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Production planning and inventory management at Grande factory

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Acknowledgment

This Master thesis is the final requirement for the degree of Master of Science in Logistics from Høgskolen i Molde (Molde University College). The thesis contributes to the Manufacturing and resource planning for Grande Fabrikker; a Norwegian furniture factory.

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Abstract

Grande Fabrikker -a Norwegian furniture factory- is facing challenges regarding the increasing demand. Grande specify inventory management and production as their most essential concerns. Currently the planning and production decisions are taken based on personal estimates and experience. These decisions do not produce the best production plans and thus an increase in the production and related costs (such as inventory and workforce salaries) is inevitable.

A more thorough methods and tools are required to provide Grande with information that is crucial to take better informed decisions regarding their production planning and inventory management. Such tools and methods should be known for their useful and practical results.

This thesis will discuss, examine and apply different tools and models. These tools are: ABC analysis which is used to classify inventory into different categories, Aggregate Production Planning which provides planning based on different strategies and their related costs (production, inventory and workforce related costs), finally Manufacturing Resource Planning and Material Requirement Planning which provides a detailed plan and schedule for all the production items.

The tools used and the findings should be regarded by Grande as a model to follow to migrate from the current decision making process to a more thorough methods. It should be stated that these tools are applied on a certain category of Grande's products and thus the findings are only limited to this category.

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Chapter 1: Introduction

This thesis aims at enhancing the current production planning for Grande Fabriker; a Norwegian furniture factory. Currently, Grande's planning and decision making processes are based on personal estimations from experts. The factory is expanding significantly every year, and with the increasing demand, the need arises for better and scientific approaches that help the management make accurate and well informed decisions. Inventory management and production planning are the most essential operational concerns that Grande face.

Due to the complexity and the lead-time needed to produce certain products within the furniture industry and the unstable receiving times of certain raw materials for the production process, it can be ineffective to apply a just-in-time concept, thus forcing the factory to keep finished goods alongside the materials in stock.

By using the inventory classification methods and long-term/short-term production planning processes, it is believed that the factory will be able to plan the production and procurement in an efficient way.

Inventory classification, aggregate planning and manufacturing resources planning are three theories that are able to help Grande make a first step toward the correct production planning which will assist the factory to meet the increasing demand and the expansion rate it predicts.

Although this thesis will focus only on products with the largest values from only one category of products that Grande produces, yet it is considered as the model that Grande should apply for all the products.

With the current limited resources and data, it is difficult to expand this study over the whole range of products owned by Grande. Yet, as demonstrated in the thesis, the results are believed to support the factory with the needed production strategy for the selected products for one year based on the sales forecast of the factory.

The outcome of this thesis is thought to be applied for Grande to take better accurate decisions related to inventory management, production planning and production scheduling.

Chapter 2: Background & Problem Description

2.1 Company Background

Grande Fabrikker is a Norwegian producer of high quality furniture with functional design. They produce categorized products like storage cabinets, tables, chairs & benches, catheters, wardrobe and kitchens and other furniture.

Grande Trevare was founded in 1954 by only four people. Grande's vision was to produce high quality furniture products to the local people. As the demand expanded outside the local region, the owners decided to split Grande Trevare and sell distributor licenses all over Norway, while keeping the production facilities to become the only producer of the Grande products and trademark, keeping only one owned distributor in Møre & Romsdal region.

The company's name changed to Grande Fabrikker and provided the name Grande Interior for the distributors. Both entities are located in the same building in Innfjorden in norway, but operate as separate entities where Grande interior is their largest customer. Grande Fabrikker since then has invested in expanding and renewed the production lines, increased the area, adapted new technologies and proposed a variety of new products. Regarding the area, Grande Trevare had an area of only 150m2 when it was founded, now they have an area of 12000m2, which is 80 fold the original area.

In 2014, Grande Fabrikker sales income reached 65 million (NOK). The company is relatively small considering the 40 working employees; yet, it has a strong position in the market. Grande Interiors customers are usually from the public sector such as: schools, kindergartens, offices, conference rooms, and health care sector. The demand is highly seasonal especially from customers like schools, which raises the need of a good production plan.

Grande frequently invest moderately in machinery in order to make the production as efficient as possible, but they do not want to invest in any new Enterprise Recourse Planning (ERP) systems, as it requires lot of resources and time to implement. ERP-systems are supposed to help the company with production and inventory management, but are complicated and expensive to implement. Grande use "Visma Global" which is an accounting system. This system has information about inventory levels, but does not deal with production planning. Visma can figure out the items in inventory, but its disadvantages are that it cannot understand which products/items are in the production yet. Items in the production process are shown in

Visma Global as available inventory while in reality they are not in the inventory; this makes it difficult to give an exact delivery date to customers.

2.1.1 Ordering cycle

Currently, Grande receives the purchase orders (PO) from its distributors and end customers via email texts or occasionally via phone calls. Receiving orders via email and phone calls means in this case that Grande manually enter the orders into Visma Global software. Entering the orders manually takes time and is not as efficient as Grande desires. The emails received are in text format with the customer's description of their needs, this description can be unclear and because of the long texts, key factors like color of different part of a product can be missed. The orders then have to be confirmed by an employee who communicates with the production leader to confirm the orders and provide a delivery date. When a purchase order from a costumer is placed it triggers a production order.

The decision makers attend a weekly meeting to create a production plan for the received orders. The production plan is entered into an excel-sheet that includes which products are ordered and its delivery date. Furthermore, the plan includes which items and the available quantities are already in stock that can be used in production, and which items needed to be produced, and also a prioritized rank of which component have to be produced first. The production employees will then follow the plan. This manually inputted production plan will usually have a margin of errors regarding for example wrong amounts, production delays. Later on this thesis will consider this problem.

2.1.2. Production cycle

Products are made from raw material like plates, which goes through different processing machines like cutting, lipping, drilling and then assembly. The inventory usually consists of plates, production components and standard components that Grande do not produce like steel, wheels and plastic components. They also have a depot for finished products, where each of their distributors has an assigned space where they can pick up their products.

Grande have a 20x30 m2 storing area, which is used for storing plates. Plates are purchased from different suppliers and are usually the same size but differ in color and the type of wood. Plates are then delivered to the cutting machine that will cut in different shapes for different products. The plates are handled with a small truck, transporting them from the storage to the cutting machine; with a maximum distance of 25 meters. The owners might want to invest in a robot machine that will store the plates when they arrive and transport them to the cutting-machine more efficiently and at lower cost.

The cutting machines allow adding programs to describe how to cut the plates by sizes and shapes. The programs have to be added and stored manually for every new product. The plates have to be placed by one or two workers into the cutting machine and then chose the program that is needed. The cutting takes between one to five minutes.

The output from the cutting machine later goes into the gluing machine, then the lipping and then the drilling machine, which runs by predefined programs. Between each process there are other processes that have to be manually performed, like installing door handles, there is also the waiting time for the next available machine, which is called buffer time. Information regarding buffer time and lead-time of finished product are not available. The buffer time (which can vary from minutes to days and even weeks on some products) happens due to the bottlenecks in the production when the demand is high, and the number of the processing machines is not coping with the high demand. When buffer time rises, Grande Fabrikker follow their prioritized rank list on which product or item needs to be produced first.

The last step in the production process is the assembly of products. Some products are assembled and stored in the depot for later use, while other products which take large space are only assembled when the need arises. The assembly process is handled by workers.

Grande Fabrikker wishes to minimize their delivery time in order to be more attractive to the customers. This is thought to be achieved with help of a good production plan that include the lead-times on components, inventory levels and their production rates. This is followed by a good production strategy. This Master thesis will focus on achieving those plans.

2.2. Research Problem

Grande’s production plan relies on subjective opinions based on experience and not accurately calculated scientific methods. This lack of a precise production plan over the short and intermediate term leads to waste of resources. Thus Grande needs to change the current production planning methods in order to better manage the current resources.

Other challenges within the production planning like the facility size, equipment procurement or job sequencing or any other problem related to logistics and supply chain are not discussed in the thesis.

2.3. Research Questions

2.3.1. Main research questions

1. What is the current production planning method used in Grande? Will the current methods be sufficient with the current expansion?
2. What are the major tools used in production planning and resource management?
3. How can aggregate planning and Material Requirement Planning/Manufacturer Resource Planning affect Grande's production planning and resources management?
4. What are the limitations of the current production planning?

2.3.2. Sub research questions

1. What is the workforce strategy that should be applied for the chosen set of products?
2. What is the inventory strategy required for the production plan ?
3. Which category of products has the highest value?
4. What is the monthly production quantity needed for each item to meet the demand?
5. When should the production of each item start? How many items should be in stock?

Chapter 3: Methodology

3.1. Methodology of the research

This thesis aims to solve a production management issue in Grande Fabrikker. As mentioned in the previous section, Grande does not have an ERP system or a well-designed production system that can narrow down the waste in operations to a zero waste. The current situation at Grande does not ensure a delay-free production; furthermore, Grande's operation does not ensure having the needed stock levels to keep the operations running and steady. The following sections will present the research's methodology to be followed in order to reach the required aims.

3.1.1 Research Methodology

This research falls under the inductive research approaches. Inductive approach is used to better understand the nature of the problem and by using the right data collection methods, data will be analyzed and tested providing new insights, hence it requires no hypothesis since it aims at developing a theory (Saunders et al, 2009). While the research purpose is considered as an exploratory research, this is useful in clarifying the understanding of the problem and eventually will help in providing solutions. As for the research strategy; "Grande Fabrike" will be the case of this study.

3.1.2 Data Collection techniques

In order to answer the research question, primary and secondary data should be collected. Primary data is the data collected by the researchers through the means of interview, observation or questionnaire. In this research interviews with Grande employees have taken place to understand the company background, current production and inventory planning, while other numerical quantitative data are collected in the form of MS Excel reports.

On the other hand, secondary data are the data found in literature. This data will be used to cover the gap in knowledge and assist any assumptions needed. Secondary data in this research are collected from library books, journals, articles and previous similar studies in databases such as: Emerald Fulltext and ScienceDirect.

3.1.3 Model

In order to answer the research questions and follow the research methodology, a more efficient production plan needs to be laid down. Several steps are followed that can answer the problems mentioned in the previous chapter, which may provide a possible production plan tailored for Grande Factory.

In the beginning, it is vital for Grande to realize the importance of each item held in the stock. This thesis relays on the ABC analysis to classify products into three main groups. Through this analysis it will be possible to identify the items that belong to A-class. Those items are responsible for the biggest part of the profits acquired for the factory. From the A class, the category with the highest profit will be chosen to continue the research

After choosing the category with the highest profit within the A-class items, an aggregate production plan will be conducted to calculate the total production cost for each product, and thus be able to have a suitable strategy to minimize the cost over the most important products in this category.

The aggregate planning process has a planning time unit of month over a planning horizon of one year. Also, Material Requirements Planning (MRP) and the Manufacturer Resource Planning (MRP II) will be conducted. MRP has a planning time unit of one week over a planning horizon of few months. Applying the MRP will give Grande a better overview over manufacturing and procurement plan.

The mathematical methods used for the aggregate production plan and MRP I and MRP II are explained in the Data Analysis and Results chapter. The mathematical model is translated to AMPL language version 20021031 (Win32) written using TextPad (a Microsodt text editor), while chosing CPLEX 9.0.0 as the solver.

The outcomes of this thesis should help create an efficient production plan that will allow Grande to expand accordingly with the increasing demand. These models will support Grande with an overview of costs (i.e. inventory costs, salary costs, etc.), and shall assist the decision making process of the factory toward a scientific approach that will reduce the waste in operations to the minimal level possible.

Chapter 4: Literature Review

4.1 Introduction

This chapter is devoted to the analysis of scientific literature, previous studies examining the mechanism of production planning and inventory management.

The chapter should be a backbone for this work, as it backs the methodology, the analysis and some of the estimated data related of this research. An ABC analysis will be considered, also, the procedure of its implementation, the conditions of application, advantages and disadvantages of ABC analysis. Material Requirement Planning (MRP1), Manufacture Resource Planning (MRP2) and Aggregate Production Planning will be discussed as well.

4.2. ABC analysis

4.2.1. General characteristic

ABC analysis is a method that allows classifying the resources of the firm according to their importance. This analysis is one of the methods that can be applied in the field of activity of any enterprise. It is based on the Pareto principle — 20% of all goods give 80% of the turnover. Pareto's Law or the Pareto principle, or the principle of 20/80 — rule of thumb, named after the economist and sociologist Vilfredo Pareto (1848-1923), in the most general form is formulated as “20% of efforts provide 80% of the result, while the remaining 80% effort 20% of the result”.

The ABC approach expands 80-20 rule and apply it to inventory management. In other words a company’s inventory should be rated from A to C (an arbitrary number of groups can be allocated depending on the goals of the analysis, but usually distinguish 3 groups, but sometimes 4-5 groups), basing its ratings on the following rules:

A-items are products with the highest annual customer value. The items making up 70-80% of the annual customer value typically accounts for only 10-20% of total commercial (inventory) items.

B-items are the intra-class items and have an average customer value. These items that comprise 10-25% of the total value, accounts for around 30% of the inventory items.

C-items are, on the contrary, items with the lowest customer value. The items making up 5% of the annual customer value, typically accounts for 60% of total commercial (inventory) items (Hype K.W, et al, 2008).

(Torabi, et al, 2012) mentioned that Data Envelopment Analysis can be combined with ABC analysis. DEA like models are used in order to overcome the shortcoming of ABC where quantitative data only is used, thus, quantitative and qualitative data are used together.

