accuracy of the capacity calculations. The accuracy of the capacity planning is determined by the ability to estimate both requirements for capacity and available capacity. The accuracy regarding requirements of capacity is affected by four factors: forecast accuracy, the precision of the conversion factors, scrap rate and precision of the setup times. All four factors affect the accuracy of the capacity requirements calculations. While forecast accuracy is dependent on external market factors, the other three factors are solely dependent on efforts from the company. The accuracy of the available capacity is affected by three factors: how accurate the number of machines and operators can be estimated, how precise the conversion factors are for capacity and to what extent losses are taken into account. To identify capacity imbalances, available capacity has to be compared with the requirements for capacity. The capacity planning accuracy will determine how well identified capacity imbalances correspond to real capacity imbalances. Two “worst-case” scenarios can be identified, see Figure 12. Scenario 1 is that real available capacity is much lower than planned and at the same real requirements for capacity is much higher. This implies insufficient capacity and thereby loss of income. Scenario 2 is the opposite, that the supply of capacity turned out to be higher and that requirements for capacity is lower than planned. This implies low capacity utilisation and thereby increased cost per unit. As seen in Figure 12, both accuracy of the requirements for capacity and the accuracy of supply of capacity can be low. This will result in a capacity planning that is difficult to trust, especially for decision-makers. Under these conditions, capacity related decisions might tend to be postponed until real demand is known. This leads to that decisions are made too late.

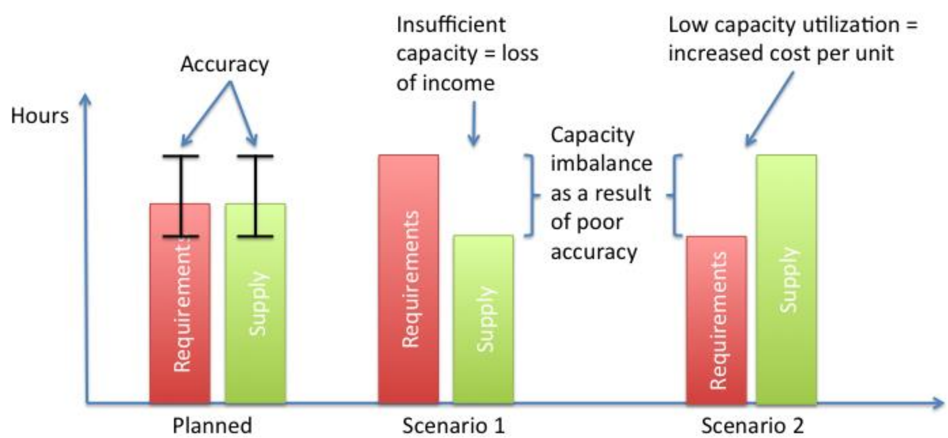

Figure 12 - Worst-case scenarios for a given capacity planning accuracy

Today Nobel Biocare bases their capacity planning on many assumptions. One of these assumptions is related to the conversion factors. The conversion factor is affecting both the requirements of capacity and available capacity. The reason for the use of assumptions is that it is time consuming to make real measurements for every SKU. The number of SKUs has increased by approximately 100 every year since 2008. This requires a lot of resources to perform real measurements for all these new launches, resources that Nobel Biocare do not have today. Hence, many assumptions based on previous products are used instead to measure these conversion factors. For the machine capacity it is a matter of how many available hours every machine corresponds to. For personnel it is how many hours every operator is available. However, every machine and operator is not capable to manufacture every SKU. In fact, the assumptions that exist today result in higher calculated available capacity compared to actual supply of capacity. This leads to less available capacity than expected from the planning.

At Nobel Biocare the calculated capacity imbalances and actions to solve these are discussed during supply review meetings. The managerial challenge is to convince stakeholders and decision-makers to take actions based on the identified capacity imbalances. The final decision regarding actions is taken by the Plant Managers in collaboration with his management team. The decision-maker, the Plant Manager, is not involved in the calculations regarding capacity requirements. In this situation it becomes critical for the Global Capacity Planner to convince the Plant Manager to take actions to solve calculated capacity imbalance. The calculations can be perceived as advanced and hard to grasp for someone that is not involved in that work. Hence, this creates a gap between the provider and receiver of the data. In Nobel Biocare's case, a gap between the Global Capacity Planner and the Plant Managers/local planners emerges. This gap implies that the Plant Manager does not always base decisions on presented data.

5.1.3 Lack of personal trust

The Global Capacity Planner presents data for the production sites and supply chain departments at the supply review meetings at Nobel Biocare. This is often doubted by the stakeholders at the production sites. The behaviour of this is a result of mainly two problems. The first is regarding lack of trust within the capacity planning process and the second is lack of understanding for other departments' activities and responsibilities. Several gaps have been identified as reasons for these two problems. These gaps are identified as *experience gap*, *geographical gap*, *hierarchical gap* and *knowledge gap*.

There exist an experience gap between the Global Capacity Planner and other employees within the capacity planning process. Many employees have not only worked within the company longer, they have also more experiences from other industries and companies. The hierarchical gap relates to the clear hierarchical structure that exists at Nobel Biocare. The Global Capacity Planner is subordinated The Global Supply Planning Manager, which is at the same level as the Plant Managers, see Figure 13. The Global Capacity Planner presents capacity data for the Plant Managers to take actions on. Nobel Biocare has created a way of trusting the hierarchical structure more than the people. The presented data is not taken seriously because of different management level between sender and receiver. The different gaps results in an asymmetry regarding capacity related information. The managers at the production sites have more accurate information regarding the production processes. The Global Capacity Planner is the one calculating the capacity requirements based on information from SAP. This has made him develop a deeper understanding and knowledge for the use of SAP's planning features compared to others. Only the information that is shared will be the basis for consensus decision-making. The information asymmetry can lead to opportunistic behaviour, which creates lack of trust.

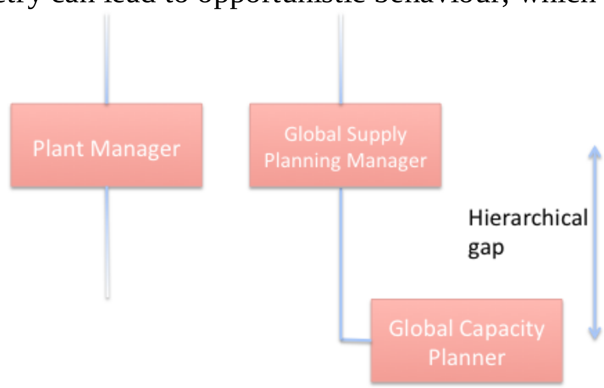

Figure 13 - Hierarchical gap between Global Capacity Planner and Plant Managers

There is a lack of understanding for other departments' activities and responsibilities at Nobel Biocare. The reasons for this is the geographical gap and the knowledge gap that exist within the company. The Global Capacity Planner is located in Gothenburg, while the production sites are located in Stockholm and Karlskoga. This division creates a geographical gap between the production sites and the Global Capacity Planner. The doubt of the Global Capacity Planner is mainly at the production sites and not at the supply chain department. The reason for this is based on the fact that the supply chain department interact with the Global Capacity Planner on a daily basis. The differences in location create an arms-length relation due to the missing of daily conversations. Whenever conflicts of interest occur the employees rather agree with the managers of their own site, creating a "we and them-feeling". There exists a knowledge gap within Nobel Biocare. The Global Capacity Planner has provided the Implant Systems production site with a tool (an Excel sheet) for calculating requirements for capacity on a weekly basis. The Production Planning Manager updates this sheet with information regarding their production every week. The Production Planning Manager does not know what these calculations are based on but have instead developed a standard way of just typing in the numbers. This standard way has made employees at the production site stop to reflect over why the calculations are done.

5.1.4 Low average capacity utilisation

The machines in Nobel Biocare's production are grouped after product groups, i.e. one work-centre is capable to produce one or several product group(s). Due to the large number of SKUs, many different product groups exist and thus many different work-centres. This also means that some work-centres only consist of 1-2 machines. Many work-centres correspond to one planning point in the long-term planning. With many work-centres the planning environment becomes complex and hard to overview.

As a result of high targets for both service level and inventory turns, Nobel Biocare suffers from overcapacity. The target for capacity utilisation is much higher than current capacity utilisation, especially for Procera, see Table 3. With a forecast accuracy of 80% and a policy that every production order should be released to the shop floor, the average requirements for capacity can deviate ±20% from what was forecasted. This is managed with a lead strategy, which results in more capacity than needed and thus low average capacity utilisation. Although the capacity utilisation is low on average, daily situations can occur when the capacity becomes insufficient. This is due to fluctuations in demand on a daily basis. A real-life example of this situation is shown in Figure 14.