(Chen, Li et al, 2008) introduced an ABC analysis case based on multifactor criteria such as lead times and criticality of Stock Keeping Units (SKU).

(Ramanathan, 2006) consented to the fact that the ABC analysis is one of main inventory classification tools.

ABC analysis can be used for a better inventory optimization, by distributing the items, it can separate the most profitable products from the products with low profits. Thus, the policies that are holding the inventory can cut from the inventory of low profit products while demand an increase of inventory over those with high profits, resulting in an intelligently applied net inventory reduction (Scheuffele and Kulshreshtha, 2007).

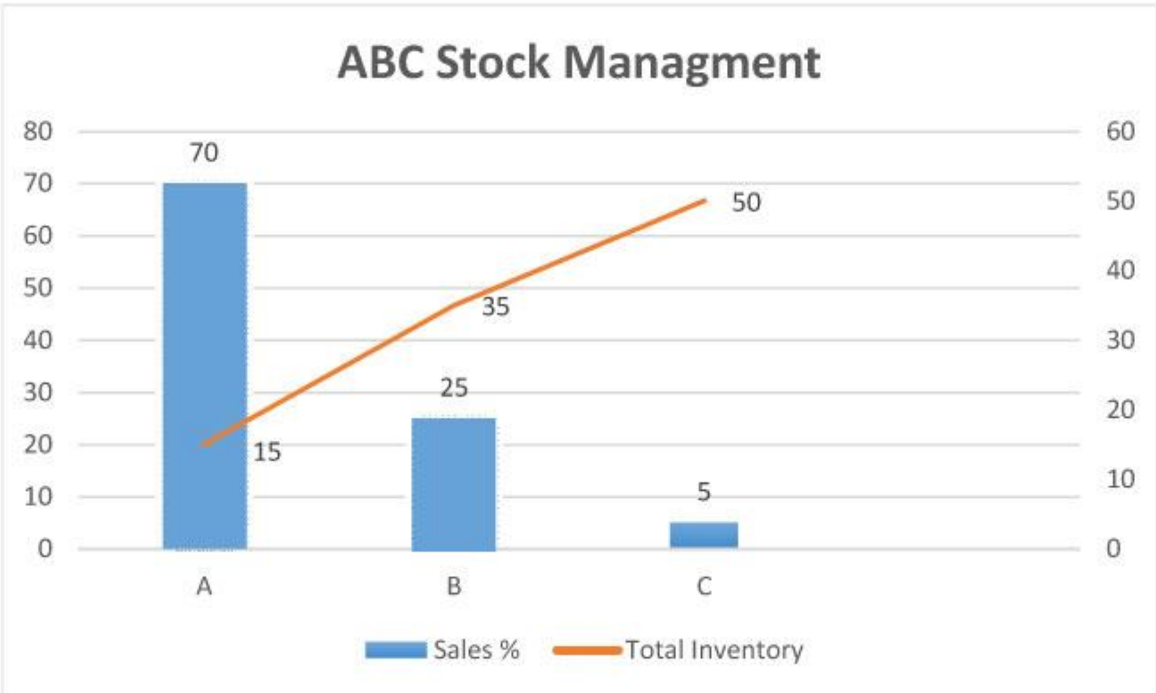

Figure 1ABC Stock Management

Figure 1(Ramanathan R., 2006, p. 695) explains that Class A of the stock represents around 70% while it only represents 15% of the total inventory. Class B of the products represents 35% of the stock available which provides 25% of the sales. While Class C of products only provide 5% of the sales.

Thus, there is no fixed threshold for each class of items, different proportion can be applied based on objective and criteria. ABC analysis is similar to the Pareto principle in that the 'A' items will typically make up a significant proportion of the overall value but a small percentage of number of items.

In fact, the ABC analysis is the ranking of assortment on different parameters. Thus, it is possible to rank suppliers and inventory, customers and long periods of sales - everything that has a sufficient amount of statistical data. The result of ABC analysis is grouping of objects according to the degree of their influence on the overall result (Ng W.L., 2007, p. 351).

4.2.2 Applicability

Due to the ABC classification ease of use, this method can be applied in almost any field of activity.

In this thesis, the ABC analysis will be used to divide the products into these three categories to understand which set of products will provide the highest value. The focus will be on category "A" set of products, on which further study will take place in order to develop an aggregate production plan.

The literature (Braglia M. et al, 2004), (Hype K.W. et al, 2008), (Hadi-Vencheh A., 2010), (Liu Q. et al, 2006) and (Ng W.L. 2007) provides examples of the ABC analysis in terms of turnover, profit, labor, material costs, and even on such parameters as noise immunity, performance, power consumption, etc. This method can be applied in respect of goods, services, customers, material and intellectual resources, etc. The most popular is its use in logistics management, inventory management.

(Hadi-Vencheh A., 2010, p.964) mentioned that in order to carry out the ABC analysis, in the company there should be a single classifier of material and technical resources in the information database, the codes of which contains the account of receipts, expenditure and inventory.

First, a key step in ABC analysis is defining the purpose of the analysis. The same set of control objects will be divided into subsets A, B and C in different ways, depending on the purpose of the analysis. Consider the table below in order to determine the general algorithm of ABC analysis.

Procedure of ABC analysis

Consecutive number	Steps
1	The formulation of the objectives of the analysis
2	Identification of control objects, analyzed by the ABC method
3	The selection of a trait on the basis of which classification of the objects of management will be implemented
4	Assessment of control objects on a selected classification criterion
5	Grouping of control objects in descending order of characteristic values
6	The construction of the curve ABC
7	The separation of a set of control objects into: group A, group B, group C

Table 1Procedure of ABC analysis

Thus, an ABC analysis is suggested as a basic tool for analyzing the characteristics of a number of items at an aggregate level. It was already mentioned above that ABC analysis is usually used in logistics management, inventory management, etc. These are the main fields of its application.

4.2.3. Inventory management policies

(Partovi F. Y. et al, 2002), (Ramanathan R., 2006), (Yu M.C., 2011), (Zhou P. et al, 2007) mentioned that through the ABC analysis, items should receive a weight in accordance with the item's class, this way any imbalance will be lifted:

A-items should have tight inventory control, more secured storage areas and better sales forecasts. Because it is vital to avoid a stock-out on the items of this class, thus, the reorders must be more frequent. Orders can be weekly or sometimes even daily depending on the usage of those items.

B-items benefit from being an intermediate group between the A-items and the C-items. The most important aspect that can be mentioned here, is that those items in class B can be subject for continuous monitoring to find out any possibilities to move some to other classes, whether it is an upgrade to become an A-class item or downgrade to the C-items. (Partovi F. Y. et al, 2002).

4.2.4. ABC analysis - advantages and disadvantages

After analyzing the scientific literature on the research topic, it is concluded that ABC analysis has some advantages and disadvantages.

(Zhou P. et al, 2007) stated the following *advantages of ABC Analysis Inventory*:

- One of the most practical methods
- The ease of use
- Better control of high-priority inventory
- More efficient cycle counts
- Universality (using the ABC-method, it is possible to analyze turnover, money, grain yield, though anything that can be divided into components)
- Resource optimization (the successful use of ABC analysis allows to reduce and release a huge amount of time and labor resources. This is achieved by concentration the work on the most important elements)

Although this method is useful and widely known, but it does not mean that ABC analysis can be applied everywhere. ABC analysis, like any other statistical method, is a tool in the hands of the analyst and has disadvantages.

(Ramanathan R., 2006, P.700) stated that: "*sales volume is not the only metric that weighs the importance of an item margin, but also the impact of a stock-out on the business of the client should also influence the inventory strategy*." Meaning that there should be other factors considered when decicing on inventory policies.

(Zhou P. et al, 2007, p.1488) stated the following *disadvantages of ABC Analysis Inventory*:

- The classical ABC analysis is one-dimensional method

- ABC analysis poses a conflict with other cost systems. ABC analysis does not meet the requirements of the Generally Accepted Accounting Principles (GAAP), which creates a conflict with the traditional costing systems used in the market.

- Separation of data, regardless of their quality characteristics

• ABC analysis requires substantial resources since the ABC maintaining more resources than the traditional costing systems.

Taking into consideration all mentioned above, one can conclude that ABC analysis has great advantages, which are expressed in the simplicity, versatility and easy implementation, but, despite this, it also has some disadvantages.

4.3. Aggregate Production Planning

4.3.1. Overview of Aggregate Planning

It is known that each organization makes production decisions at three levels: long term, medium term and short term. Long term solutions include: selection of products and services (i.e., determining the type of goods and services that the company offers to consumers), determination the volume and location of production, the questions of selection and placement of equipment. Long-term decisions determine the basic strategy and the framework in which the medium-term planning operates. Medium-term solutions relate to the overall level of employment, volume of production and reserves, and -in turn- define the limits for short-term planning. Short-term decisions determine the best way to achieve the desired results within the limits indicated by long-term and medium-term solutions. This includes work schedules, determining the level of utilization of the equipment, the sequence of the workflow, etc. (Foote, B.L. et al, 1998, p. 131).

In other words as (Lin Pan et al, 1995, p.4) said: "*The goal of aggregate planning is to achieve a Production plan which will effectively utilize the organization's resources to satisfy expected demand*"

(R.-C. Wang, 2004, pp. 17-18) summarized the aims of aggregate production planning to set production levels for products, to adapt to uncertain demand and take decisions regarding employees (hiring, laying off, overtime), while also help in determining backorders, and when to subcontract.

According to (Porkka P. et al, 2003, p. 1141), Aggregate Production Planning (APP) involves the setting of production rate of the group or other broad categories of goods in the medium term (6 to 18 months). Aggregate Planning is essentially a comprehensive approach to planning. It usually does not focus on specific goods and services - of course, except for the case when the organization offers only one product or service.

It is necessary to note that the aggregate production plan differs in different companies. The general approach is that the plan is based on annual corporate plan. In some firms it is a formalized report that contains the scheduled job and assumptions on which they are based. In others, mainly in small firms, the owner can perform simple calculations of required number of workers that will be reflected in staffing that will be its aggregate plan (Porkka P., Vepsalainen, A.P.J., Kuula, M., 2003, p. 1134).

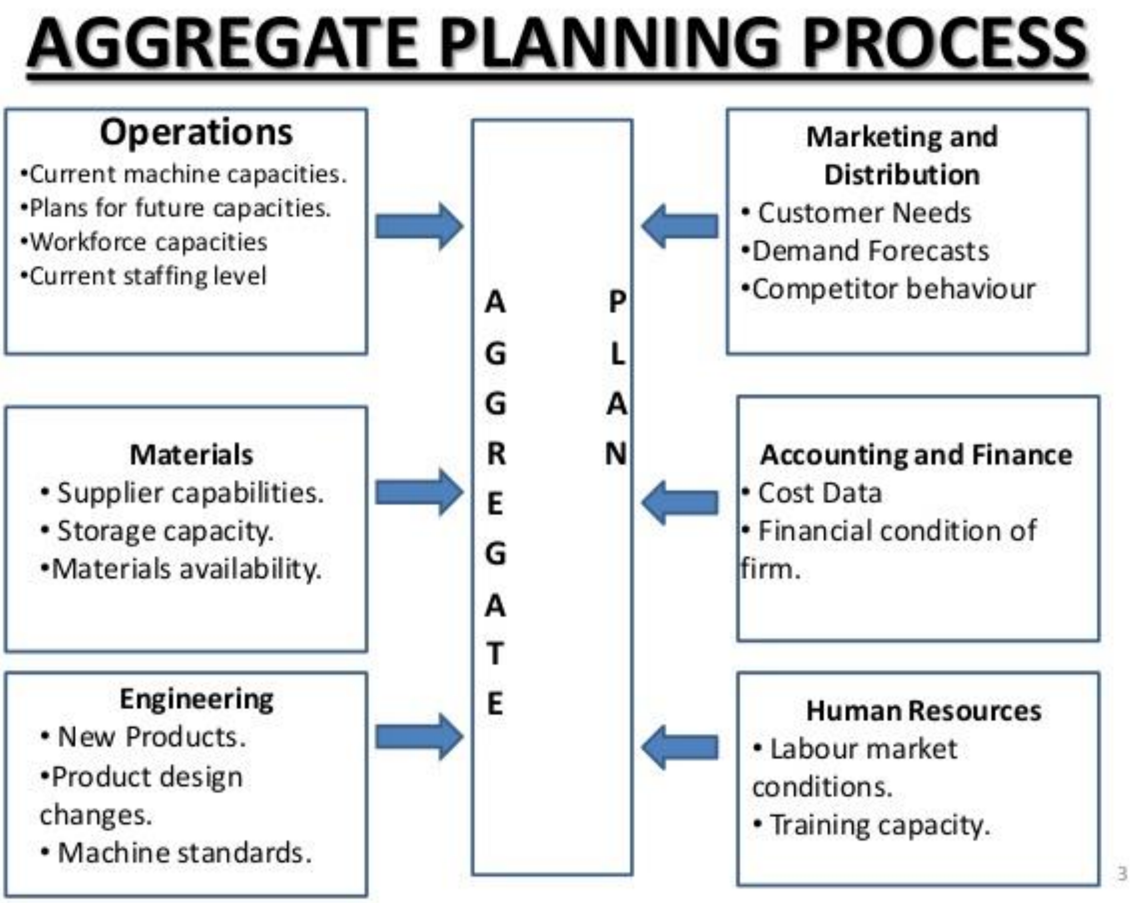

Figure 3 Aggregate planning process

(Access: http://www.slideshare.net/NeilKizhakayilGeorge/models-of-aggregate-planning)

(Foote. et al, 1998, p. 131) mentioned that when developing a comprehensive plan it is possible to simulate different variants of the basic production plan and calculate the related requirements in production facilities. This will determine whether there is enough cash, labor and equipment to perform the forecasted orders. If the resources don`t correspond to the required capacity, then for each production line the owner determines the needs for overtime work, subcontracting, additional manpower, etc. All this is introduced in a preliminary version of the plan. This plan is then modified using the intuitive method (trial and error) or mathematical methods, and receives the final version of the plan, in which all costs are minimized.

4.3.2. Purpose and range of Aggregate Planning

The main objective of an Aggregate plan is to establish the optimal combination of production rate, workforce and amount of inventory. Under the pace of production is understood the number of units of output produced per unit time (per hour, per day). The labour force is the number of workers necessary to produce a given level of output. On-hand inventories constitute the remains unused in the previous production period (Shi Y. et al, 1996, p. 132).

For the purpose of this thesis, the aggregate planning method will be deployed. The outcome from the “A” category of the ABC analysis will be used, an aggregate production plan with different strategies will be developed for category “A” products.

The Demand and supply Concept

The analysis of scientific literature on the research topic (Porkka P. et al, 2003, p. 1132), (Foote, et al, 1998, p. 134), (Shi Y. et al, 1996, p. 131) shows that Aggregate Planning works with quantitative and temporal characteristics of expected demand. If the total expected demand in the planning period is significantly different from the production possibilities in the same period, the main task of the planners is to try to increase demand (if it is significantly less than the offer), or to increase the production capacity if demand exceeds supply). On the other hand, even if supply and demand in the planning period are approximately the same, the planners maybe faced with the problem of fluctuating demand within a scheduling interval. In some periods, the expected demand may exceed production capacity, at other times, the demand is much lower that the supply, and sometimes these two variables have the same value. Aggregate planning aims at achieving an approximate matching of supply and demand levels for the entire planning period

4.3.3. Methods of Aggregate Production Planning

A large number of different methods help planners carry out an Aggregate Planning. In general, they fall into one of two categories: informal experimental methods and mathematical methods. Nevertheless, a large number of studies is carried out with application a mathematical apparatus and although mathematical methods are not as widely used, they often serve as the basis of comparison of efficiency of alternative methods of Aggregate Planning. Therefore it will be useful to consider both of these categories (Porkka P. et al, 2003, p. 1130).

General procedure of Aggregate Planning includes the following steps

1. Determining the demand for each period.
2. Determining the production capacity for each period (working hours, overtime work, subcontracting).
3. Determining the company's policy in this area - for example, maintaining a stable reserve at the level of 5% of demand, maintenance of a relatively stable workforce, etc.
4. Determining the costs per unit of output in the case of the normal mode of work, overtime work, subcontracting and other important items of expenditure.
5. Developing the alternative plans and computing the cost of implementing each of them.
6. If appropriate plans are found, choose one that is most fit for the purpose. Otherwise, return to step 5 (Porkka P. et al, 2003, p. 1130).

It is useful to use a spreadsheet, which lists the general factors of demand, production capacity and costs for each plan. In addition, planners can use graphs and charts for the analysis of alternative. These factors are related to workers (Release, Normal, overtime, suncontracting), Stocks (Initial level, Final level, Average index, The delay of orders), Costs (workers salaries, stock, stockouts and order delays) and production.

Informal methods

Having studied the scientific literature, it is concluded that informal methods consist in creating the simple tables or graphs that allow planners to visually compare the design value of demand with existing manufacturing capabilities. Alternatives are usually evaluated in terms of their total cost. The main disadvantage of these methods - is that they do not always lead to an optimal Aggregate plan (Porkka P. et al, 2003, p. 1118).

The graphics are very often used for the creation and analysis of alternatives. Some experts prefer the cumulative graphs, and other diagrams of consistent development. These alternatives provide different choices regarding the production plan.

In summary, the aggregate production planning can be defined as an approach that focuses on satisfying the demand by relating the outcome to different models such as the labor force, inventory control, production, etc… and connecting the results to the operations management applied by the practitioner. In other words, aggregate production plan gives suggestions as to what resources to be procured/stocked and when, how many workers will be needed and on what bases and the different costs related to the production plan (salaries, productions costs, carrying costs).

The products are of similarities by its components.

4.4. Material Requirement Planning (MRP1)

4.4.1. General concept of MRP1

60 years ago, Joseph Orlicky and Oliver Wight created a method of calculating the materials needed for the production, known as MRP (Material Requirements Planning). Thanks to dedicated work of the American Association for the management of inventory and production (APICS), the method MRP has become widespread throughout the Western world, and in some countries is treated as a standard, although it is not so.

(Pandey P.C. et al, 2000, p.115) defined the Material Requirements Planning (MRP1) as: "*system of material requirements planning, one of the most popular in the world of logistics concepts*"

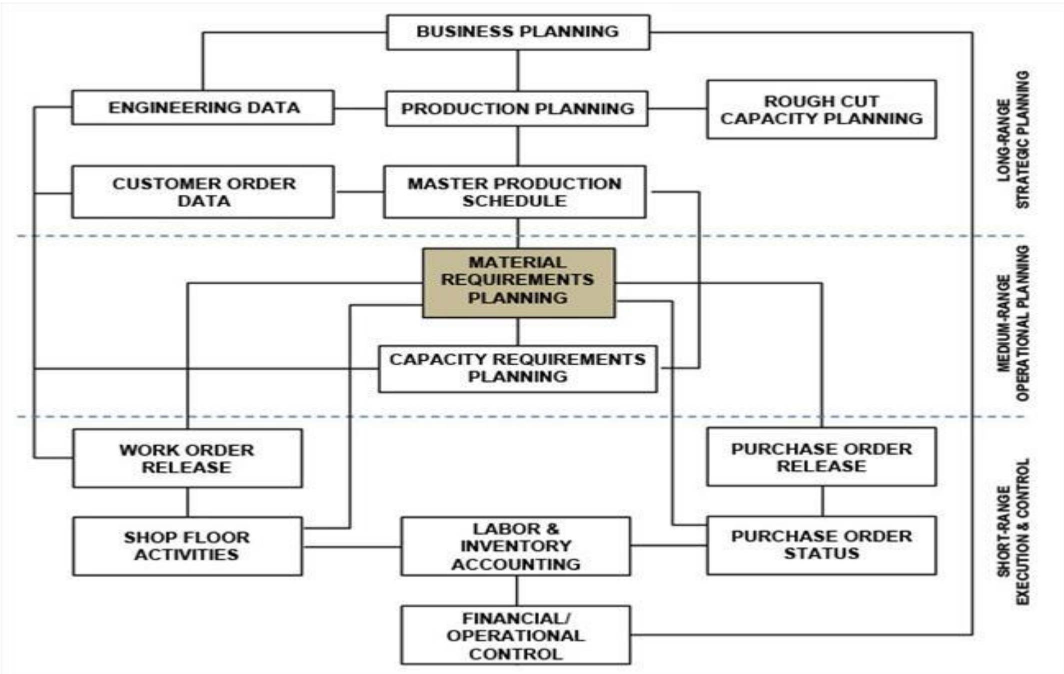

Figure 4 MRP1 system

MRP1 system is represented in figure 4:

The main objectives of MRP1 system are summarized as:

- Satisfaction of the needs in materials, components for the planning of production and delivery to the consumer
- Maintaining a low inventory levels of material resources and finished products
- Planning of production operations, delivery schedules, procurement operations

One of the main developers of MRP1 J. Orlicky wrote: “Material Requirements Planning in the narrower sense consists of a series of logically related procedures, decision rules and requirements that transform a production schedule in "the chain of requirements", synchronized in time, and planned "covering" of these requirements for each unit of reserve components necessary for production schedules. MRP system reschedules the sequence of requirements as a result of changes in either the production schedule or in the structure of reserves, or in attributes of the product” (Ptak & Smith, 2011).

(Lambert D.M. et al, 2000), (Minner S., 2003), (Pandey P.C. et al, 2000), (Wacker J.G., 1985) agreed – which is also in accordance with the thesis-that the basic functions of an MRP system include inventory control, bill of material processing, and elementary scheduling. MRP is usually used to plan production, procurement and operations activities.

4.4.2. MRP1 Standard steps

(Lambert D.M. et al, 2000, p. 82) defined that the method of MRP1 envisages a number of *standard steps*:

The first step is the collection of the data required. Of this data: the number of required materials, assemblies and components is estimated taking into account the stock or production in progress.

The second step is the calculation of net material requirements in time on the basis of data on the composition of the product. At this stage, the necessary amount is calculated taking into account all receipts and expenditures of materials.

The third step is the determination of the timing of the purchase and manufacture. At this stage, for planning and supply departments MRP1 system determines the dates of the beginning of action to implement the calculated net needs.

4.4.3. MRP1 - advantages and disadvantages

(C.J. Ho, W.K. Law and R. Rampal, 1995, p.489) pointed out the *advantages* of applying MRP1 method - the possibility to take into account the future needs of an enterprise, to generate orders to replenish stocks at the right time and in the right amounts. In our opinion, the disadvantage of MRP1 is the inability to take into account the limited resources of an enterprise.

(Ali Hasan, 1996) determined the main *disadvantages of MRP systems:*

- A significant amount of computation and data pre-processing
- Increase in logistics orders for processing and transportation if the company seeks to further reduce inventories or fulfill small orders but with high frequency of execution
- Insensitivity to short-term changes in demand
- A large number of failures due to the high dimensionality of the system and its complexity.

These are the main advantages and disadvantages of Material Requirement Planning (MRP1).

4.4.4. MRP1 Basic problems

The main problems encountered when implementing MRP system refer to development of informational, mathematical software of calculations and selection of the complex of hardware and office equipment, that is, those problems that are typical for the automated control systems of production and technological processes.

4.5. Manufacture Resource Planning (MRP2)

4.5.1. Definition

Manufacturing Resource Planning (MRP2) — an integrated information system used by businesses; a method based on the use of material requirements planning, including the functions of warehouse management, supply management, sales and production management.

Most of the authors (European J. Industrial Engineering, 2010) believe that MRP II serves as an extension of MRP1 (closed loop manufacturing resource planning, also abbreviated as CLMRP). The typical MRP2 system employs a modular organizational structure.

MRP2 system is represented at the block diagram below:

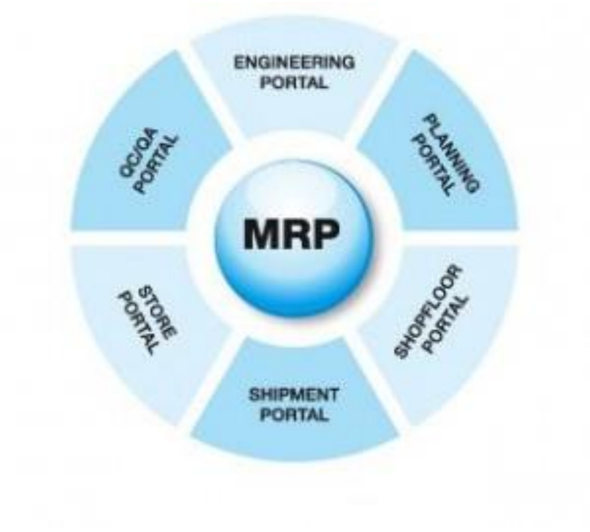

Figure 5 Manufacturing Resource Planning system

The American Production and Inventory Control Society (APICS) based the basic objectives of Manufacturing Resource Planning system on the centralization, integration and processing information in order to make effective decisions for the scheduling, inventory management and cost in manufacturing.

A software product of MRP2 class, according to the standards approved by APICS, includes the following 16 functions:

1. Sales and Operation Planning
2. Demand Management
3. Master Production Scheduling
4. Material Requirements Planning
5. Bill of Materials
6. Inventory Transaction Subsystem
7. Scheduled Receipts Subsystem
8. Shop Flow Control
9. Capacity Requirement Planning
10. Input/output Control
11. Purchasing
12. Distribution Resource Planning
13. Tooling Planning and Control
14. Financial Planning
15. Simulation
16. Performance Measurement (APICS, 2014)

4.5.3. Principle of operation of MRP2

The principle of operation of MRP2 is based on three basic aspects of the hierarchical structure, the interactivity and the integration (Monk E. et al, 2006).

The hierarchical structure means that every link in the production chain is assigned to a level, the totality of which forms the hierarchical ladder. Planning of activity of enterprise is carried out from the higher degrees; reliable feedback mechanism operates simultaneously with it.

The essence of interactivity of Manufacture Resource Planning (MRP2) lies in the possibility of analysis and forecasting of developments.

Integration means combining the multiple aspects of a certain organization, including the production planning, supply of production, marketing of products, the execution of the production plan, cost accounting and other functions of the enterprise.

4.5.4. MRP2 Benefits

(Monk E. et al, 2006) defined a great number of benefits of MRP2 system.

According to their opinion, MRP2 systems can provide:

- Better control of inventories
- Improved scheduling
- Productive relationships with suppliers

In addition, for design / engineering it can provide:

- Improved design control
- Better quality and quality control

Moreover, for financial and costing it can also provide:

- Reduced working capital for inventory
- Improved cash flow through quicker deliveries

4.6. Conclusion

This chapter of the thesis is dedicated to the study of theoretical aspects of ABC analysis, production planning and inventory management. A Literature review was carried out. Several important questions were considered: ABC analysis, Material Requirement Planning (MRP1), Manufacture Resource Planning (MRP2).