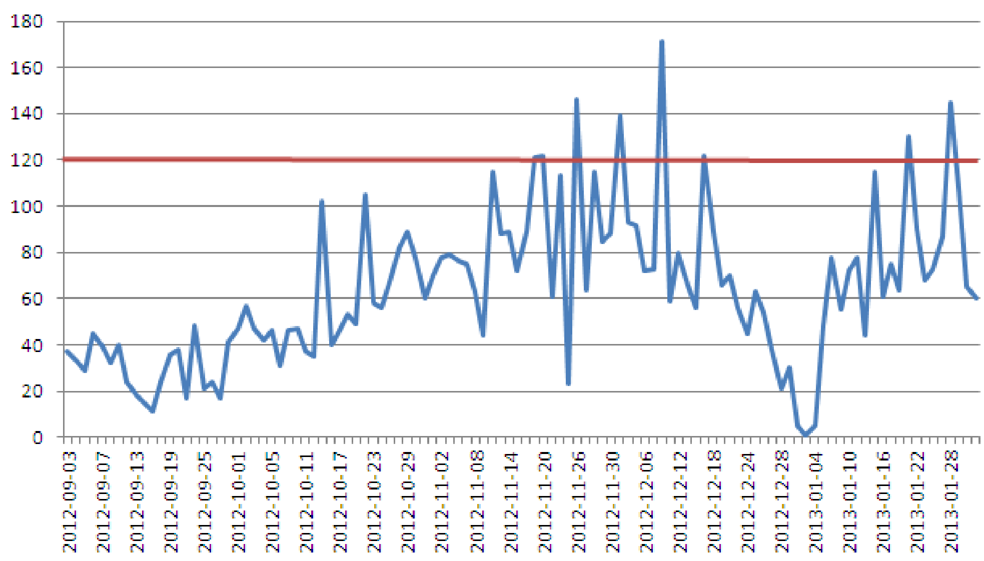

Figure 14 - Daily requirements for capacity (blue) and constant daily available capacity (red). Five occasions were the demand exceeded the daily capacity for Procera.

The workload at different work-centres is also uneven. An important reason for this is that work-centres, especially machines, are dedicated for certain product groups. The demand for product groups varies over time. One period the demand could be high for one group and low for another, the next period it can be the opposite. This implies that the requirements for capacity will vary in the same manner. An example of this is showed in Appendix 4.

Unclear for operators what the workload is at different work-centres
Nobel Biocare is not using any visual control to signal the workload at the different work-centres or the occurrence of queues. Neither are all operators trained to operate all machines. This sets limits on how well the workload can be balanced between the work-centres in terms of personnel. Furthermore, both Implant Systems and Procera have work-centres that are located at different floors in the facility. This increases the difficulties in creating an overview over the work-centres workload. At the shop floor in Nobel Biocare, this leads to situations when work-centres have insufficient capacity, while others have low utilisation. This creates an inefficient use of the operators. Hence, the lack of visibility and ability to re-allocate operators contribute to low flexibility.

When products are developed at Nobel Biocare they are not optimised for production processes. The products are rather designed in a way that makes them more complex to produce. This requires that operators get training prior to product launches. This mind-set has been used for almost every product in Nobel Biocare's assortment. It implies not only that new machines are needed but it also requires a high skill-level among the operators. The latter limits the possibility to train personnel for different product groups. Furthermore, it makes it very difficult to use temporary personnel. In short, the high complexity of the production processes harms the flexibility at Nobel Biocare.

5.1.5 Decision conflict with KPI targets

Nobel Biocare has several different KPIs that they are measuring within their organisation, see Table 3. Some of the main KPIs are inventory turn and service level. Despite that inventory turn is one of the main KPIs, production orders are released to the shop-floor whenever they are triggered from the system. This increases work-in-progress (WIP), which will lead to a decrease in inventory turn. Nobel Biocare´s behaviour of continuously increasing their assortment increases the inventory. This limits the possibility to increase their high targets for inventory turns. There exist also situations when the use of lean principles creates difficulties regarding decision-making. The KPIs and lean principles can be contrary, creating situations when the possibility to use lean principles and achieving KPI targets do not exist.

5.1.6 Inefficient meetings

One of the responsibilities of the Global Capacity Planner is to host two monthly sequential meetings: the pre-supply review meeting and the supply review meeting. The pre-supply review meetings are held separately with each production site once a month. Several issues have been identified regarding these meetings. The first identified issue is unclear the roles and functions of the participants. Moreover, there exists a lack of consensus in decision-making. The meetings are also missing an evaluation regarding deviations from the plan.

The pre-supply review meeting and the supply review meeting have no clearly stated purpose, which makes it difficult to limit the subjects discussed in these meetings. The large scope of the subjects contributes to inefficient meetings. The lack of clear purpose creates a doubt among the participant regarding what decisions that should be made during these meetings. There also exists an uncertainty regarding who is responsible for what decision. The supply review meetings at Nobel Biocare are missing a structure for the execution. This means that during the meetings different subjects can discussed every time. The structure of the meeting could also be different from meeting to meeting. This contributes to the lack of understanding for the presentations done by the Global Capacity Planner.

The Global Capacity Planner is presenting data that should be used as a basis for the decision-making. Unfortunately, there exist many uncertainties regarding what decisions are supported by this data. This is due to lack of understanding and knowledge regarding this presented data as explained before in this chapter. However, the decisions made in the current meetings are not always made in consensus. Furthermore, the risks with certain decisions are not shared among the participants.

Nobel Biocare is missing a process for the evaluation of deviations in the capacity plan. The execution of the actions that are decided at a lower planning level is not followed up. For instance, the Global Capacity Planner does not know if the production plants used night shifts instead of over time, even though night shifts were decided. This creates a gap regarding the information between different planning levels.

5.1.7 Different opinions regarding SAP

The production sites and the supply chain department have different opinions regarding to what extent SAP should be used for planning and the benefits of using the system for planning. Employees at Nobel Biocare have different levels of knowledge and skills of the system. This creates uncertainties about the features of the system and creates a desire to use Excel-sheets instead of trusting the system. The system would make it possible to limit the involvement of human interaction for the processes. Typically, these people at the production sites have low skill level of using SAP but at the same time better knowledge about the operations at the shop floor. The opposite side has unrealistic trust to the system. They do not see the limitations of using SAP for planning. Typically these people have high skill level of using SAP but poor knowledge about what limitations that exist at the shop floor. Simplified, two extreme opinions can be identified at Nobel Biocare, see Figure 15. The two dots represent the two extreme sides.

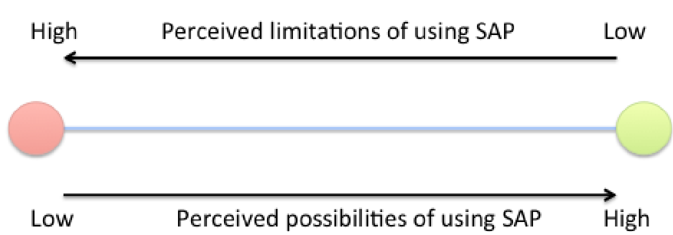

Figure 15 - Two extreme points regarding SAP knowledge vs. limitations

5.1.8 Overlapping planning levels

At Nobel Biocare three planning levels are used. The decided time horizon for the long-term planning is 4-15 months. This means that decisions that affect this time horizon should be discussed in the monthly supply review meetings. The mid-term planning should focus on week 1-12. However, a longer time horizon is used in the mid-term planning and decisions are made more than 12 weeks ahead. This lead to an overlap between the long-term and the mid-term planning levels, see Figure 16. In many cases it means duplication of work. It becomes less meaningful to discuss actions during the supply review meetings, if other actions are decided locally at the production site in the mid-term planning.

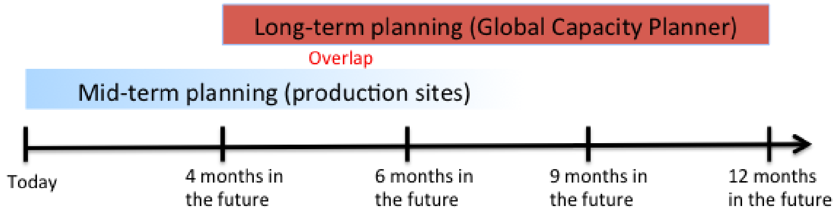

Figure 16 - Overlap between long-term and mid-term planning

5.1.9 Summary of problems

Eight different problem areas have been described related to Nobel Biocare's capacity planning process. Based on these problem areas, 17 different problems can be stated. How these problems are linked to different problem areas is shown in Table 4. Out of the 17 problems, 13 can be mitigated by the use of lean principles. The four problems that could not be mitigated with lean principles are marked with grey.

Table 4 - Identified problems related to Nobel Biocare's capacity planning process

Problem area	Problem
Lack of lean philosophy	Lack of lean philosophy
Lack of trust to the presented capacity data	Low accuracy of capacity planning
	Difficult to estimate conversion factors
	Low understanding for the presented capacity data
Lack of personal trust	Lack of trust within the capacity planning process
	Lack of understanding for other departments activities and responsibilities
Low average capacity utilisation	Complex planning environment
	Low average capacity utilisation
	Uneven short-term workload between work-centres
	Unclear what the current workload is at different work-centres
	Complex production processes
Decision conflict with KPI targets	Decision conflict with KPI targets
Inefficient meetings	Unclear what roles different stakeholders have in processes
	Lack of consensus in decision-making
	Lack of evaluation of deviation from plan
Different opinions regarding SAP	Different opinions regarding SAP
Overlapping planning levels	The mid-term planning uses a longer time-horizon than predefined

5.2 Solution analysis

In this section solutions are analysed to mitigate the identified problems. These solutions will be based on lean principles that the reference companies have applied in their capacity planning processes or theoretically applicable lean principles.

5.2.1 Identified lean principles to mitigate problems in the capacity planning process

The potential solutions to mitigate the identified problems are based on lean principles described in the theory. Many of these lean principles have been used in the three different reference companies' capacity planning processes. Some of the lean principles have been implemented consciously, while others are considered to been implemented by the researchers. A summary of the lean principles that the reference companies have implemented can be seen in the Table 5. To be able to compare, the table also shows what lean principles have been implemented in the capacity planning process at Nobel Biocare.