Summarizing all mentioned above, it is necessary to conclude that in materials management, the ABC analysis is an inventory categorization technique. Traditionally, ABC analysis has been used to classify various inventory items into three groups of A, B and C. Researchers in operations and inventory management have proposed numerous approaches to multi-criteria ABC classification. Having studied the scientific literature, thus it is concluded that ABC analysis processes and defines the way stock should be managed, and it is considered the basis for material management. It makes it possible to form the foundations for different activities such as the inventory arrangements, later on production plans can be developed as in the case of this thesis, the calculations of reorders and determining the intervals that carried out intervals checks.

Material requirements planning (MRP) is a production planning, scheduling, and inventory control system used to manage manufacturing processes. Manufacturing resource planning, also known as MRP2 is a method that can effectively plan the resources that manufacturer obtains. MRP2 is made of several connected functions as: operations and sales planning, business planning, capacity requirements planning and all the systems that are related to those functions. All of these methods have some benefits and drawbacks. They were considered in this chapter of our work.

Chapter 5: Data analysis and Results

5.1 Introduction

This chapter describe the analysis of the data collected and the outcome of the ABC, aggregate planning, MRP I and MRP II models described in the "Model" part in the Research Methodology chapter. The chapter will be divided into sections; each section will focus on one of the mentioned models.

5.2 ABC

As mentioned in the literature review chapter, ABC analysis is used to classify the products into categories in order to be able to determine which of these products have the highest turnover and thus consider them as an A class products.

On the other hand Grande Factories has 552 products (a list of the finished products is available at the appendix), which will require an extensive amount of data to be used in the mathematical modeling in order to able to generate an aggregate plan and a material requirement plan for all of the finished products and their components.

5.2.1. Difficulties in Data collection from Grande

Data collected from Grande was provided as MS Excel sheets. The first list is the article numbers and the product names. The first list of data demonstrated some difficulties which hindered the analysis. These difficulties are: The finished products were not separated from the components, and the components were not linked to the right finished products. The second list of data represents the prices and monthly demands of 2014, this list also had some difficulties in interpreting it, for instance: Prices of the products are not linked to the previous sheet (article numbers and products names). In both cases, MS Excel was used to filter and match products, but also the company's catalogue book was used to hand pick and assign different attributes as the components to the finished products and then to the price and demand.

5.2.2. ABC analysis outcome

Total turnover for sales was used as the parameter in order to be able to determine the items that generate the largest share of the total sales. As mentioned before the ABC categories are:

- Products in group A makes 80 % of turnover and used 20 % of items
- Products in group B makes 15 % of turnover and used 30 % of items
- Products in group C makes 5 % of turnover and used 50 % of items

When categorizing the products through the ABC analysis, the following steps are completed in MS Excel:

1. Calculate the price of each product and multiply with the total sales of each product to get the total value of sales for all products.
2. Sort the total value of each product in decreasing order.
3. Calculate the cumulative total value
4. To get the share of each product in relation to the total value for all products, the cumulative total value of each product is divided by the total value for all products
5. Then, the boundaries of ABC groups are calculated. (In order to calculate percentage of the item, products in relation to the total number of products are calculated)
    a. From 0 to 80 present of the total cumulative value makes the A groups
    b. From 80 to 95 percent makes B groups
    c. From 95 to 100 percent makes C groups
6. Build an ABC-curve.

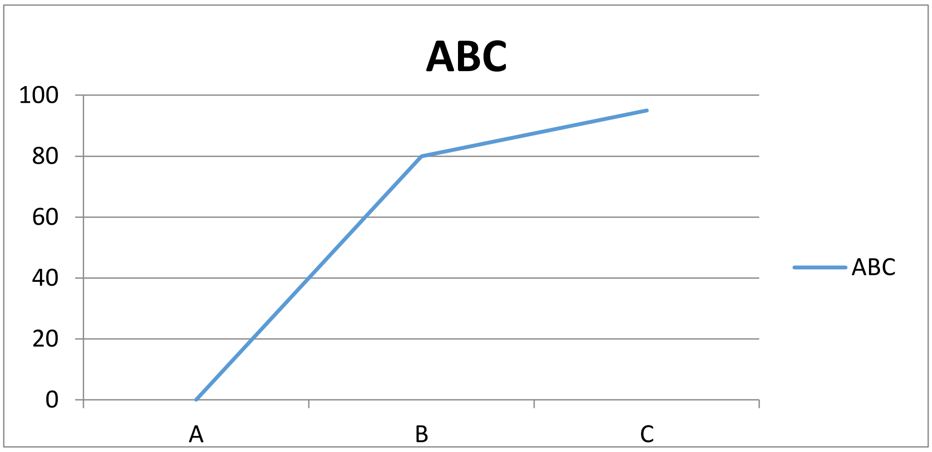

Figure 6 ABC Figure

The results from ABC analysis presented in table 2 and show how much of the total value are generated from all of Grande's products produced in 2014.

ABC Analysis: percentage of cumulative total value		percentage of items
A	79,9819	27,8899
B	14,8260	30,2752
C	4,9879	41,4679

Table 2 ABC boundaries

Table 2 identifies the ABC categories, which are represented as following:

- 80 % of the total value are generated by 28 % of the items in group A
- 15 % of the total value are generated by 30 % of the items in group B
- 5 % of the total value are generated by 42 % of the items in group C

5.5.3. A Class products

Grande Fabrikker has five products categories in group A. In the next step, one category will be chosen and create an aggregating production plan and a manufacturer resources planning for this category. The reason behind choosing only one category is to focus on one group; Group A that represents 80% of the total value. A-class products will be classified into production categories while presenting the total sales for each one of them.

Divers	Kjøkken	Oppbevaring	Kateter	Garderob
kr 1 616 341,00	kr 5 857 307,00	kr 5 504 957,00	kr 4 030 248,00	kr 7 317 511,00
7 %	23 %	23 %	17 %	30 %

Table 3 Sum categories

Table 3 describes the total sales of the A-class products from each category with a percentage of each category from the total sales made by the factory last year. As presented, the "Garderob" (wardrobes) products category has 7,317,511.00 kroner sales revenue from its A-class products, and that counts for 30% from the total sales, which is the highest revenue collected from all the categories. Thus, the "Garderob" category will be the one chosen for our next steps in this research (the Aggregate Production Planning, the Material Requirement Planning and the Manufacturer Resource Planning).

5.3 The Aggregate Production Planning

5.3.1. The Aggregate Production Planning: Mathematical model

T	Number of periods (i.e., the planning horizon)
C^W	Salary cost per worker
C^H	Cost of hiring one worker
C^L	Cost of firing one worker
C_i^P	Cost of producing one unit of a product
C_i^I	Cost of carrying one unit of product *i*
W_t	Number of workers available in period *t*
H_t	Number of workers hired in period *t*
L_t	Number of workers fired in period *t*
P_{it}	Number of product *i* produced in period *t*
I_{it}	Number of product *i* stored in inventory in period *t*
I_0	Beginning inventory
D_{it}	Demand for product *i* in period *t*
n_{it}	Productionrate for product *i* that can be made by one worker in period *t*

The APP formulation

Minimize:

$$\min \sum_{t=1}^{T} (C^W\, W_t + C^H\, H_t + C^L\, L_t + \sum_{i=1}^{N} (C_i^P\, P_{it} + C_i^I\, I_{it})) \qquad (1)$$

Subject to:

$$\sum_{i=1}^{N} \left(\frac{1}{n_{it}}\right) P_{it} \le W_t \qquad t = 1,2, \dots, T \qquad (2)$$

$$W_t = W_{t-1} + H_t - L_t \qquad t = 1,2, \dots, T \qquad (3)$$

$$I_t = I_{it-1} + P_{it} - D_{it} \qquad t = 1,2, \dots, T;\ i = 1,2, \dots, N \qquad (4)$$

$$I_0 = (it) \qquad (5)$$

$$W_0 = (wt) \quad (6)$$

$$P_{it}, W_t, H_t, L_t, I_{it} \qquad t = 1,2, \dots, T\ ;\ i = 1,2, \dots, N \quad (7)$$

5.3.2. Description of the Aggregate production planning mathematical model

The aggregated production planning overall goal is to satisfy the demand for aggregated products by the use of available resources, in this thesis the available recourses are: workers and stock products over a planning horizon cycle.

The objective function (1) is to minimize the total costs over whole time period T. The following cost components were used: C^W is salary cost of one worker, C^H is cost of hiring one worker, C^L — cost of firing one worker, C_i^P — cost to produce one unit of product *i*, C_i^I — cost of carrying one unit of product *i*. For all the components there is a decision variable stated respectively: W_t is the number of workers available in period *t*, H_t is the number of workers hired in period *t*, L_t — number of workers fired in period *t*, P_{it} — number of units of product *i* produced in period *t*, I_{it} — number of held units of product *i* in inventory in period *t*.

Production capacity constraint (2) represents a capacity limit of a workforce required to produce some quantity of a product *i* in time period *t*. Production rate n_{it} shows the number of units of product *i* that can be made by one worker in time period *t*.

Workforce capacity constraint (3) represents a workforce balance between periods, in other words it is the number of workforce for the given time period *t*.

Inventory balance constraint (4) represents a net inventory for the given time period, where D_{it} is a forecasted number of units of product *i* demanded in period *t*.

Constraints (5) and (6) represent the amount of initial inventory for each product and initial number of workers at the beginning of planning horizon accordingly. Constraint (7) represents non-negative decision variables.

After selecting the products that this research's results are going to be based on, and after processing the needed data through the aggregate production planning mathematical model, the best suitable two strategies for Grande will be applied. While different strategies can be applied using the aggregate production planning, the first strategy limits the planning to a fixed number of three workers through the year, and the second strategy relies on hiring and firing actions of the workforce depending on the demand in 2014.

5.3.3. Aggregate Production plan: First Strategy "No Hire/No Fire"

The following section describes the outcome of the aggregate plan when a "No hire/no fire" strategy was set. The model calculated the total cost to be 5379550.

Month	Workforce	Salary (Kr)	Demand	Production	Stock	Holding cost(kr)	Total production cost (kr)
1	3	76500	170	170	0	0	279 950,00
2	3	72675	134	134	0	0	207 267,00
3	3	84150	100	100	0	0	161 048,00
4	3	84150	60	84	24	17040	158 805,00
5	3	76500	341	384	67	47 570	677 680,00
6	3	84150	551	425	0	0	648 176,00
7	3	84150	98	98	0	0	99 434,00
8	3	80325	238	259	21	14910	353 443,00
9	3	80325	471	450	0	0	617 665,00
10	3	80325	231	231	0	0	451 271,00
11	3	72675	164	164	0	0	530 030,00
12	3	84150	141	141	0	0	155 183,00
Total		960 075				79520	4 339 952

Table 4 No Hire/No Fire strategy

The previous table 4 describes a No Hire/Fire strategy, regarding the workforce needed, salary, demand, production quantities, stock, holding cost and total production costs. The strategy suggests that three workers are going to be responsible for the production of the selected products.

Regarding the salaries of the workforce in the No Hire/Fire strategy; the total sum of the salaries cost will be 960075 kroner. There will be no hiring costs and no firing costs because the strategy relies on fixed workforce quantity, thus the hiring and firing costs are set to zero. As shown in the table, there are differences in the salary costs each month. The reason of those differences is the amount of the working days that is changed due to vacations and national holidays

While regarding the production plan, the production quantity in 9 months out of 12 months will meet exactly the forecasted demand of the products, while in 3 months; a specific amount of products will be placed in stock to fulfil future products demand. For example in January there is a total demand of 170 and the production plan suggests to produce exactly a total of 170 products representing the demand of each product during January. The same applies for the other 8 months (February, March, June, July, September, October, November and December) that the strategy suggests that exact production match with the demand forecasted.

While in April, May and August, the strategy suggests stocking products with quantites of 24, 67 and 21 respectively to meet future demands due to limited production resources or to acquire inventory that will be used in the next period.

It is also observable in the table, the production costs in May increases over 4 times the production cost in April, which indicate the arrival of a high sales season and a high demand in May, June and July. The production cost declines to nearly 100,000 kroner in July, to raise again in August and September to reach 617,665.00 kroner in September that is mainly resulted to a very seasonal demand due to the start of the new school year and to meet

5.3.4. Aggregate Production plan: Second Strategy "Hybrid or Allow Hire/Fire"

The second aggregate production planning strategy that will be discussed is the Hybrid Strategy. The hybrid strategy is related directly to the workforce needed to meet the forecasted demand on a monthly period for one-year time line. The following table represents the hybrid aggregate production planning workforce decisions.

Month	Work force	Hired	Fired	Cost(Kr)	Hire Cost	Demand	Production	Stock	Holding cost	Total production cost (Kr)
0	3									
1	2	0	1	51 000	0	170	170	0	0	279 950
2	1	0	1	24 225	0	134	134	0	0	207 267,00
3	1	0	0	28 050	0	100	100	0	0	161 048,00
4	1	0	0	28 050	0	60	60	0	0	83 517,00
5	3	2	0	76 500	10 608	341	342	1	710	525 496
6	4	1	0	112 200	5 304	551	550	0	0	875 648
7	1	0	3	28 050	0	98	98	0	0	99 434
8	2	1	0	53 550	5 304	238	259	21	14910	356 348
9	3	1	0	80 325	5 304	471	450	0	0	614 760
10	2	0	1	53 550	0	231	231	0	0	451 271
11	2	0	0	48 450	0	164	164	0	0	530 030
12	1	0	1	28 050	0	141	141	0	0	155 183
				612 000	26 520				15620	49071320

Table 5 Hybrid strategy work force plan

By applying a hybrid strategy, the production plan suggests different hire and fire decisions to be taken through the year 2014. Table 5 sums the hybrid strategy aggregate plan in regard to the workforce needed and the related salaries and costs, the hire/fire decisions, demand, production, stock, holding cost and the total production costs. It should be noted that the "Fire" cost is Zero, because Grande borrows employees from a manpower company. There is no fire cost, by the salary for those workers is high.