Table 5 - Lean principles implemented at Nobel Biocare and the reference companies

Lean principle	Nobel Biocare	Autoliv	Emerson	Parker
1		X	X	X
2		X		X
3	X	X	X	
4		X	X	X
5				
6		X	X	X
7		X	X	
8				
9				
10				
11				
12		X	X	X
13				X
14	X	X	X	X
A				
B				
C			X	X
D		X	X	X
E				
F				X
G				
H				

The lean principles that were implemented at the reference companies are potential solutions to the identified problems, see Table 5. These lean principles were used in this analysis and are presented below:

- Lean principle 1 - Lean philosophy
- Lean principle 2 - Continuous flow
- Lean principle 3 - Pull-based production
- Lean principle 4 - Level out the workload
- Lean principle 6 - Standardisation

- Lean principle 7 - Visualisation
- Lean principle 12 - Root-cause analysis
- Lean principle 13 - Go-slow approach
- Lean principle 14 - Continuous improvements
- Lean planning principle C- Clear define roles and responsibilities
- Lean planning principle D - Mitigate risks in the planning process
- Lean planning principle F - Bottom-up feedback

As seen in Table 5, there exist lean principles that have not been perceived as implemented at the reference companies. The problems regarding calculations and presentation of capacity data were identified as specific for Nobel Biocare. Therefore, two additional lean principles were identified to mitigate these problems. These two principles were found theoretical applicable from the literature about lean planning principles. The additional lean principles are:

- Lean planning principle B - High accuracy and right level of aggregation
- Lean planning principle G - Visual presentation during meetings

The lean principles listed above are the basis for the potential solutions to the identified problems. How the lean principles and the potential solutions are related is analysed below. The structure of this analysis is based on the identified problems.

5.2.2 Lack of a lean philosophy

The lean philosophy is *lean principle 1* and works as the foundation for all other lean principles. It is essential that companies implement a lean philosophy in order to be lean. The implementation of one philosophy contributes to a common view regarding lean within the company. The one common view regarding lean should be focused on customer value and how to maximise this. This leads to that personnel at the company have one clear definition of lean, to maximise customer value. A clear lean philosophy is stated at all three reference case companies.

5.2.3 Low accuracy of capacity planning

According to *lean planning principle B*, having high accuracy in the capacity planning is a prerequisite to make the best possible decision. For lean oriented companies with small inventories but still high service level, it becomes vital to be able to assess required and available capacity accurately. As described above the accuracy of the capacity planning is affected by:

- Forecast accuracy
- Precision of conversion factors (both for required and available capacity)
- Scrap rate
- Precision of setup time estimation
- Accuracy of number of available resources
- Estimation of losses

As suggested by *lean planning principle F*, bottom-up feedback is important to continuously improve the accuracy. Currently this is done for the demand planning through the measurement of forecast accuracy, i.e. the forecasted volumes in the demand plan are compared to actual sales. Actions are then implemented accordingly to increase the forecast accuracy. Similar bottom-up feedback is also purposed for the accuracy of capacity planning. This kind of bottom-up feedback exists at the reference company, Parker.

A KPI is introduced to continuously improve the capacity planning accuracy. The KPI is called *capacity utilisation accuracy*. It compares the planned capacity utilisation on different work-centres with actual capacity utilisation. This definition can be found in the List of Definitions.

Since the calculation of capacity utilisation takes both required and available capacity into consideration, this KPI covers all six factors listed above. The purpose with this KPI is to identify sources of error in the capacity planning calculations. However, deviations can be an effect of short-term changes in demand and the purpose of the KPI is not to constrain the ability to adapt accordingly. The planned capacity utilisation should therefore be assessed as late as possible to fulfil the purpose of the KPI. For instance, the planners can calculate the capacity utilisation in the beginning of every day when the orders have been released to the shop floor and allocated to different work-centres. The result is planned capacity utilisation at each work-centre. When the actual production occurs, the operators can measure the actual capacity utilisation. By the end of each month, the planners can calculate average values of the planned and actual capacity utilisation and calculate the KPI. The outcome of the KPI should be discussed with the production and the capacity planner(s). This approach makes it possible to continuously improve the accuracy of the capacity calculations.

If the accuracy of capacity utilisation is lower than expected, the *lean principle 12* suggests that the root-cause to the problem has to be found. It can be either the accuracy of the requirements for capacity or the accuracy of available capacity. It can also be that the accuracy is low for both of them. If the root-cause is the conversion factors, they should be adjusted in the master data accordingly. However, it is important to consider the forecast accuracy's impact on the calculations and isolate this impact before making adjustments in master data.

The company needs to set reasonable targets for this accuracy. The main application area is for the long-term planning where some inaccuracy could be accepted. The goal is to have capacity data that is accurate enough to base long-term decisions on it. In situations when KPIs and lean principles are contrary, it is essential that decisions will be based on the alternative that creates the most perceived customer value.

5.2.4 Difficult to estimate conversion factor

A major source of error in the capacity calculations is rough assumptions of the conversion factors. When making capacity calculations real measurements should be used to the greatest possible extent. This would decrease the use of assumptions and increase the accuracy of the capacity plan. However, it is time-demanding to assess all the involved planning parameters by physically measuring them for every single SKU. Therefore, a balance between measuring real capacity and assumptions has to be found. It might be accurate enough to use assumptions for some parameters. Hence, it is essential to prioritise what parameters to measure.

Lean principle 6 implies standardised work. This principle is an approach to facilitate the measurements of conversion factors. When physically measuring, it is important to use parameters that are represented for the entire personnel. All three reference companies have implemented standardised work in their production. The standardised work has been dedicated to certain time for performing the tasks. The use of standardisation makes measurements for processes more accurate, since the tasks are done in the same way every time. The influence of differences between operators will be limited but not possible to ignore entirely. The operators have different experiences and training in the specific production. They will therefore perform the tasks differently but still within the standards.

5.2.5 Low understanding for the presented capacity data

In order to manage the problem regarding lack of understanding for the presented data the Global Capacity Planner needs to communicate the data in a simple and relevant way. This is emphasised in *lean planning principle G*. This should be done by taking consideration to the actual receiver. The presentation of data, e.g. during meetings, should be illustrative and follow a predefined structure. The receiver should be able to question the presented data if uncertainties occur. Hence, a climate of open lines of communication is an important prerequisite to collaborate effectively.

5.2.6 Complex planning environment

By following *lean principle 2*, both Autoliv and Parker strive for continuous flows when setting up the production layout. This leads to a simplified planning environment. Having a cellular or line production layout simplify the planning environment, since the planning points are reduced.

The cell can be seen as one planning point instead of that each resource corresponds to one planning point. This means that the capacity planner have fewer resources to plan. For instance, if a production has a job shop layout consisting of three machines, this corresponds to three planning points. If the layout was changed to one cell, the planning points would be reduced to one, see Figure 17. From a long-term perspective it will become easier to plan capacity only for this cell instead of three separate machines. This leads to that the capacity planner can have a higher focus on fewer resources, which will lead to a more efficient planning. There will also be more time on implementation of continuous improvements.

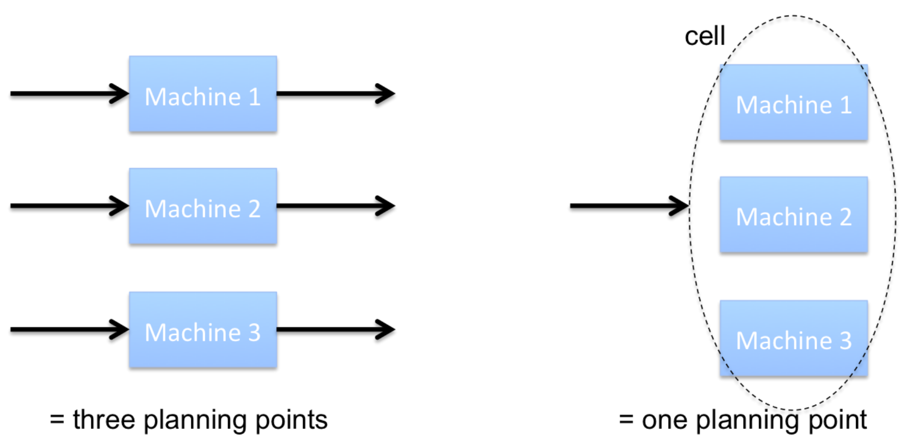

Figure 17 - How a robot reduces the planning points from three to one

When companies have production with continuous flows, problems are also brought up to the surface. The visual discovery of queues in the production shows that downstream resources are over utilised. Often queues arise when a machine or personnel have a higher utilisation that is possible to manage. By having continuous flows, it therefore becomes clear and visual where current bottlenecks are at the shop-floor.

5.2.7 Low average capacity utilisation

The average capacity utilisation at Nobel Biocare is low but daily fluctuations in demand can lead to situations with insufficient capacity. *Lean principle 4* states that the workload should be levelled in order to increase capacity utilisation. This will also lead to a decreased average need for capacity. If the company decides to freeze the production plan for a certain time period in advance, the corresponding production orders could be levelled. This approach would imply that production orders are released only if capacity exists. This eliminates unnecessary buffers in the production and lowers the WIP.

To be able to freeze the production plan, lead-times have to be long enough. For instance, if the frozen period is one week, the lead-time has to be at least one week so that new demand can be covered by the next week. In addition, longer lead-times will require that inventories exists that absorb short-term variations in demand during the frozen period. There is a trade-off between levelled production and low inventories. Companies have to compare the benefits of having levelled production with the benefits of having low inventories for a certain service level. It will be different depending on industry e.g. for high-value products the cost of holding inventory is higher than for low-value products.