Grande's workforce is set to 3 at the beginning of 2014. The plan suggests keeping only two workers for January and firing 1 worker when the year starts. In February, another lay off action will take place, and the production will rely on only 1 worker in February to meet the forecasted demand, and the workforce will stay at 1 worker for March and April as well.

Due to an estimated increase in demand in May, the hybrid strategy suggests to hire 2 workers, thus, the total number of workers will be 3 in that month. Another worker will be hired in June due to an ongoing increase in the demand, which needs more workforces to support the increasing production of the factory. In July, the demand goes down again to a very low level, where there will be no need to have 4 workers to meet the sales forecasts for future orders. The strategy in July suggests a fire action of 3 workers, and to have only 1 worker in the production process responsible for the chosen products for our thesis.

An increase in production will take place in August, thus the strategy suggests hiring a worker at that month, also hiring another worker in September as well to have a total of workers of three to meet the demand in September. A small decrease in sales is forecasted in October and November, so the hybrid strategy suggests firing one worker at the beginning of October, so there will be 2 workers in October and November responsible for the production of the selected products. At last, the demand and production in December will decrease again, thus, the strategy suggests laying off another worker to have only one worker in the last month of the year 2014.

The continuous hiring and firing of workers through the year of 2014 and the different working days in each month (because of the holidays), the salaries cost will vary a lot from one month to another. Table 5 also describes the exact costs of workers for each month in relation with the hiring and firing actions that will take place if the hybrid strategy becomes effective.

The hybrid strategy suggests a slightly different production and inventory planning in the year 2014. The demand meets exactly the production in the first four months (January, February, March and April). While for May and August the production is increased to meet the extra demand required in the other months.

Due to the various actions of hiring and firing in the workforce, and the differences in demand in each month of the year, the production cost will then increase or decrease depending on the case of each month. Yet, it is still easy to notice the seasonal demand on the selected products through the year 2014. As an example, the production cost reach its highest amount in June

(875,648.00 kroner), and declines to the second lowest cost in the July the month after, which is a cost of only 99,434.00.

The second strategy that depends on hiring and firing actions, suggesting the need of 4 workers when the demand at its highest. This number of workforce made it possible for the factory to produce more in relation with the demand. The second strategy suggests hiring an extra worker than the first strategy in the high demand season. However, the strategy therefore does not require early productions for a certain forecasted demand in previous months. Thus the inventory cost was reduced from 79,520.00 kroner in the first strategy to only 15,620.00 kroner as required in the second strategy.

Since the two strategies are going to be applied over the same forecasting plan. Then, the products going to be manufactured have the same quantities. Therefore, the production cost is not attached to strategy chosen. The production cost for both strategies is the same.

In conclusion to what was mentioned before, the second strategy with hiring and firing workers saves a total amount of 385,445.00 kroner from having a fixed amount of workers all over the year. It is logical for Grande to choose the second strategy, but only in case the factory was absolutely capable of proceeding with a hiring and firing plan through the year. Some factories due to external reasons such as geographic locations, very rare production system, etc… are not capable of finding the right workforce for their operations. Thus, the re-hiring option can be a little too hard sometimes. Grande has to choose a strategy that best suits its strategies.

	Strategy 1	**Strategy 2**	**Difference**
Salary cost	kr 960 075,00	kr 638 520,00	kr 321555
Inventory cost	kr 79 520,00	kr 15 620,00	Kr 63900
Production cost	Kr 4 339 952,00	kr 4 339 952,00	kr 0
Total cost of plan	**Kr 5 379 547,00**	**kr 4 994 092,00**	**kr 385455**

Table 6 Comparision between Aggregate production plan two stratgies

Table 6 compares between the two strategies suggested by the aggregating production planning. The salary cost of the second strategy is less by 321,555.00 kroner from the salary cost of the first strategy. The second strategy suggests a continuous hire and fire actions through the year matching the production demand of each month, and thus applying a suitable salary costs that is perfectly tied to the demand. While the first strategy suggests a fixed number of workforce, which resulted in extra salary costs with nearly 50% of the costs that will occur of applying the second strategy.

5.4 Material Requirement Planning (MRP)

5.4.1 MRP: Mathematical model

P	Number of SKUs
T	Number of periods (i.e., the planning horizon)
LT(i)	Lead time for SKU *i*
R(i,j)	Number of *i*'s needed to produce one *j*
D(i,t)	External demand for *i* period *t*
I(i,0)	Initial inventory of SKU *i*
LS(i)	Lot size for SKU *i*
M	A large number (i.e., 1 + largest D(*i*,*t*) times largest R(*i*,*j*))

Minimize:

$$\sum_{i=1}^{P} \sum_{t=1}^{T} (T-t)\ x_{i,t} \qquad (1)$$

Subject to:

$$\sum_{\tau=1}^{t-LT(i)} x_{i,\tau} + I(i,0) - \sum_{\tau=1}^{t}\left(D(i,\tau) + \sum_{j=1}^{P} R(i,j)\ x_{j,\tau}\right) \geq 0 \quad i = 1, \dots, P,\ t = 1, \dots, T \qquad (2)$$

$$x_{i,t} - \delta_{i,t} LS(i) \geq 0 \qquad i = 1, \dots, P,\ t = 1, \dots, T \qquad (3)$$

$$\delta_{i,t} - \frac{x_{i,t}}{M} \geq 0 \qquad i = 1, \dots, P,\ t = 1, \dots, T \qquad (4)$$

$$\delta_{i,t} \in \{0,1\} \qquad i = 1, \dots, P,\ t = 1, \dots, T \qquad (5)$$

$$x_{i,t} \geq 0 \qquad i = 1, \dots, P,\ t = 1, \dots, T \qquad (6)$$

(Vos & Woodruff, 2003)

5.4.2 MRP Model Description

The objective of the MRP model is to delay production as late as possible, but not later. Thus, the objective function (1) is to minimize production periods that will result in delaying production as late as possible. Where *P* stands for number of SKUs, *T* is number of periods in planning horizon. It is assumed that *T* is represented by month for a planning horizon of a year. Variable $x_{i,t}$ is the quantity of SKU *i* to be produced or ordered in period *t*.

Demand and material requirements constraint (2) insures that the sum of initial inventory of each SKU *I(i,*0*)* and the production of each SKU in each period has to be at least equal to the total of SKUs' demands *D(i,t)* and demands of all the assemblies *R(i,t)* that are used to make SKU in every period. Lead time for the particular period *i* is represented by *LT(i)* and stands for the time between the moments of ordering or purchasing and fulfillment. The summation for production is over *t - LT(i)* to insure that work is started *LT*-periods before it can be used further.

Lot size requirements (3) states the quantity of SKU to be produced in a given period has to be at least as much as the minimal lot size *LS(i)*. Integer constraint for production indicator $\delta_{i,t}$ (5) is binary variable showing if the production if SKU *i* takes place in period *t*. *M* is a relatively big number.

Modelling constraint for production indicator (4) forces $\delta_{i,t}$ to take values greater than zero if the production of SKU *i* takes place in period *t*.

The last constraint (6) forces the production for all SKUs in each period to be non-negative.

It is important to mention that MRP has in this case same solution as in MPR II, but without capacity constraint. Thus the research will proceed directly to MPR II results. First we explain the mathematical modeling of MRP II.

5.5 Manufacturing Resource Planning (MRP II)

5.5.1 The MRP II Mathematical model

P	Number of SKUs
T	Number of periods (i.e., the planning horizon)
LT (*i*)	Lead time for SKU *i*
R (*i*,*j*)	Number of *i*`s needed to produce one *j*
D (*i*,*t*)	External demand for *i* period *t*
I (*i*,*0*)	Initial inventory of SKU *i*
K	Number of resources
U (*i*,*k*)	Fraction of resources *k* needed to make one unit of *i*
M	A large number (i.e., 1 + 1/ (smallest U))

Minimize:

$$\sum_{i=1}^{P} \sum_{t=1}^{T} (T-t)\ x_{i,t} \qquad (1)$$

Subject to:

$$\sum_{\tau=1}^{t-LT(i)} x_{i,\tau} + I(i,0) - \sum_{\tau=1}^{t}\left(D(i,\tau) + \sum_{j=1}^{P} R(i,j)\, x_{j,\tau}\right) \geq 0 \quad i = 1,\dots,P,\ t = 1,\dots,T \qquad (2)$$

$$\sum_{i=1}^{P} U(_{i,k})\, x_{i,\tau} \leq 1 \qquad t = 1,\dots,T,\ k = 1,\dots,K \qquad (3)$$

$$x_{i,t} - \delta_{i,t} LS(i) \geq 0 \qquad i = 1,\dots,P,\ t = 1,\dots,T \qquad (4)$$

$$\delta_{i,t} - \frac{x_{i,t}}{M} \geq 0 \qquad i = 1,\dots,P,\ t = 1,\dots,T \qquad (5)$$

$$\delta_{i,t} \in \{0,1\} \qquad i = 1,\dots,P,\ t = 1,\dots,T \qquad (6)$$

$$x_{i,t} \geq 0 \qquad i = 1,\dots,P,\ t = 1,\dots,T \qquad (7)$$

(Vos & Woodruff, 2003)

5.5.2 MRP II model Description

MRP 2 model retains most of the constraints and logic compared to the MRP model. Basic MRP model is extended with the routing and resource capacity information. The retained logic of MRP helps to determine the production plan and extended part of the MPR2 helps each SKU to follow the sequence operation determined for each resource, where K is a number of such resources.

Capacity constraint for each resource k and period t (3) shows that the production quantity of each SKU should not exceed the capacity of the resources for each time period t. $U(i,k)$ is the fraction of resource k capacity during time period t that is used to produce one SKU i.

There are five resources in total that are used in the production process of any finished product: cutting, gluing, lapping, drilling and assembly. Each resource has its own capacity per time period which are maintained by 13 workers for process 1-4 and 7 workers for process 5 and it doesn't change over periods. The utilization fraction of each resource is calculated as the ratio between times needed to process one SKU through some resource and the available time of resource in each time period.

5.5.3 Bill of Material

	Sider	Topp	Botn	Hyller	Topplate	SiderM	Rygg	Dorer	Gror20	Opphenglist	Korger
par11850	0	1	1	4	0	3	1	10	0	0	0
par293	0	0	0	0	1	6	1	0	5	0	0
par295	0	0	0	0	1	4	1	0	5	0	0
par285	0	0	1	1	1	6	0	0	1	5	0
par573	0	0	0	9	1	4	0	0	0	0	0
par283	0	1	1	3	0	4	0	0	3	3	0
par284	0	0	1	1	0	5	0	0	2	4	0
par521	0	1	1	1	0	3	1	2	0	0	5
par384	0	1	1	0	0	6	0	0	1	0	0
par221BJ	0	1	1	1	0	3	1	2	0	0	5
par222BJ	0	1	1	1	0	3	1	2	0	0	5
par294	0	0	0	0	1	3	1	0	5	0	0
par394	0	0	0	0	1	3	1	0	5	0	0
par11820	0	1	1	1	0	3	1	4	0	0	0
par383	0	0	1	1	0	5	0	0	1	0	0
par564	2	1	1	1	0	0	1	1	0	0	5
par563	2	1	1	1	0	0	1	1	0	0	5
par393	0	0	0	0	1	3	1	0	5	0	0
par522	0	1	1	1	0	3	1	2	0	0	0
par398	2	0	0	0	0	0	1	0	0	0	0
par159	0	0	0	0	3	0	0	0	1	3	0
par283TR	0	0	1	1	0	4	0	0	2	3	0
par572	0	0	0	6	1	3	0	0	0	0	0
par292	0	0	0	0	1	6	1	0	5	0	0
par221	0	1	1	1	1	3	1	2	0	0	5
par11800	0	1	1	2	0	3	1	2	0	0	0
par510	0	1	1	1	0	2	1	2	1	0	0
par282	0	1	1	2	0	2	0	0	2	2	0
par11870	0	1	1	0	0	3	1	2	0	0	0

par11851	0	**1**	**1**	**4**	0	**2**	**1**	**5**	0	0	0
par397	**2**	0	0	0	0	0	**1**	0	0	0	0
par382	0	**1**	**1**	0	0	**4**	0	0	**1**	0	0

Table 7 MRP II Bill of Material

The bill of material or BOM as it is called, shows which component is included and their amount for each product. This help the model to know how many of each components to produce in order to be able to assembly the products when they are needed. In this thesis, lead-times, lot-sizes and the initial inventory was provided by Grande.

5.5.4 MRP II Outcome

The outcome of the MRP II model is shown in the next two tables below, which tells us the weekly production plan for a time horizon of four months (16 weeks).

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
par11850	0	0	6	0	3	0	2	0	0	0	0	0	0	0	1	0
par293	0	2	0	2	4	0	0	0	0	0	2	0	0	0	0	0
par295	2	11	0	0	1	3	2	0	0	3	1	0	0	0	0	0
par285	0	15	0	2	0	3	0	2	1	3	0	0	0	0	0	0
par573	0	2	0	0	0	0	0	0	0	0	1	0	0	1	0	0
par283	0	11	3	5	0	5	1	0	2	0	0	0	2	0	0	0
par284	0	22	8	5	11	8	0	0	0	3	0	0	0	0	0	0
par521	0	0	13	0	0	0	0	2	1	0	2	10	6	3	5	0
par384	3	15	1	5	4	3	1	1	3	3	7	1	4	3	0	0
par221BJ	0	0	0	0	0	0	1	1	2	1	1	0	1	0	0	0
par222BJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
par294	2	20	0	5	0	0	0	0	0	2	0	1	0	0	0	0
par394	0	0	2	0	6	0	3	1	3	3	3	2	3	7	0	0
par11820	0	0	0	3	2	5	0	0	0	0	0	0	0	2	0	0
par383	0	13	0	3	2	0	0	0	0	1	0	0	0	0	0	0
par564	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
par563	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
par393	0	5	0	0	0	0	1	0	0	2	0	0	0	0	0	0
par522	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
par398	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
par159	2	0	0	2	5	4	4	1	3	3	4	2	4	3	0	0

Table 8 MRP II production plan (16 weeks) 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
par283TR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
par572	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
par292	0	2	0	0	0	3	0	2	4	0	0	0	0	0	0	0
par221	0	2	0	1	2	0	1	0	1	3	2	1	0	2	0	0
par11800	0	0	2	0	0	0	0	1	0	5	0	0	0	0	0	0
par510	0	0	0	0	0	0	0	1	3	2	2	0	0	0	0	0
par282	0	1	2	1	0	4	3	2	3	0	0	0	0	0	0	0
par11870	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
par11851	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0
par397	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
par382	0	8	0	0	0	2	0	3	0	2	0	0	0	0	0	0

Table 9 MRP II Production plan (16 weeks) 2

The next table below illustrates how the production plan works with an illustration on the part "Par295". It is observable that the Gross requirement (Demand) in week 3, 4, 7, 8, 9, 12 and 13, is 2, 11, 1, 3, 2, 3 and 1. There is zero Inventory on-hand (Initial inventory). Net requirement is the amount of products that we don't have and it is needed in order to med the full demand in that particular week. Planned order receipt tells us when the produced products are expected to be ready to deliver. The planned order release indicates when the production of the products has to start, which is regulated by the lead-time.

par295	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gross requirement			2	11			1	3	2			3	1			
Inventory -on-hand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net requirement			2	11			1	3	2			3	1			
Planned order Receipt			2	11			1	3	2			3	1			
Planned order Release	2	11			1	3	2			3	1					

Table 10 Example on par295 Production plan

MRP II does not in this case consider producing to stock inventory since the minimum production or lot-sizing of any finished product can be one. While for the components there will be inventory. The Table below tells us production amount of each component for each week that is needed in order to meet the production plan for the products.

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sider	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Top	0	50	0	0	50	0	0	0	71	0	0	0	0	0	0	0
Botn	50	51	0	65	0	0	50	0	57	0	0	0	0	0	0	0
Hyller	55	66	60	0	78	0	0	59	0	0	50	0	0	0	0	0
Topplate	50	0	0	63	0	0	0	50	0	58	0	0	0	0	0	0
SideMidtside	572	133	143	156	161	50	61	89	128	90	50	60	82	0	0	0
Rygg	0	80	0	0	0	0	0	50	0	0	50	0	0	0	0	0
Dorer	0	63	0	50	56	0	0	50	0	0	74	0	0	0	0	0
Gror20mm	0	305	50	64	88	81	71	0	57	70	61	0	70	0	0	0
Opphenglist	0	154	50	50	57	120	0	0	98	0	0	0	0	9	0	0
Korger	0	0	50	0	0	0	0	50	0	5	50	90	0	0	50	0

Table 11 Production amounts per item (16 weeks)

The components are produced by machines, the machines alone have a high produciton capacity, but they have to be managed by workers who have limited hour per day, which limits the production capacity.

	M1_Cutting	M2_Glue	M3_Lipping	M4_Drilling	M5_Assembly
1	79 %	89 %	85 %	77 %	5 %
2	51 %	38 %	58 %	56 %	84 %
3	22 %	22 %	24 %	22 %	27 %
4	40 %	44 %	40 %	42 %	21 %
5	41 %	38 %	42 %	43 %	24 %
6	5 %	6 %	6 %	5 %	28 %
7	14 %	11 %	13 %	12 %	12 %
8	32 %	32 %	39 %	40 %	12 %
9	32 %	26 %	29 %	28 %	17 %
10	16 %	22 %	17 %	17 %	23 %
11	25 %	21 %	32 %	33 %	15 %
12	6 %	8 %	7 %	6 %	13 %
13	9 %	10 %	10 %	9 %	13 %
14	0 %	0 %	0 %	0 %	13 %

15	0 %	0 %	0 %	0 %	5 %
16	0 %	0 %	0 %	0 %	0 %

Table 12 Weekly machine utilization

We can see from the previous table the weekly utilization of each machine. For example in week one the utilization of machine M1_Cutting will be at 79 % of its full capacity, while at the end of the last month (week 13 to 16) utilization decreased from 9% in week 13 down to 0% utilization in week 14, 15 and 16.

Chapter 6: Conclusion

This section concludes this thesis, first a summary of the key issues will take place, and then a deduction and discussions will follow. The authors will share their personal opinion on the discussed thesis, while also mentioning the limitations, implications and future research.

6.1 Brief summary

This thesis focal research was on Grande Fabrikker, the Norwegian furniture producer. The main scheme of the thesis is to emphasize the need to better manage the production, operations, inventory and scheduling at Grande, since the management's old and subjective opinion based decision making, from which the importance of this research is developed. It is important to note that the thesis proposes basic enhancements of the current system and a more thorough deployment and development of this research should be considered.

The thesis introduced well established tools and models, known for their improvements regarding the mentioned managerial and logistical areas. These tools are: The ABC classification, the Aggregate Production Planning (APP), the Material Requirement Planning (MRP) and the Manufacturing Resource Planning (MRP II). Each of these tools and models is extensively reviewed in the literature (Chapter 4) and a thorough analysis of the application and the results of this tools and models are completed in the chapter entitled "Data Analysis and Results".

Through the deductions and discussions, the research questions should be answered. The deductions and discussions will follow the same sequence used in the previous chapters; first the ABC analysis will be discussed and then followed by the Aggregate Production Planning the Material Requirement planning and Manufacturing Resource planning.

6.2 Deductions and discussions

6.2.1 ABC Analysis

Through using the ABC analysis, it was feasible to classify the 552 products that Grande manufacturer. Although there were difficulties regarding the data collection of the finished products and the prices, yet that did not cease to hinder the analysis. The results of the analysis are concluded in the following table:

ABC Analysis: percentage of cumulative total value			percentage of items
Class A	Garderob, Kjøkken, Oppbevaring, Kateter and Divers	79,9819	27,8899
Class B		14,8260	30,2752
Class C		4,9879	41,4679

Table 13 ABC analysis and percentages

In the initial phase of the research, a full management of all classes was planned, as well as the application of the other tools and models on the three categories. Later on, this plan was canceled due to different reasons that will be discussed later. Thus, only the “Garederob” category from class A was considered. The “Garderob” category alone presents 30% of the revenue Class A of Grande’s products. In other words, the “Garderob” category at Grande represents around 37.5% revenue of all of Grande’s products. It is believed that better managing this category, it will yield better outcome. Other class A categories are: “Kjøkken” with 24%, “Oppbevaring” with 23%, “Kateter” with 17% and “Divers” with 7%.

6.2.2 Aggregate Production Planning

The analysis of the Aggregate Production planning was divided into two strategies. The first was based on that the same number employees will exist through this plan, while the other different decisions regarding the hiring and firing of the employees will be taken based on the production needs. The results of both strategies are summed in the following table:

	Strategy 1	**Strategy 2**	**Difference**
Salary cost	kr 960 075,00	kr 638 520,00	kr 321555
Inventory cost	kr 79 520,00	kr 15 620,00	Kr 63900
Production cost	Kr 4 339 952,00	kr 4 339 952,00	kr 0
Total cost of plan	**Kr 5 379 547,00**	**kr 4 994 092,00**	**kr 385455**

Table 14 Aggregate Production Planning strategies outcome

It is deducted that both strategies have a fixed production cost, hence the number of the workers is the variable hence the different salary costs. The second strategy proves to be better in terms of the salary and inventory costs. Yet, preferring the second strategy might have uncalculated possible threats, for instance, hiring and firing workers might not be an easy task, financial and relate human resources decisions have to be thought. On the other hand such a reduction on the inventory costs is good considering a simple tool as the Aggregate Production Planning (APP). If complicated tools or an extension of the APP is applied, Grande is believed to achieve better results.

6.2.3 Material Requirement Planning (MRP) and Manufacturing Resource Planning (MRP II)

As mentioned in the "Data analysis and results" chapter, the MRP II adds the capacity (and its related constraints) in addition to the original MRP model, thus this section-same as the Chapter 5-skips the MRP results and move forward to the MRP II conclusion.

The MRP II outcome represented in the tables: Bill of Material and MRP II outcome and Components production amounts provides a detailed plan and schedule for all of the items required in the production of the "Garderob" category in the Class A of products mentioned in the ABC analysis section.

From the table "Bill of Material", it is concluded that certain items will be needed more than the others. For instance, 20 pieces of Par11850 will be required for the production, and only 3 pieces of Par398 will be required, and thus different decisions regarding the inventory can be considered (higher inventory for the Par11850) while a pull based inventory strategy (where production will only be intiated by real demand) can be considered for the other items.

While the MRP II outcome table shows which item will be need on which week. It is concluded that most parts is demanded in the first 8 weeks and while the second 8 weeks (week 9 to 16) are seldom required. And through scrutinizing and analyzing the outcome, it is seen that specifically the first month require a higher demand for the parts than the later month(s). This information is very helpful when managing the inventory, inventory controllers can establish a plan/schedule set specifically to better adapt this requirement and later on will reduce costs. For instance, and depending on the carrying costs and other decisions (order size, warehouse capacity), one can order the whole amount required of a certain part at the beginning of the production, other, can order per month (since the first month have the higher demand).

The table Par295MRP II example showed an illustration of the MRP II outcome for a specific item, i.e. Par295. It presented the Gross requirement of that part, the current inventory, the net requirements, the planned order recite and planned order release. The MRP II provides such information for all of the items (parts) required for the production of the “Garderob” category in the class A products of Grande’s products.

6.3 Limitations

As mentioned before, Grande follows old and subjective managerial business model. This was present in the data collection, and the way of doing business (the subjectivity of decision making). Such obstacles limited the research to be thorough as planned regarding the usage of other complicated tools, formulating a full Aggregate Production Plan, MRP and MRP II for of the items and all of the classes, which require massive amounts of information which Grande cannot provide at the mean time.

On the other hand, if such information is available (which is not), a timing problem will arise. This amount of data will need more time to be filtered and more time to be fitted in the mentioned models.

Also, the available data and the current database are not integrated. For instance, the database does not differentiate between finished products and production components (items/parts). Moreover the components are not linked to the finished products. Even more, the prices and demands of the finished products are not linked together, nor are they linked to the previous data (list of products and components).

6.4 Recommendations

First, further research should be done on Grande, especially on the managerial business model followed. The authors believe that by using the tools and models presented in this thesis a reduction of costs is the least of benefits Grande can gain.

Second, the authors believe that Grande should invest in“Database” software, as for the current manual data entry is inefficient and costly. Grande’s decisions (as well the authors’ tasks) would have been well-organized and resourceful if such software existed.

Also the authors believe that Grande will benefit from investing in a software that deals with production, inventory levels in real time together with a customer order system. This will make cutomer ordering easier, efficient and delivery will be timily.

Third, the tools and models used in this research are only applied on the “Garderobe” category in class A products, Grande is believed to apply these models on the whole set of categories they offer in order to maximize the benefits.

Fourth, the research used basic tools and models, it is recommended to use more complex and advanced models to ensure more variables are integrated, and a comprehensive research and analysis is completed.

Last but not least and most importantly, Grande should first apply carefully the methodology and results of this research in order to realize the benefits, enhancements should be done if available, and then a completion of the research and including other classes.

Chapter 7: References

1. Ali Hasan (1996). Material Requirements Planning System – for Low – Volume, Make–to– Order Company. M E. Thesis, MNREC Allahabad, India, 1996.

2. Braglia, M., Grassy, A., & Montana, R. (2004). Multi-attribute classification method for spare parts inventory management. Journal of Quality in Maintenance Engineering, 10(1), 55-65. 4.

3. Candace Araiyna and Robert C. Carlson (1987). Interaction between frequency of rescheduling and the role of safety stock in Material Requirements Planning systems. Int. J. Prod. Res., 25, 2, 221-232.

4. Chen, Y., Li, K. W., Levy, J., Hype, K. W., & Kilgore, D. M. (2008). A rough set approach to multiple criteria ABC analysis. In Transactions on rough sets VIII (pp. 35-52).

5. Cheng I.C.E. (1987).A Simulation Study of MRP Capacity Planning with uncertain operation times. Int. J. Prod. Res., 25, 2, 245-258.

6. European J. of Industrial Engineering, 2010 Vol.4, No.2, pp.167 – 188.

7. Foote, B.L., Ravindran, A., Lashine, S., (1998). Production planning and scheduling: Computational feasibility of multi-criteria models of production, planning and scheduling. Computers and Industrial Engineering 15(1), 129–138.

8. Hadi-Vencheh, A. (2010). An improvement to multiple criteria ABC inventory classification. European Journal of Operational Research, 201(3), 962-965. 11.

9. Ho C.J., Law W.K. and Rampal R. (1995). Uncertainty dampening Methods for reducing MRP Systems nervousness. Int. J. Prod. Res., 33, 2, 483-496.

10. James R. Ashby (1995). Scheduling and Order Release in a single stage production system. J. of manufacturing systems, 14, 4,290-306.