5.2.8 Uneven short-term workload between work-centres

Lean principle 4 also implies that the work-load should be balanced between work-centres. The solutions for this problem are to make products possible to manufacture in several machines or to reallocate operators. The possibility to use several machines for products with high demand will increase the output for these processes. This leads to the possibility to meet customer demand without increasing the delivery lead-time. Since the machines need to be managed by operators, they can become a limiting factor. The operators need to have knowledge and training in several machines, which increases the flexibility in production. The operators can then manage several different machines. By the use of *lean principle 7*, visual control such as flat screens or physical tables/billboard it will be easier for the operators to identify current bottlenecks. This makes it possible for operators to be aware of the need for reallocation to another floor, in order to balance the work-load.

Autoliv uses a planning tool that is integrated with the ERP-system. This planning tool makes it possible to level the capacity and balance the workload in-between. This is an implementation of *lean principle 4*. This makes it possible to plan capacity and balance the workload between work-centres for the upcoming week. It is also a way to control bottlenecks at each cell or line.

5.2.9 Unclear what the workload is at different work-centres

The balancing of the workload is related to the capacity utilisation. When the production is located at several floors it is essential to use *lean principle 7*, visualisation. The visualisation should inform the operators about the current workload at another floor. The visual control could be to use flat screens or physical tables/billboards. Autoliv is a company that use visualisation to inform operators regarding the actual workload in every work-centre. The company is using Heijunka-tables as visualisation. The tables make the teams at the shop-floor aware of the workload at each work-centre. The use of visualisation should also inform operators about future utilisation of machines. This will increase the possibility to identify potential bottlenecks in time.

Emerson is also applying *lean principle 7* by using screens to visualise the available capacity, already before orders are released. This makes it possible for the employees at the company to get an overview over the production. When changes are made in capacity it can be seen at the screens. In this way the order-planner are always updated on the current capacity. It is also their responsibility to level out the orders according to this capacity. If changes in capacity are made on short-term it might not be possible to adjust already registered orders. This way of arranging order according to available capacity makes the planning more efficient. It limits the need to adjust capacity because of peaks in demand. The approach to plan orders according to available capacity will also decrease the work in progress. The orders that are released are based on that there exists capacity. If this is not the case, orders should not be released since these will only lead to more buffers in the production. This will increase the work in progress and the large amount of material can create confusion. The high volume of work in progress will limit the visualisation of the processes.

5.2.10 Decisions conflict with KPI targets

Mitigating the risks in the planning is the *lean planning principle D*. One major risk in planning is that decisions are taken without consideration to customer value. Many companies are working with KPIs to measure the performance of their organisations. The chosen KPIs should be closely linked to the customer value. To make decisions that increase customer value, these should therefore be made according to the company's KPIs. It is important to consider how different actions are affecting the KPIs and therefore customer value.

There should be a limit of how orders are released to the shop floor with consideration to available capacity. *Lean principle 3* contains that pull-based production should be used in order to avoid overproduction. When releasing orders according to available capacity, this will decrease the risks of overproduction. The use of capacity screens as at Emerson, would make it possible to only release orders when capacity is available. Lean planning principle D means that risks should be limited in the planning. This will be achieved when the available capacity is already considered in the order-planning stage.

5.2.11 Unclear what roles different stakeholders have in processes

According to *lean planning principle C* there should be a clearly stated purpose and defined roles in the capacity planning process. This will contribute to a more efficient decision-making. The identified problem regarding meetings is that one large meeting can be seen as unstructured and inefficient. This has resulted in stakeholders not knowing their roles and responsibilities. One approach to solve this is to do as Parker has done, by dividing one meeting into several ones. Parker has four different meetings in their monthly planning. The different meetings have well-defined purpose for each of them. The different steps in the capacity planning process are divided among these four meetings.

The four meetings create a clear division of subjects to discuss for each meeting. This will increase the understanding for the participants. Discussing several subjects at one meeting can lead to confusion. The confusion can be based on the fact that it can be difficult to keep track on what subject is discussed during a certain time. The division of meeting based on subject will also make it possible to limit the participants for each meeting. The involved personnel only need to attend the meeting where they are affected. This will decrease the time spent in meeting discussing concerns that do not affect all participants. More time can be spent on value-adding activities. It should be a clear delegation regarding the responsibilities of the meeting, where everyone knows that is expected from him or her.

Lean principle 6 emphasises that every process should be standardised. This approach is also applicable for meetings. The meetings should be based on a standardised structure, where the purpose of the meeting should be presented each time. The structure should be closely linked to the purpose of the meetings. The meeting structure should be easy to follow, with clear milestones for each decision before continuing to the next step. Standardised meetings facilitate the use of continuous improvements, since it becomes more convenient to compare with previous meetings.

5.2.12 Lack of consensus in decision-making based on customer value

To reach consensus in decision-making, *lean principles 12 and 13* are useful approaches. Autoliv is one company that have combined these two. *Lean principle 12* claims that the root-cause to problems has to be identified before solutions are elaborated. An important aspect of this is to go-and-see for yourself the actual situation of the problem. *Lean principle 13* states that companies should use a go-slow approach when making decisions. In order to increase the awareness regarding the risks with a certain decision, the risks should be mapped and evaluated before decisions are made. In collaboration it will be possible to mitigate the risks and achieve consensus. However, it is important that meetings are held with open lines of communication regarding personal judgements. The decisions in the meetings should not be rushed due to time limitations.

A precondition to use *lean principle 12* in the capacity planning is that the production department and planning department are located within reasonable geographical distances. In many companies the production is located at multiple locations in different countries, while planning is centralised. This makes it difficult to go-and-see the actual situation, which might lead to that not the most suitable action is taken. The distance will also make it difficult to achieve close collaboration between these departments. If it is impossible to have the two departments located at one site, trust and great communication is essential to make suitable actions.

5.2.13 Lack of evaluation of deviation from plan

According to *lean principle 14,* companies should continuously reflect upon how to improve their processes in order to become a learning organisation. Learning organisations have a competitive advantage in a changing environment since they are moving forward. Moving forward requires the company to learn from previous experiences and therefore evaluation is motivated. The capacity planning is one of the processes in a company that needs to be continuously improved. An evaluation of this process is thus necessary.

Lean principle 6 regarding standardisation can also be applied for following up deviations. This would lead to higher understanding for the challenges in the capacity planning. The evaluation can be used as a control for the capacity planner to ensure that the production sites trust his/her recommendation of actions. This process could be implemented in an ERP-system. If the production sites use the system to plan short-term capacity, the actual capacity would be available in the system. This would make it possible for the capacity planner to get access to this data directly through the system. It enables him/her to verify the implemented actions without the need to contact the production sites.

5.2.14 Overlapping of planning levels

Lean principle 2 does not only suggest continuous flow for material and information. It also links processes and people together in a defined way. The capacity planning process involves many people from different departments. It is therefore important to define how to link these people to the process. The planning hierarchy containing different planning levels is a way of structuring this link. The different planning levels should have different planning objects and planning goals. This would decrease the feeling of duplication of work, which can occur when several planning levels are overlapping. Separating the different planning objects and goals would also increase the mutual dependency between the capacity planner and the production sites. The capacity planner and the production sites will need information from each other in order to aggregate and disaggregate the data. A clear definition between the different planning goals at each level would decrease the uncertainty regarding responsibilities among stakeholders. The different goals at the different levels make it easier to determine the necessary involved people for meetings and decision-making. Hence, a clearly defined planning hierarchy includes clear roles and responsibilities.

5.2.15 Summary of identified problems and potential solutions

Different problems were identified at Nobel Biocare. In connection to these problems, different solutions were elaborated. These solutions are closely related to lean principles. The identified problems and solutions as well as relation to lean are summarised in Table 6. These solutions lead to several important considerations for companies and thus they are incorporated in a conceptual model presented later in this report.

Table 6 - Identified problems at Nobel Biocare and potential solutions

Identified problem at Nobel Biocare	Lean principles that mitigate the problem	Solution	Potential outcome
I. Lack of lean philosophy	Lean principle 1	1.Implementing one philosophy	• A precondition for effective implementations of other lean principles
II. Low accuracy of capacity planning	Lean planning principle B Lean planning principle F Lean principle 12	2. Increase capacity data accuracy	• Increase the possibility to make more accurate decisions
III. Difficult to estimate conversion factors	Lean principle 6	3.Implement standardised work	• Available capacity based on real measurements and independent of the operator
IV. Low understanding for the presented capacity data	Lean planning principle G	4. Clear presentation of data	• Increase the possibility for convincing decision-makers
V. Complex planning environment	Lean principle 2	5. Strive for continuous flows	• The planning context is simplified by reducing the planning points • Problems are easier identified.
VI. Low average capacity utilisation	Lean principle 4	6. Level out the production	• Higher average capacity utilisation • More even production
VII. Uneven short-term workload between work-centres	Lean principle 4	7. Balance the workload between work-centres	• Higher possibility to avoid bottlenecks
VIII. Unclear what the current workload is at different work-centres	Lean principle 7	8. Visualise the workload for all work-centres	• Operators become aware about the current capacity utilisation
IX. Decision conflict with KPI targets	Lean planning principle D Lean principle 3	9. Release orders according to available capacity	• Reduce work in progress • Decrease short-term adjustments in capacity
X. Unclear what roles different stakeholders have in processes	Lean principle 6 Lean planning principle C	10. Standardise administrative processes	• Stakeholders know what is expected from them and how decisions are made.
XI. Lack of consensus in decision-making	Lean principle 12 Lean principle 13 (main goal of lean planning is to have increase customer value)	11. "Go-slow" approach	• Time to identify root-causes for problems • Increase the possibility to choose the alternative that increases customer value the most
XII. Lack of evaluation of deviation from plan	Lean principle 6 Lean principle 14	12. Standard process for following up deviations	• Continuous improvements
XIII. Overlapping of planning levels	Lean principle 2	13. Clearly defined planning hierarchy	• A consistent planning

5.3 Incorporating the solutions into a model

Based on lean principles, different solutions presented in this chapter were elaborated in order to solve identified problems at Nobel Biocare. These solutions imply important aspects to consider in the capacity planning process. A new approach to capacity planning has been applied. This approach is based on lean principles. The solutions from previous section will be categorised into the three different stages of the theoretical capacity planning process: preconditions, planning hierarchy and planning cycles. The problems have been identified in a certain part of the capacity planning process. This links the solutions to the same part of the capacity planning process. The categorisation is therefore based on this link.

The findings from the previous section lead to additional aspects to consider in the capacity planning process. The combination of the theoretical structure of the capacity planning process and the findings based on lean principles leads to a lean approach to capacity planning. This is referred to as the *lean capacity planning process*. In lean a great focus is on continuous improvements. Therefore, the planning cycle with a lean approach contains an additional step, Evaluation. The result is a planning cycle with six steps, see Figure 18.

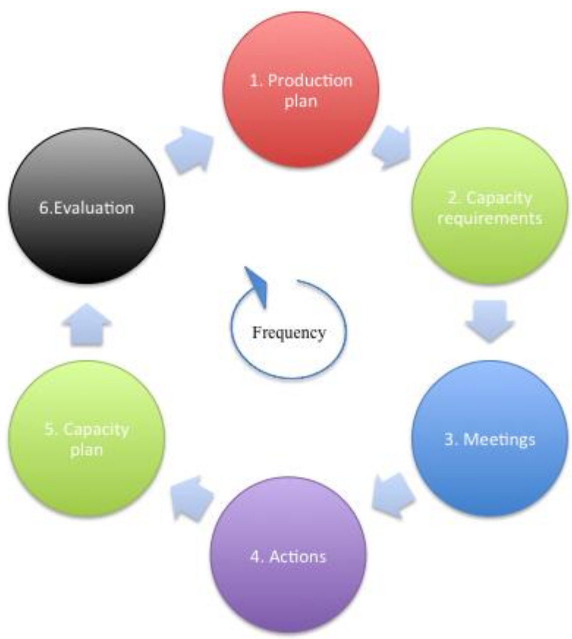

Figure 18 - Lean planning cycle

The lean capacity planning model incorporates several lean principles. The lean principles make companies to focus on the customer value when making capacity-related decisions. The focus on customer value will increase companies' long-term profitability. It will also be easier to reach consensus in the decision-making, since all stakeholders have a common goal. Lean principles will also facilitate the use of continuous improvements in processes. In the long run, the latter leads to a more accurate capacity planning.

How the three stages in the theoretical framework are affected by the solutions from previous section are described below.

5.3.1 Assess preconditions for planning

The preconditions that are mention in the theoretical framework regarding manufacturing approach, production, ERP-system, market and demand, people and lean should still be considered when planning capacity. In addition, companies should have a clear defined lean philosophy and simplify the planning environment.

Companies need to have a clearly stated lean philosophy (Solution 1). This philosophy should include the purpose of the use of lean principles and one clear definition. The philosophy is the base for all other lean principles and is therefore essential to have.

Companies should strive to decrease the number of planning points in order to simplify the planning. This could be achieved by having continuous flow (Solution 5). Visualising of the available capacity should be used (Solution 8). Considerations regarding available capacity should be taken in the order-planning stage. This will decrease the risks in the planning regarding potential capacity imbalances.

5.3.2 Define planning hierarchy

When defining the planning hierarchy it is essential to consider the company´s context. The planning hierarchy should be clearly defined (Solution 13). This means that the planning levels should have different planning objects and planning goals. This will decrease the overlapping of work between the different levels.

In the process the roles and responsibilities need to be clearly defined. In order to decrease the uncertainty, companies should implement standardised administrative processes (Solution 9). This results in that stakeholders know what is expected from them and how decisions are made. The stakeholders know when they need to take actions on problems, since their area of responsibility is clearly stated.

5.3.3 Design planning cycles

Nine solutions have been identified to be important to consider when designing companies planning cycle. These have been divided into the five different steps in the planning cycle described in the theory. This model has been extended with one step, evaluation. This results in a capacity planning cycle containing six steps.

1. Production plan

The first step in the lean capacity planning cycle is to create a demand plan. The demand plan consists of forecasting future demand. It consists of several forecasts that are merged into one used throughout the entire organisation. These forecasts should come from the sales forces, since they are working close to the customers. It is important that the data that are used as input for the demand plan have high accuracy. The demand is then converted into a production plan by taking inventories into account. In order to level the production later in the planning cycle, the production plan should be frozen for a certain time in near future e.g. the nearest week. This will also make it possible to use takt-time for production. The orders should be released according to available capacity. This means that there should exist a limitation regarding the number of released production order (Solution 11). This will result in that the work in progress and adjustments in capacity made on short-term can be decreased. The production plan is used as input for calculations regarding requirements of capacity.

2. Capacity requirements

In this step, the production plan is converted into capacity requirements. The calculations should be based on high capacity data accuracy (Solution 2). This will lead to a more accurate capacity planning. Accurate capacity planning leads to better decision-making and decisions are not postponed.

In this step the capacity requirements are also compared with available capacity. The latter also has an accuracy to consider for companies. Measuring the throughput-time can assess the machines' conversion factor. A prioritisation is necessary due to the time consuming of measuring processes. The measurement should be based on average operation-time when working according to standards (Solution 3). In order to achieve higher average capacity utilisation and a more even production, it is essential to level out the production (Solution 6).

When companies have increased the accuracy of both the capacity requirements calculations and the available capacity calculations, the identification of potential imbalances can begin. These capacity imbalances should be a main topic for discussion during the next step in the planning cycle, the meetings.

3. Meetings

The third step of the lean capacity planning process involves meetings. The meetings should be used for discussions and decisions regarding adjustments in the demand plan, actions for capacity imbalances and other issues. In line with the go-slow-approach (Solution 10), there should be several meetings, where each meeting has a clear purpose. The participants and subject discussed during each meeting should be closely linked to the purpose of the meeting.

During meetings it is essential that the participants know what is expected from them and how decisions are made. This can be achieved by the implementation of standardised administrative processes (Solution 9). These administrative processes should be standardised with regards to their structure and content, where these are closely linked to the purpose of the meeting. Visualisation is an important factor to create understanding and should therefore be used during meetings. The presentations used at meetings should be simple and clear in order to increase understanding among the participants (Solution 4). The responsible planner has to consider whom the receiver is to make a presentation that is understandable for every participant.

4. Actions

The fourth step is actions. The actions are decided on the meetings and are therefore not included in the solutions. The actions that should be implemented are decided in meetings and these are in this step executed.

5. Capacity plan

When actions are decided and eventually implemented, the resulting changes in capacity requirements and/or available capacity can be taken into account. This results in a production plan that is feasible to execute for the production sites. It implies that capacity imbalances should be solved based on maximum customer perceived value.

The workload between different work-centers should be balanced (Solution 7). It is desired to manufacture products in several machines and reallocate operators. The workload should be visualised to inform operators regarding potential bottlenecks and reallocation is needed. This requires that operators can manage several processes.

6. Evaluation

Companies should have a standard process for following up deviations (Solution 12). Implementing a standard process for following up deviations is considered essential for the continuous improvements of the company´s performance. The following-up should be done in a careful way, to make sure that the root-cause of deviations are found. The deviations should be documented in order to enable learning from previous experiences in the future. Different KPIs should be used to monitor the process. For the demand plan, forecast accuracy is recommended. For the capacity requirements, the accuracy of the capacity utilisation is useful. By evaluating deviations for several KPIs, companies are striving for continuous improvements of their capacity planning process.

Summary

The key points for the lean planning cycle can be seen in Figure 19.

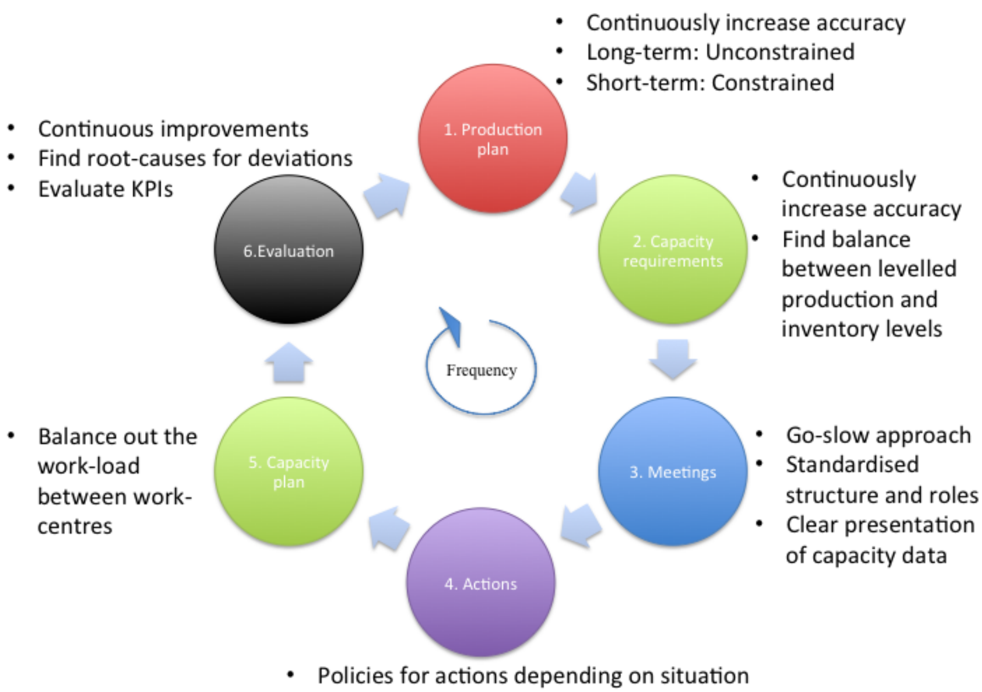

Figure 19 - Key points of the lean planning cycle

6 Discussion

This chapter is introduced by the recommendation given to Nobel Biocare. Second is the contribution of this thesis in terms of theoretical and managerial implications. Alternative approaches are also discussed in this chapter. Finally, suggestions regarding future research are presented.