11. John, G., Wacker (1985). A theory of Material Requirements Planning (MRP) uncertainty in MRP Systems. Int. J. Prod. Res., 23, 4, 807-824.

12. Kabir, G., Hasin, M. A. A., & Khondokar, M. A. H. (2011). Fuzzy analytical hierarchical process for multicriteria inventory classification. Proceedings of the International Conference on Mechanical Engineering, 18-20 December, Dhaka, Bangladesh.

13. Lagodimos A.G. and Anderson E.J. (1993). Optimal Positioning of Safety Stocks in MRP. Int. J. Prod. Res, 31, 8, 1797-1813.

14. Lambert, D.M. & Cooper, M.C. (2000). Issues in supply chain management. Industrial Marketing Management, 29, 65-83.

15. Liu, Q., & Huang, D. (2006). Classifying ABC inventory with multi-criteria using a data envelopment analysis approach. In Intelligent systems design and applications, 2006. ISDA'06. Sixth International Conference on IEEE (Vol. 1, pp. 1185-1190).

16. Minner, S. (2003). Multiple-supplier inventory models in supply chain management: a review. Intern. J. Prod. Economics, 81-82, 265-279.

17. Mirzapour Al-e-hashem, S. M. J., Malekly, H., & Aryanezhad, M. B. (2011). A multi-objective robust optimization model for multi-product multi-site aggregate production planning in a supply chain under uncertainty. In. J. Prod. Eco., doi:10.1016/j.ijpe.2011.01.027.

18. Monk, E. and Wagner, B., Concepts in Enterprise Resource Planning, 2nd Edition, 2006, Editor, Mac Mendelsohn, Canada: Thomson Course Technology.

19. Ng, W. L. (2007). A simple classifier for multiple criteria ABC analysis. European Journal of Operational Research, 177(1), 344-353.

20. Pandey, P.C., Yenradee, P. & Archariyapruek, S. (2000). A finite capacity material requirements planning system. Production Planning & Control, 11, 113-121.

21. Partovi, F. Y., & Anandarajan, M. (2002). Classifying inventory using an artificial neural network approach. Computers & Industrial Engineering, 41(4), 389-404.

22. Ramanathan, R. (2006). ABC inventory classification with multiple-criteria using weighted linear optimization. Computers & Operations Research, 33(3), 695-700.

23. Porkka, P., Vepsalainen, A.P.J., Kuula, M., (2003). Multiperiod production planning carrying over set-up time. International Journal of Production Research 41(6), 1113–1148.

24. Shi Y., & Haase, C. (1996) Optimal trade-offs of aggregate production planning with multiple objective and multi-capacity demand levels. International Journal of Operations and Quantitative Management 2(2), 127–143.

25. Sridharan V. and William Berry L. (1990).Master production Scheduling make to stock product: A Frame work for analysis. Int. J. Prod. Res., 28, 3, 541– 558.

26. Yu, M. C. (2011). Multi-criteria ABC analysis using artificial-intelligence-based classification techniques. Expert Systems with Applications, 38(4), 3416-3421.

27. Zhou, P., & Fan, L. (2007). A note on multi-criteria ABC inventory classification using weighted linear optimization. European Journal of Operational Research, 182(3), 1488-1491.

28. S. Voß and D.L. Woodruff, An Introduction to Computational Optimization Models for Production Planning in a Supply Chain, Springer, 2003. P 27

29. Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research Methods for Business studies* (изд. 5th). Essex: Pearson Education Limited.

Electronic resources

30. Aggregate Planning Process [Electronic resource]. - Access: http://www.slideshare.net/NeilKizhakayilGeorge/models-of-aggregate-planning

31. Managing Business Resources with Software Tools – Enterprise Application Suite [Electronic resource]. - Access: http://bizxc.com/

32. Material Requirement Planning (MRP1) system [Electronic resource]. - Access: https://acc.dau.mil/communitybrowser.aspx?id=520804

Chapter 8: Appendix

8.1 ABC-Analysis: Outcome

ABC-Analysis for all Products								
Article #	**Price(kr)**	**Demand**	**Profit(kr)**	**Item #**	**Cum. profit(kr)**	**Cum. (%)**	**(%)of items**	**Group**
11850	10549	62	654038	1	654038	2,15	0,18	A
362	2703	231	624393	2	1278431	4,20	0,37	A
293	2552	204	520608	3	1799039	5,92	0,55	A
295	4248	108	458784	4	2257823	7,42	0,73	A
15420	5505	83	456915	5	2714738	8,93	0,92	A
285	3960	113	447480	6	3162218	10,40	1,10	A
15702	3677	120	441240	7	3603458	11,85	1,28	A
9210600	2132	203	432796	8	4036254	13,27	1,47	A
573	5450	79	430550	9	4466804	14,69	1,65	A
283	2374	168	398832	10	4865636	16,00	1,83	A
15461	5428	73	396244	11	5261880	17,30	2,02	A
15141	3013	131	394703	12	5656583	18,60	2,20	A
284	3170	120	380400	13	6036983	19,85	2,39	A
15462	5428	70	379960	14	6416943	21,10	2,57	A
17102	4342	82	356044	15	6772987	22,27	2,75	A
521	6535	54	352890	16	7125877	23,43	2,94	A
17802	4342	80	347360	17	7473237	24,57	3,12	A
9210500	2064	168	346752	18	7819989	25,71	3,30	A
384	1972	173	341156	19	8161145	26,83	3,49	A
221BJ	8900	38	338200	20	8499345	27,94	3,67	A
375	5101	61	311161	21	8810506	28,97	3,85	A
222BJ	8900	34	302600	22	9113106	29,96	4,04	A
17502	4342	67	290914	23	9404020	30,92	4,22	A
4210600	1925	149	286825	24	9690845	31,86	4,40	A
294	3398	83	282034	25	9972879	32,79	4,59	A
3763	3586	74	265364	26	10238243	33,66	4,77	A
17202	4342	61	264862	27	10503105	34,53	4,95	A
15011	4099	63	258237	28	10761342	35,38	5,14	A
15042	2549	97	247253	29	11008595	36,19	5,32	A
394	1778	138	245364	30	11253959	37,00	5,50	A
4020602	2357	104	245128	31	11499087	37,81	5,69	A
15147	4606	52	239512	32	11738599	38,60	5,87	A
15830	10193	23	234439	33	11973038	39,37	6,06	A
9020501	2478	94	232932	34	12205970	40,13	6,24	A
15143	7591	30	227730	35	12433700	40,88	6,42	A
11820	6657	34	226338	36	12660038	41,62	6,61	A
383	1478	146	215788	37	12875826	42,33	6,79	A

2050500	3987	53	211311	38	13087137	43,03	6,97	A
9020502	2478	84	208152	39	13295289	43,71	7,16	A
10217	330	605	199650	40	13494939	44,37	7,34	A
564	4497	44	197868	41	13692807	45,02	7,52	A
376	5352	36	192672	42	13885479	45,65	7,71	A
9230601	2132	86	183352	43	14068831	46,26	7,89	A
4030600	5602	32	179264	44	14248095	46,85	8,07	A
4722	1511	117	176787	45	14424882	47,43	8,26	A
12112	1553	111	172383	46	14597265	47,99	8,44	A
4050600	4099	42	172158	47	14769423	48,56	8,62	A
563	4497	38	170886	48	14940309	49,12	8,81	A
17101	3205	53	169865	49	15110174	49,68	8,99	A
9230602	2132	78	166296	50	15276470	50,23	9,17	A
1168	1982	83	164506	51	15440976	50,77	9,36	A
393	1335	123	164205	52	15605181	51,31	9,54	A
2030600	5602	29	162458	53	15767639	51,84	9,72	A
2210600	1925	81	155925	54	15923564	52,35	9,91	A
15575	4493	34	152762	55	16076326	52,86	10,09	A
15102	2519	59	148621	56	16224947	53,35	10,28	A
2210500	1857	79	146703	57	16371650	53,83	10,46	A
4020601	2357	62	146134	58	16517784	54,31	10,64	A
4431	11638	12	139656	59	16657440	54,77	10,83	A
1210800	2531	55	139205	60	16796645	55,23	11,01	A
4622	4087	34	138958	61	16935603	55,68	11,19	A
15049	3823	36	137628	62	17073231	56,13	11,38	A
99218	4805	28	134540	63	17207771	56,58	11,56	A
522	6535	20	130700	64	17338471	57,01	11,74	A
17536	5634	23	129582	65	17468053	57,43	11,93	A
15021	1884	67	126228	66	17594281	57,85	12,11	A
3771	2751	45	123795	67	17718076	58,25	12,29	A
4050800	4564	27	123228	68	17841304	58,66	12,48	A
398	2727	45	122715	69	17964019	59,06	12,66	A
4010800	2900	41	118900	70	18082919	59,45	12,84	A
2050600	4099	29	118871	71	18201790	59,85	13,03	A
159	826	140,5	116053	72	18317843	60,23	13,21	A
15046	3213	36	115668	73	18433511	60,61	13,39	A
283TR	2742	41	112422	74	18545933	60,98	13,58	A
5050600	4099	27	110673	75	18656606	61,34	13,76	A
2020601	2357	45	106065	76	18762671	61,69	13,94	A
572	3633	29	105357	77	18868028	62,04	14,13	A
1348	3548	29	102892	78	18970920	62,37	14,31	A
17836	5634	18	101412	79	19072332	62,71	14,50	A
3781	2897	35	101395	80	19173727	63,04	14,68	A
15811	5571	18	100278	81	19274005	63,37	14,86	A

12132	2066	48	99168	82	19373173	63,70	15,05	A
19831	16204	6	97224	83	19470397	64,02	15,23	A
9210800	2945	33	97185	84	19567582	64,34	15,41	A
1327	3548	27	95796	85	19663378	64,65	15,60	A
12342	1805	53	95665	86	19759043	64,97	15,78	A
15705	4315	22	94930	87	19853973	65,28	15,96	A
429-60	1129	84	94836	88	19948809	65,59	16,15	A
4618	3511	27	94797	89	20043606	65,90	16,33	A
99210	2551	37	94387	90	20137993	66,21	16,51	A
2020602	2357	40	94280	91	20232273	66,52	16,70	A
99216	4182	22	92004	92	20324277	66,82	16,88	A
99220	3820	24	91680	93	20415957	67,13	17,06	A
292	1697	54	91638	94	20507595	67,43	17,25	A
17302	4342	21	91182	95	20598777	67,73	17,43	A
372	1684	54	90936	96	20689713	68,03	17,61	A
4628	4087	22	89914	97	20779627	68,32	17,80	A
15451	4873	18	87714	98	20867341	68,61	17,98	A
15452	4873	18	87714	99	20955055	68,90	18,17	A
221	8482	10	84820	100	21039875	69,18	18,35	A
17136	5634	15	84510	101	21124385	69,45	18,53	A
11800	5565	15	83475	102	21207860	69,73	18,72	A
9030600	6382	13	82966	103	21290826	70,00	18,90	A
13170	4328	19	82232	104	21373058	70,27	19,08	A
15048	8050	10	80500	105	21453558	70,54	19,27	A
15107	3522	22	77484	106	21531042	70,79	19,45	A
1011000	3073	25	76825	107	21607867	71,04	19,63	A
4210600H	2437	31	75547	108	21683414	71,29	19,82	A
9020601	2564	29	74356	109	21757770	71,54	20,00	A
15022	2095	35	73325	110	21831095	71,78	20,18	A
5020602	2357	31	73067	111	21904162	72,02	20,37	A
371	1684	43	72412	112	21976574	72,26	20,55	A
1165	1982	35	69370	113	22045944	72,48	20,73	A
9030500	6265	11	68915	114	22114859	72,71	20,92	A
9050600	4567	15	68505	115	22183364	72,94	21,10	A
4011000	3073	22	67606	116	22250970	73,16	21,28	A
510	4776	14	66864	117	22317834	73,38	21,47	A
1010800	2900	23	66700	118	22384534	73,60	21,65	A
282	1586	42	66612	119	22451146	73,82	21,83	A
229-60	1129	59	66611	120	22517757	74,04	22,02	A
3773	1949	34	66266	121	22584023	74,25	22,20	A
4071142	5975	11	65725	122	22649748	74,47	22,39	A
1324	4674	14	65436	123	22715184	74,68	22,57	A
15101	2181	30	65430	124	22780614	74,90	22,75	A
4410601	5015	13	65195	125	22845809	75,11	22,94	A