6.1 Recommendations to Nobel Biocare

The lean capacity planning process that was developed in the previous chapter has been applied in theory at the case company Nobel Biocare. It is structured in the three stages: assess preconditions, define planning hierarchy and design the planning cycle.

6.1.1 Assess preconditions for planning

Nobel Biocare's current preconditions for planning were presented in the empirical findings. Many of these preconditions contribute to a complex planning environment, e.g. the wide and growing assortment, customers' demand for 24-hour deliveries, regulations and complicated production layout. All these preconditions are not possible to change for Nobel Biocare. For instance, the regulations and customers' behaviour affect the whole industry and Nobel Biocare cannot deviate from these. The focus is therefore on the preconditions that Nobel Biocare can affect as a single company and the changes that lead to a simplified planning environment.

Nobel Biocare has several definitions of lean, leading to a scattered view on lean. Therefore, the recommendation is to implement one common lean philosophy. It is important to strive for a continuous flow in production in order to reduce the planning points. This will simplify the planning. Nobel Biocare should with the use of industrial robot consolidate machines into cells, if possible. Another improvement would be to visualise the workload at every work-centre. Screens or physical boards can be used to create visualisation. This is especial important at Procera, since the production is located at several floors.

6.1.2 Defining planning hierarchy

The planning at Implant Systems should be divided into three levels: long-term, mid-term and short-term level. This division is necessary to achieve a continuous flow between people at the company. The Global Capacity Planner should be responsible for the long-term planning with a time-horizon of 4-12 months. The decisions taken at this level are machine investments and recruitments. The mid-term planning should have a time horizon of 1-3 months. The production sites should independently be responsible for decisions at this level. These decisions include shift planning, training and maintenance. The integration between the long-term and mid-term level is illustrated in Figure 20. The short-term planning is the daily planning, conducted at the shop floor.

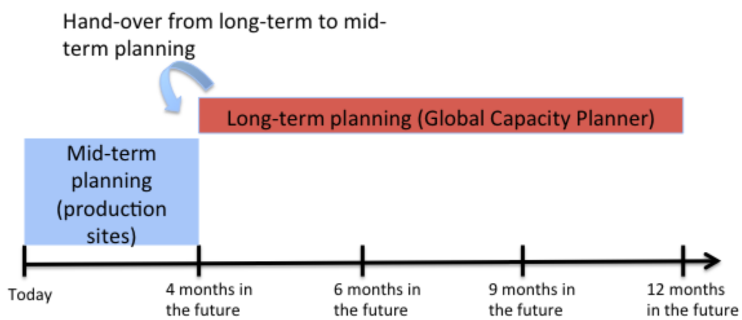

Figure 20 - Division of time-horizons between long-term and mid-term planning (without overlap)

6.1.3 Design planning cycle

The lean planning cycle was applied at the current capacity planning process. When applying the lean capacity planning process at Nobel Biocare, the following implications are described below. These implications have resulted in capacity planning process according to Figure 21.

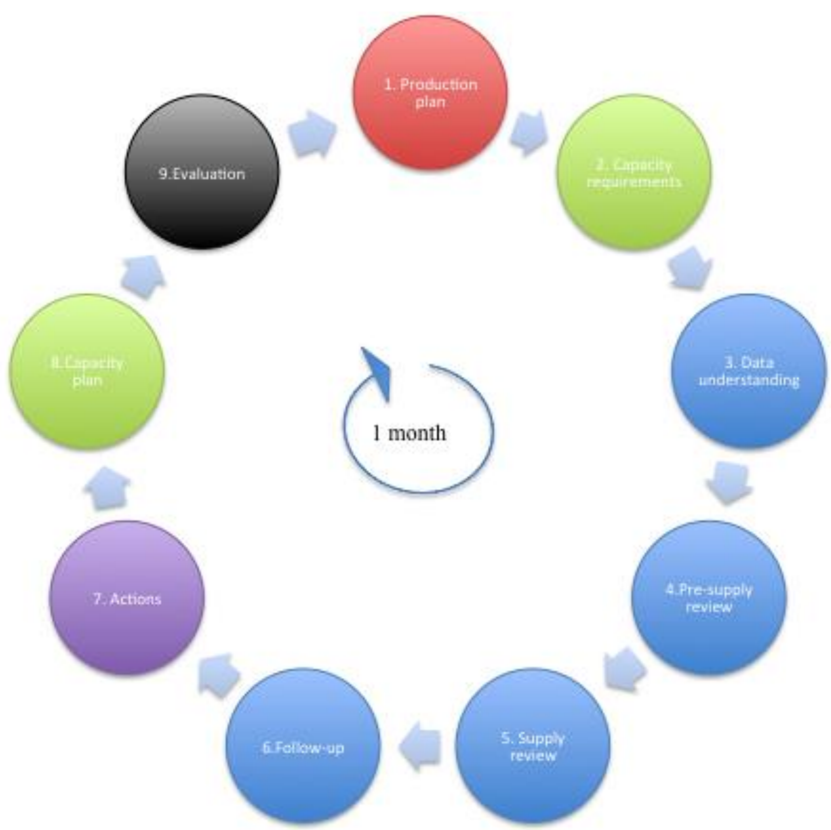

Figure 21 - Lean planning cycle at Nobel Biocare

1. Production plan

To be able to level the production a frozen production plan can be implemented for the short-term planning. Orders should only be released if there exist available capacity in the production.

2. Capacity requirements

The calculation of both requirements for capacity and available capacity is based on rough assumptions today, which harms the accuracy. Nobel Biocare should increase the accuracy by measuring the conversion factors and continuously update the scrap rate. Increasing the accuracy of Nobel Biocare's capacity planning leads to more accurate identifications of capacity imbalances.

The Global Capacity Planner is making the calculations regarding required capacity. The production sites should confirm the available capacity. If there exist a difference between the required capacity and available capacity, these imbalances need to be discussed during the Pre-supply review. By sharing the responsibility between the Global Capacity Planner (required capacity) and the production sites (available capacity), the risk of mistakes are shared.

3.Data-meeting

The first meeting should have the purpose to create an understanding of the presented data. In the long-run this meeting should be eliminated as a result of increased understanding for the presented data.

4.Pre-supply review-meeting

The second meeting should contain discussions regarding how to manage identified capacity imbalances. The meeting should have a go-slow approach, where all available alternatives are discussed. No time should be spent on explaining the data in this stage.

5.Supply review-meeting

Decisions about the alternatives for actions that were discussed in the pre-supply review should be made in this meeting. During this meeting the participants should confirm their responsibilities. This is done to make sure actions are implemented and not forgotten or ignored.

6.Follow-up-meeting

The evaluation from the previous period is discussed during this meeting. The actions that were decided should be followed up. This gives Nobel Biocare a possibility to still implement the decided actions in order to manage long-term future capacity imbalances. The follow-up meeting gives Nobel Biocare time to reserve for evaluating KPIs. This will contribute to the continuous improvement of the company.

7. Actions

The actions decided in the supply review meeting are implemented locally at the production sites. These actions can be divided into two categories according to the planning hierarchy; the actions for capacity imbalances on long-term and actions for capacity imbalances on mid-term.

8. Capacity plan

The implemented actions imply changes to the required and/or available capacity and future capacity imbalances should now be managed. The capacity plan should be feasible to execute for the production in order to meet demand on long-term. However, some sources of error cannot be eliminated completely. It is therefore important to have a high short-term flexibility at the shop floor.

9. Evaluation
Nobel Biocare should implement a standard process for the evaluation and follow-up of the actions taken. The evaluations should include a comparison between the actions decided in the supply review meeting and the actions implemented. It should also include how the capacity imbalances were managed. The last meeting regarding follow-up should be a part of the standardised process.

The connection between KPIs and actions should be followed-up and investigated. Nobel Biocare should work on continuously improving the accuracy of the capacity planning. The suggested KPI *capacity utilisation accuracy* is recommended to measure this accuracy.

6.2 Contribution to theory

The result of the analysis implies different contributions to theory. These are related to the gaps in literature that were identified in the background.

In this thesis, problems that can exist in a capacity planning process were identified. This is a major contribution to theory. The different sources of error that affect the accuracy of capacity planning are key takeaways. While theory focuses on forecast accuracy, this thesis brings up a number of other factors that lead to poor capacity planning accuracy. In addition, the consequences of having a low accuracy are discussed and exemplified. Another contribution is the influence of the human factor in a process like capacity planning with many involved people. Issues as a result of this are perhaps even more in a capacity planning process like Nobel Biocare's, which has a centralised capacity planning process for multiple sites where different stakeholders are separated geographically. Mistrust as result of different gaps and overlapping planning levels is the main contribution from this kind of capacity planning process.

The other major contribution is how lean principles affect and can be applied to solve the identified problems. It provides an overview of how lean principles are related to capacity planning, which is a gap in current literature. Many lean principles affect the planning environment in which the capacity planning is executed. A key contribution is that lean principles can simplify the planning environment by reducing the amount of planning points and increasing the flexibility. Especially lean principle 4 - balance the workload, is also an approach to find solutions regarding capacity utilisation issues. Continuous improvements and go-slow-approach were applicable to increase the accuracy of the capacity planning and make consensus decisions, respectively. Another contribution to theory is what part of the capacity planning process that the solutions affect. It is important to understand that some of the lean principles affect the preconditions and others are applicable in the planning cycle.

6.3 Relevance of the results for other companies

This thesis is mainly based on the case company Nobel Biocare. The companies working in industries with similar characteristics will be able to learn and take inspiration from this thesis. Other companies with other planning environment will also be able to use these findings but they might need to adjust them. The reason for this is that the specific planning environment at Nobel Biocare affects some of the problems.

One of the aspects in Nobel Biocare's planning environment is the geographical division of the planning function and the production function. This division implies several challenges and important considerations when planning capacity. Some of these challenges and considerations have been included in this thesis. Companies with the same or similar division can use this thesis to get inspiration for the implementation of a capacity planning process.

One of the identified trends was that several companies in many industries have experienced that the margins on the sold products are declining. This forces companies to become more cost efficient in their planning and processes. One approach to reduce the costs in organisation and focus on customer value is the use of lean principles. This have been investigated in this thesis how to use lean principles to achieve cost efficiency. Companies can therefore use the result of this thesis to get inspirations to increase customer value and decrease costs with the use of lean principles in their capacity planning process.

6.4 Alternative approaches

The results from this thesis have been affected by the chosen approach. It is therefore valuable to discuss what alternative approaches that were available and how these would affect the result. The alternative approaches were not applied due to the evaluation that they were not suitable for the scope.

The identified problems are collected from one company. The planning context and the planning process are thus specific to this company. The approach could have been instead to investigate several companies´ problems. This would lead to a wider range of problems and identification of additional problems to include in this study. The focus in this thesis is on how lean principles can mitigate the identified problems. Therefore companies with a strong lean focus could be included to investigate what problems that exist in their processes. These companies might have problems that are related to their commitment to lean.

The three reference companies chosen have not the entirely the same planning context as the case company. The solutions are partly inspired from these reference companies. If these had the same planning context, the solutions would have higher possibility to be applied for the identified problems. The solutions would not be adapted in the same extent, as they have been done in this thesis.

The elaborated solutions are partly based on solutions that exist at three reference companies. The number of reference companies could be increased to find more and/or alternative solutions. This would lead to a wider range of investigation. The analysis based on the reference companies could become deeper due to a comparison of the companies could be achieved. The increased number of solutions adapted from the reference companies would also be increased.

The identified problems come from the case company Nobel Biocare. Later in the thesis, the developed model is applied on this company. This means that the problems and the application are based on the same company. The application could have been done on another company in order to increase the validity of the model. This application could also mean that there will be recognition of new problems that were not identified before. This will also be used as a measurement regarding the considerations of the planning context.

The scope of the thesis was to identify problems and how these could be mitigated by the use of lean principles. Out of the 17 problems identified, four problems could not be solved by the use of lean principles but could be mitigated with other approaches. The solutions to the remaining problems are to achieve personal trust, create mutual understanding of each other's work, simplify production processes for new products and evaluate SAP. These are still as important as the other solutions but due to the scope of this thesis they are not included.

6.5 Future research

The alternative approaches that were presented in previous section are suggestions for further research. These approaches might result in other findings. As mentioned earlier the identified problems that could not be solved by lean principles have not been included in this thesis. The solution to these remaining problems could be an area for further research. When Nobel Biocare reduced their inventory, the production had to manage the fluctuations in demand instead. A further research could be to investigate how other companies that also have reduced their inventories prepared their production to handle these fluctuations.

7 Conclusion

This chapter concludes the results from this thesis and the main contributions to theory as well as suggestions for future research.

Capacity planning has become more important lately since many companies have reduced inventories and at the same time want to respond faster to fluctuations in demand. This has lead to that these fluctuations are managed by production capacity instead of inventory. Concurrently, many companies have applied lean principles in their processes to increase their competitiveness. In theory there exists a gap regarding how lean principles can be applied in the capacity planning process to increase competitiveness. This gap was the background of this thesis and its purpose, *how companies can apply lean principles in their capacity planning process with the aim of improving it*. To fulfil this purpose three research questions were answered.

To answer the first research question, *what problem can be identified in a company´s capacity planning process and its related context?* a problem analysis was conducted at Nobel Biocare. 17 problems were identified at the company´s capacity planning process. These problems have been categorised into 8 problem areas based on their characteristics. Some of the problem areas are lack of trust to the presented capacity data, low average capacity utilisation and overlapping planning levels. These problems affect the performance of the capacity planning process with the aim of balancing available and required capacity.

The answer to research question 2, *how can lean principles be applied as potential solutions to the identified problems?* links the capacity planning process with lean principles. In relation to the gap in theory lean principles have been used as an approach to mitigate the identified problems in research question 1. The conclusion is that 13 of the 17 identified problems could be mitigated by the use of lean principles. 9 out of Liker and Meier´s (2006) 14 lean principles were used. In addition, 5 out of Lenders et al.'s (2011) 8 lean planning principles were also applied. Since emphasis in lean is to increase customer value, applying lean principles in the capacity planning will make companies become more customer focused in their decisions. With the use of lean principles it will also be easier to reach consensus in the decision-making, since all stakeholders have a common goal. Lean principle 14, continuous improvements, makes companies adapt to changes in their business environment, such as decreasing margins. This will lead to a higher competitiveness. Finally, lean principles contribute to a standardised capacity planning process.

The solutions from research question 2 were applicable in different parts of the capacity planning process. Three distinguishable parts were identified as a structure for the capacity planning process. The structure includes preconditions for planning, planning hierarchy and planning cycle. To answer research question 3, *how can the solutions be applied in the capacity planning process by incorporating them into a model?*, these three parts have been the basis for categorising the solutions. The result from this categorisation was summarised into a model, called lean capacity planning process. Companies that follow this model will be able to use lean principles to mitigate identified problems in their capacity planning process. These companies will be able to increase their competitiveness.

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Appendix 1 - Interviewees at Nobel Biocare

Several interviewees at Nobel Biocare were conducted based on their involvement in the capacity planning process. The persons and their responsibilities are presented below:

- Global Capacity Planner - identifies capacity imbalances by converting the global demand plan to requirements for capacity and comparing with supply of capacity. Identified capacity imbalances are discussed during monthly meetings where actions are proposed. The main objective is to provide data to support different decisions that need to be taken in the capacity planning process, rather than making them.
- Global Demand Planning Manager - collects local demand plans every month and consolidates these into a global demand plan. This global demand plan is used as input for the material- and capacity planning.
- Global Supply Planning Manager - responsible for the supply planning process and related KPIs, especially the trade-off between service level and inventory turns.
- Global Operations Project Manager - incorporates the planning functions into the product launch process in order to be able to produce and distribute new products.
- Plant Managers - Procera and Implant Systems - outermost responsible for the operations and supporting functions at the production sites. The Plant Managers are decision-makers when it comes to adjustments of capacity in terms of floor space, machines and personnel.
- Production Managers - Procera and Implant Systems - are, as the name reveals, responsible for the production function at the factories. They make sure that the decided supply of capacity exists when and where it is needed. They are also responsible for maintenances.
- Logistics Manager - Procera - responsible for the inbound and outbound logistics at the Procera plant.
- Production Planning Manager - Implant Systems - responsible for the inventories of materials used for production and to release production orders according to the demand plan.
- Production Controller - Implant Systems - responsible for the collection and measurements of financial statistics. Other responsibilities are reporting, budget and calculations regarding investments.

Appendix 2 - Interviewees at the reference companies

Several interviewees at the reference companies were conducted based on their involvement in the capacity planning process. The persons and its responsibilities are presented below:

- Manufacturing manager - responsible for the planning of capacity regarding personnel and machines for the three business units, Emerson Process management, Tank gauging products and Marine tank management products.

- The Division Lean Manager - responsible for the continuous improvements at his division by supporting business functions with lean. He was involved in the development of the capacity planning process that is used today at Parker.
- Acting Logistics Manager - current responsibilities are inbound and outbound logistics. Involved in the manufacturing planning activities in Vårgårda, especially the planning of logistics.
- AMC (Autoliv Manufacturing Center) Manager - Responsible for the production in one division where e.g. the airbags are produced. Involved in the manufacturing planning activities in Vårgårda, especially the planning of the production within his division.

Appendix 3 – Interview guides

This appendix presents the interview templates at Nobel Biocare for the supply chain department and the production plants as well as for the reference companies.

Interview guide - Nobel Biocare - Supply Chain Department

Introduction: Present who we are, where we come from and what we are doing our master thesis about.

Areas we want to discuss with you about: Capacity planning context, goals, Lean, process, planning levels, capacity issues, meetings, improvements

Title:

- Is your title correct?
- Could you please tell us more about your work?
- What is your role in the capacity planning process?

Capacity planning context

1. Is there something in Nobel Biocare context (Manufacturing process, production layout, business environment, regulations, locations, customers, suppliers..) that you can identify as important for the capacity planning process?

Capacity planning goals

2. What is the purpose of having a capacity planning process?
3. Do you think it achieves its purpose?
4. What targets (KPIs) are you being measured upon?

Lean

5. What is lean for you?
6. In what way have Nobel Biocare implemented lean?
7. Are there any on-going or planned lean-related projects?

Process

8. What is your input? (From who?)
9. What detail-level do you need to conduct your planning?
10. What are the main steps in your planning process?
11. What is your time-horizon, including time fences for changes?
12. What tools do you use for capacity planning at your level? (incl. SAP modules)
13. How often does the capacity planning process take place?
14. How do you keep updated on the capacity in the plants?
15. Do you implement lean principles in your planning process? (If yes, how?)
16. Do the targets (KPIs) influence decisions? (if yes, how?)

17. What factors determine if an order should be allocated to a certain production site? (e.g. Karlskoga instead of Yorba Linda)
18. What are the main differences for planning between Procera and Implant systems?
19. What is the output for the process used for?
20. Who do you report to?

Integration between planning levels

21. Who is responsible at the different levels?
22. What authority do they have?
23. What communication exists between the different planning levels?
24. How is this communication done?
25. The levels are missing a system support for integration. How would you like this to be done?

Capacity issues

26. What are common problems that occur related to capacity?
27. Who is responsible for what problems?
28. What available actions exist to solve issues at your planning level?
29. What determines what action to take?
30. How is these deviations being documented and followed-up?
31. What actions are usually taken and why? (standardized routines?)
32. When deviations occur, how are they followed up?
33. Who takes decisions regarding machine investments?
34. What restrictions exist to balance capacity between different plants? (between different countries)
35. Are there any financial limitations regarding capacity planning?

Launches & Holidays

36. How often do you launch new products?
37. How does these affect the capacity planning?
38. What is the time-horizon for these launches?
39. How does holidays and planned vacation affect the capacity planning?

Capacity meeting

40. What is the purpose for these meetings?
41. Who are attending?
42. How often does it take place?
43. What topics are discussed?

Potential improvements

44. What areas of improvement have you identified in your work regarding planning?
45. If you had the possibility to decide. How would the capacity planning look like?

Interview guide – Nobel Biocare - Production plants – Plant manager

Introduction: Present who we are, where we come from and what we are doing our master thesis about.

Areas we want to discuss with you about: Capacity planning context, goals, Lean, process, limitations, capacity issues, improvements

Title:

- Is your title correct?
- Could you please tell us more about your work?
- What is your role in the capacity planning?

Capacity planning context

1. Is there something in Nobel Biocare context (Manufacturing processes, production layout, business environment, regulations, locations, customers, suppliers.) that you can identify as important for the capacity planning?

Planning goals

2. What targets (KPIs) are you being measured upon?
3. How does these influence decisions regarding the capacity planning?

Lean

4. What is lean for you?
5. Have you implemented lean in Nobel Biocare´s plant in Karlskoga?
   - Which principles have you implemented?
   - How have you implemented these?
   - Why have you chosen these principles?
   - What is the result of the implementation of lean principles?
6. Do you implement lean principles in your planning process? (If yes, how?)
7. Is there any on-going or planned lean-related projects?

Process

8. What is your input? (From who?)
9. Are you involved in the planning of capacity in your plant?
   - What are the main steps in your planning process?
   - What is your time-horizon, including time fences for changes?
   - What tools do you use for capacity planning at your level? (incl. SAP modules)
10. What are the outputs from the process used for?
11. Who do you report to?’

Capacity issues

12. What are common problems that occur related to capacity in your plant?
13. What available actions exist to solve these issues?
14. What determines what action to take?

15. What actions are usually taken and why?
16. What limitations exist for personnel planning?
17. How is the attitude towards working extra and overtime among the operators?
18. What financial limitations exist regarding capacity planning?

Potential improvements

19. What areas of improvement have you identified in your work regarding planning?
20. If you had the possibility to decide. How would the capacity planning look like with regards to planning levels, decisions and responsibility?

Interview guide – Nobel Biocare - Production plants – Production Planner

Introduction: Present who we are, where we come from and what we are doing our master thesis about.

Areas we want to discuss with you about: Capacity planning context, Lean, production planning, bottlenecks, goals, process, planning levels, capacity issues, improvements etc.
Title:

- Is your title correct?
- Could you please tell us more about your work?
- What is your role in the capacity planning?

Capacity planning context

1. Is there something in Nobel Biocare context (Manufacturing processes, production layout, business environment, customers, suppliers etc.) that you can identify as important for the capacity planning?

Lean

2. What is lean for you?
3. How have you implemented lean in your planning process?
4. Are there any on-going or planned lean-related projects?

Capacity planning goals

5. What is the purpose of having a capacity planning?
6. Do you think it achieves its purpose?
7. What targets (KPIs) are you being measured upon?
8. How do these targets influence decisions regarding the capacity planning?

Planning Process

9. What is your input? (From who?)
10. How do you keep updated on the capacity in the plants?
11. What are the main steps in your planning process?
12. When planning, do you concern to level out the production?
13. What is your time-horizon, including time fences for changes?
14. What tools do you use for capacity planning at your level? (incl. SAP modules)
15. How do you communicate between different planning levels?

16. Who is responsible for the material planning and related inventories?
17. What is the output for the process used for?
18. Who do you report to?

Production

19. What are the main bottlenecks in the production?
20. How does these affect the planning of capacity?
21. How do you plan machine maintenances?
22. How does the maintenances affect the capacity planning?

Central warehouse in Belfeld

23. How is the collaboration done with the central warehouse in Belfeld?
24. Who is responsible for the inventory levels in Belfeld?
25. How is the logistics managed?

Capacity issues

26. What meetings are held regarding capacity planning?
27. What are common problems that occur related to production planning?
28. Who is responsible for what problems?
29. What available actions exist to solve these issues?
30. What determines what actions to take?
31. How are deviations from plan being documented and followed-up?
32. Are there any financial limitations that will affect the capacity planning?

Potential improvements

33. What areas of improvement have you identified in your work regarding planning?
34. If you had the possibility to decide. How would the capacity planning look like with regards to planning levels, decisions and responsibility?

Interview guide - Reference companies

Introduction: Present who we are, where we come from and what we are doing our master thesis about.

Areas we want to discuss with you about: planning context, demand, capacity planning, lean, tools
Title:

- Is your title correct?
- Could you please tell us more about your work?
- What is your role in the capacity planning process?

Capacity planning context

1. Is there something in Emerson's planning context (Manufacturing process, business environment, locations, abilities, customers, suppliers..) that you can identify as important for the capacity planning process?

2. Does Emerson produce make-to-stock (MTS) or make-to-order (MTO) or both?
3. How does the production layout look like? (job shop, functional, cell, line etc.)

Scope: A high-value product that is produced (preferably in CNC machines) with a small number of sourced components.

Demand

4. How do you manage fluctuating demand for this product?
5. How long is the order-to-delivery cycle for this product?

Capacity planning

6. How is the capacity planning conducted for the product's related resources, i.e. machines and personnel? (main steps, meetings, action guidelines etc.)
7. Do you have different planning levels? (e.g. Sales & Operation planning, Master production scheduling, Order planning and Execution, respectively)
8. How do you make sure that capacity plans are consistent between planning levels and corresponding organizational departments?
9. What are common capacity planning issues for this product?
10. How do you plan capacity prior to the summer vacation? (In terms of production stop, temporary personnel and inventory etc.)
11. When new products are launched, how do you plan capacity prior to these? (Phase-in rate etc.)
12. How do you take machine maintenances into account in the capacity planning?

Lean

13. How do you define lean?
14. How do lean principles affect the capacity planning? (logic, process and decisions)
15. In practice, how do you level your production (Heijunka)?
    - Man
    - Machine
    - Material
16. What are the pre-conditions to have a weekly takt-time?
17. How do bottlenecks affect the takt-time?

Tools

18. What tools are used to support the capacity planners in their work?
19. What ERP-system is used at Emerson?
20. Is the ERP-system used for capacity planning?

Thank you!

Appendix 4 – Example of uneven capacity utilisation

This appendix provides an example of the how uneven different work-centres are utilized at Nobel Biocare.

The capacity utilisation for different work-centres at Implant Systems is shown for a 12 months period in Figure 22. While the utilisation is 118% in average at WC610, it is only 29% in WC631. The demand for products produced in WC631 is much lower compared to the capacity that exists in that work-centre.

WC 610 (7 Machines)	WC 611 (3 Machines)	WC 620 (5 Machines)	WC 631 (1 Machine)	WC 650 (4 Machines)	WC 680 (3 Machines)
CapLoad 2 Shift	CapLoad 2 Shift	CapLoad 2 Shift	CapLoad 2 Shift	CapLoad 2 Shift	CapLoad 2 Shift
107%	96%	121%	24%	95%	145%
125%	104%	122%	31%	94%	84%
118%	91%	110%	24%	88%	100%
128%	120%	129%	35%	92%	97%
117%	101%	113%	32%	79%	91%
127%	98%	121%	25%	90%	99%
120%	98%	111%	31%	72%	98%
103%	72%	94%	33%	70%	86%
112%	78%	98%	30%	78%	80%
125%	95%	116%	22%	71%	83%
112%	79%	108%	36%	69%	92%
125%	95%	116%	30%	71%	84%
118%	94%	113%	29%	81%	[illegible]

Figure 22 - Capacity utilisation at different work centres