4712	1114	58	64612	126	22910421	75,33	23,12	A
5020601	2357	27	63639	127	22974060	75,54	23,30	A
4060600	2758	23	63434	128	23037494	75,74	23,49	A
529-60	1129	54	60966	129	23098460	75,94	23,67	A
11870	3744	16	59904	130	23158364	76,14	23,85	A
4050500	3987	15	59805	131	23218169	76,34	24,04	A
5210600	1925	31	59675	132	23277844	76,53	24,22	A
118	2127	27	57429	133	23335273	76,72	24,40	A
9020602	2564	22	56408	134	23391681	76,91	24,59	A
17236	5634	10	56340	135	23448021	77,09	24,77	A
2060600	2758	20	55160	136	23503181	77,28	24,95	A
17518	7833	7	54831	137	23558012	77,46	25,14	A
2210600H	2437	22	53614	138	23611626	77,63	25,32	A
15176	614	87	53418	139	23665044	77,81	25,50	A
4625	4087	13	53131	140	23718175	77,98	25,69	A
17808	10466	5	52330	141	23770505	78,15	25,87	A
5011000	3073	17	52241	142	23822746	78,33	26,06	A
102	7436	7	52052	143	23874798	78,50	26,24	A
4210500H	2335	22	51370	144	23926168	78,67	26,42	A
17803	4254	12	51048	145	23977216	78,83	26,61	A
17812	5630	9	50670	146	24027886	79,00	26,79	A
9211000H	3853	13	50089	147	24077975	79,17	26,97	A
11851	5562	9	50058	148	24128033	79,33	27,16	A
4020501	2271	22	49962	149	24177995	79,49	27,34	A
397	2754	18	49572	150	24227567	79,66	27,52	A
l	2357	21	49497	151	24277064	79,82	27,71	A
382	986	50	49300	152	24326364	79,98	27,89	A
231	3513	14	49182	153	24375546	80,14	28,07	B
9050500	4455	11	49005	154	24424551	80,30	28,26	B
4020402	2121	23	48783	155	24473334	80,47	28,44	B
4210800	2531	19	48089	156	24521423	80,62	28,62	B
99212	3608	13	46904	157	24568327	80,78	28,81	B
9220600H	4255	11	46805	158	24615132	80,93	28,99	B
1344	4674	10	46740	159	24661872	81,09	29,17	B
7500053	1920	24	46080	160	24707952	81,24	29,36	B
210	6568	7	45976	161	24753928	81,39	29,54	B
15576	5108	9	45972	162	24799900	81,54	29,72	B
2210800	2531	18	45558	163	24845458	81,69	29,91	B
241	3781	12	45372	164	24890830	81,84	30,09	B
9011000	3487	13	45331	165	24936161	81,99	30,28	B
4410602	5015	9	45135	166	24981296	82,14	30,46	B
542	2991	15	44865	167	25026161	82,28	30,64	B
2070901	8943	5	44715	168	25070876	82,43	30,83	B
4020401	2121	21	44541	169	25115417	82,58	31,01	B

15611	2058	21	43218	170	25158635	82,72	31,19	B
1318	3548	12	42576	171	25201211	82,86	31,38	B
15560	3826	11	42086	172	25243297	83,00	31,56	B
2020501	2271	18	40878	173	25284175	83,13	31,74	B
2020502	2271	18	40878	174	25325053	83,27	31,93	B
1172	2725	15	40875	175	25365928	83,40	32,11	B
1175	2725	15	40875	176	25406803	83,53	32,29	B
9430601H	8099	5	40495	177	25447298	83,67	32,48	B
15149	5771	7	40397	178	25487695	83,80	32,66	B
1020602	2357	17	40069	179	25527764	83,93	32,84	B
530	7953	5	39765	180	25567529	84,06	33,03	B
3030600	5602	7	39214	181	25606743	84,19	33,21	B
3210600H	2437	16	38992	182	25645735	84,32	33,39	B
5050400	3877	10	38770	183	25684505	84,45	33,58	B
4030500	5485	7	38395	184	25722900	84,57	33,76	B
7490020	913	42	38346	185	25761246	84,70	33,94	B
12142	1805	21	37905	186	25799151	84,82	34,13	B
4220600	3137	12	37644	187	25836795	84,95	34,31	B
9211000	3116	12	37392	188	25874187	85,07	34,50	B
145	9163	4	36652	189	25910839	85,19	34,68	B
99226	6076	6	36456	190	25947295	85,31	34,86	B
11821	3644	10	36440	191	25983735	85,43	35,05	B
1322	4521	8	36168	192	26019903	85,55	35,23	B
13106	5128	7	35896	193	26055799	85,67	35,41	B
4071141	5975	6	35850	194	26091649	85,79	35,60	B
2070902	8943	4	35772	195	26127421	85,90	35,78	B
11802	2975	12	35700	196	26163121	86,02	35,96	B
1410601	5015	7	35105	197	26198226	86,14	36,15	B
4240600	2441	14	34174	198	26232400	86,25	36,33	B
4020502	2271	15	34065	199	26266465	86,36	36,51	B
17503	4254	8	34032	200	26300497	86,47	36,70	B
222	8482	4	33928	201	26334425	86,58	36,88	B
15043	5579	6	33474	202	26367899	86,69	37,06	B
11852	5562	6	33372	203	26401271	86,80	37,25	B
182	1369	24	32856	204	26434127	86,91	37,43	B
15590	4652	7	32564	205	26466691	87,02	37,61	B
1030400	5367	6	32202	206	26498893	87,12	37,80	B
2030400	5367	6	32202	207	26531095	87,23	37,98	B
15816	6424	5	32120	208	26563215	87,34	38,17	B
4612	3511	9	31599	209	26594814	87,44	38,35	B
392	890	35	31150	210	26625964	87,54	38,53	B
1210400	1700	18	30600	211	26656564	87,64	38,72	B
1211000	2702	11	29722	212	26686286	87,74	38,90	B
2211000	2702	11	29722	213	26716008	87,84	39,08	B

1050600	4099	7	28693	214	26744701	87,93	39,27	B
2410501	4715	6	28290	215	26772991	88,03	39,45	B
4410501	4715	6	28290	216	26801281	88,12	39,63	B
3020601	2357	12	28284	217	26829565	88,21	39,82	B
17212	5630	5	28150	218	26857715	88,30	40,00	B
5030600	5602	5	28010	219	26885725	88,40	40,18	B
4500061	1329	21	27909	220	26913634	88,49	40,37	B
1346	3480	8	27840	221	26941474	88,58	40,55	B
210BJ	6902	4	27608	222	26969082	88,67	40,73	B
2030500	5485	5	27425	223	26996507	88,76	40,92	B
5030500	5485	5	27425	224	27023932	88,85	41,10	B
2050400	3877	7	27139	225	27051071	88,94	41,28	B
4050400	3877	7	27139	226	27078210	89,03	41,47	B
184	2082	13	27066	227	27105276	89,12	41,65	B
4030400	5367	5	26835	228	27132111	89,21	41,83	B
1070901	8943	3	26829	229	27158940	89,30	42,02	B
1070902	8943	3	26829	230	27185769	89,38	42,20	B
242	3781	7	26467	231	27212236	89,47	42,39	B
2010800	2900	9	26100	232	27238336	89,56	42,57	B
15601	2605	10	26050	233	27264386	89,64	42,75	B
1162	1982	13	25766	234	27290152	89,73	42,94	B
17103	4254	6	25524	235	27315676	89,81	43,12	B
9050800	5032	5	25160	236	27340836	89,89	43,30	B
1410602	5015	5	25075	237	27365911	89,98	43,49	B
183	1539	16	24624	238	27390535	90,06	43,67	B
2011000	3073	8	24584	239	27415119	90,14	43,85	B
3011000	3073	8	24584	240	27439703	90,22	44,04	B
4081141	4868	5	24340	241	27464043	90,30	44,22	B
9430602H	8099	3	24297	242	27488340	90,38	44,40	B
1220600H	4048	6	24288	243	27512628	90,46	44,59	B
9240600	2648	9	23832	244	27536460	90,54	44,77	B
282TR	1827	13	23751	245	27560211	90,61	44,95	B
17218	7833	3	23499	246	27583710	90,69	45,14	B
17818	7833	3	23499	247	27607209	90,77	45,32	B
2210500H	2335	10	23350	248	27630559	90,85	45,50	B
9060600	2914	8	23312	249	27653871	90,92	45,69	B
3010800	2900	8	23200	250	27677071	91,00	45,87	B
396	2568	9	23112	251	27700183	91,07	46,06	B
9210500H	2542	9	22878	252	27723061	91,15	46,24	B
3050800	4564	5	22820	253	27745881	91,22	46,42	B
17336	5634	4	22536	254	27768417	91,30	46,61	B
4210400	1700	13	22100	255	27790517	91,37	46,79	B
1148	1838	12	22056	256	27812573	91,44	46,97	B
4210300	1655	13	21515	257	27834088	91,51	47,16	B

3020602	2357	9	21213	258	27855301	91,58	47,34	B
17805	5264	4	21056	259	27876357	91,65	47,52	B
17508	10466	2	20932	260	27897289	91,72	47,71	B
1326	3480	6	20880	261	27918169	91,79	47,89	B
15145	4042	5	20210	262	27938379	91,86	48,07	B
373	1684	12	20208	263	27958587	91,92	48,26	B
12301	1050	19	19950	264	27978537	91,99	48,44	B
241BJ	3952	5	19760	265	27998297	92,05	48,62	B
242BJ	3952	5	19760	266	28018057	92,12	48,81	B
230	9800	2	19600	267	28037657	92,18	48,99	B
17811	6461	3	19383	268	28057040	92,25	49,17	B
4430602	6456	3	19368	269	28076408	92,31	49,36	B
1060600	2758	7	19306	270	28095714	92,38	49,54	B
99222	4819	4	19276	271	28114990	92,44	49,72	B
15570	4818	4	19272	272	28134262	92,50	49,91	B
1210800H	3202	6	19212	273	28153474	92,57	50,09	B
2410502	4715	4	18860	274	28172334	92,63	50,28	B
4410502	4715	4	18860	275	28191194	92,69	50,46	B
15026	4686	4	18744	276	28209938	92,75	50,64	B
9070901	9357	2	18714	277	28228652	92,81	50,83	B
9071141	6182	3	18546	278	28247198	92,87	51,01	B
9071142	6182	3	18546	279	28265744	92,93	51,19	B
9030400	6147	3	18441	280	28284185	92,99	51,38	B
1210300H	2043	9	18387	281	28302572	93,06	51,56	B
2050800	4564	4	18256	282	28320828	93,12	51,74	B
597	2282	8	18256	283	28339084	93,18	51,93	B
11822	3644	5	18220	284	28357304	93,24	52,11	B
4210200	1655	11	18205	285	28375509	93,30	52,29	B
7490020H	1063	17	18071	286	28393580	93,35	52,48	B
4070901	8943	2	17886	287	28411466	93,41	52,66	B
5210800	2531	7	17717	288	28429183	93,47	52,84	B
4410401	4415	4	17660	289	28446843	93,53	53,03	B
4410402	4415	4	17660	290	28464503	93,59	53,21	B
3210600	1925	9	17325	291	28481828	93,64	53,39	B
17312	5630	3	16890	292	28498718	93,70	53,58	B
553	4209	4	16836	293	28515554	93,76	53,76	B
554	4209	4	16836	294	28532390	93,81	53,94	B
1030600	5602	3	16806	295	28549196	93,87	54,13	B
3050600	4099	4	16396	296	28565592	93,92	54,31	B
1210500H	2335	7	16345	297	28581937	93,97	54,50	B
129-60	1129	14	15806	298	28597743	94,03	54,68	B
1080901	7769	2	15538	299	28613281	94,08	54,86	B
1080902	7769	2	15538	300	28628819	94,13	55,05	B
1050400	3877	4	15508	301	28644327	94,18	55,23	B

1430601H	7685	2	15370	302	28659697	94,23	55,41	B
1430602H	7685	2	15370	303	28675067	94,28	55,60	B
9081142	5075	3	15225	304	28690292	94,33	55,78	B
5410602	5015	3	15045	305	28705337	94,38	55,96	B
144	7480	2	14960	306	28720297	94,43	56,15	B
11801	2975	5	14875	307	28735172	94,48	56,33	B
1210500	1857	8	14856	308	28750028	94,53	56,51	B
5010800	2900	5	14500	309	28764528	94,57	56,70	B
4211000H	3439	4	13756	310	28778284	94,62	56,88	B
5020501	2271	6	13626	311	28791910	94,66	57,06	B
5211000	2702	5	13510	312	28805420	94,71	57,25	B
4230603	1925	7	13475	313	28818895	94,75	57,43	B
730	1033	13	13429	314	28832324	94,80	57,61	B
9010800	3314	4	13256	315	28845580	94,84	57,80	B
9230603H	2644	5	13220	316	28858800	94,88	57,98	B
561	3278	4	13112	317	28871912	94,93	58,17	B
4210400H	2156	6	12936	318	28884848	94,97	58,35	B
1430601	6456	2	12912	319	28897760	95,01	58,53	C
2430601	6456	2	12912	320	28910672	95,05	58,72	C
4430601	6456	2	12912	321	28923584	95,10	58,90	C
15148	6451	2	12902	322	28936486	95,14	59,08	C
1142	1838	7	12866	323	28949352	95,18	59,27	C
9230604	2132	6	12792	324	28962144	95,22	59,45	C
4020301	2121	6	12726	325	28974870	95,27	59,63	C
181	1219	10	12190	326	28987060	95,31	59,82	C
5210600H	2437	5	12185	327	28999245	95,35	60,00	C
3050500	3987	3	11961	328	29011206	95,39	60,18	C
5050500	3987	3	11961	329	29023167	95,42	60,37	C
2071142	5975	2	11950	330	29035117	95,46	60,55	C
4090405	3980	3	11940	331	29047057	95,50	60,73	C
2210400	1700	7	11900	332	29058957	95,54	60,92	C
13101	2924	4	11696	333	29070653	95,58	61,10	C
9020301	2328	5	11640	334	29082293	95,62	61,28	C
4210603H	2896	4	11584	335	29093877	95,66	61,47	C
263BJ	5789	2	11578	336	29105455	95,69	61,65	C
15027	2315	5	11575	337	29117030	95,73	61,83	C
1410601H	5752	2	11504	338	29128534	95,77	62,02	C
4410601H	5752	2	11504	339	29140038	95,81	62,20	C
4410602H	5752	2	11504	340	29151542	95,85	62,39	C
1372	5730	2	11460	341	29163002	95,88	62,57	C
1020501	2271	5	11355	342	29174357	95,92	62,75	C
1020502	2271	5	11355	343	29185712	95,96	62,94	C
99224	5674	2	11348	344	29197060	96,00	63,12	C
13136	2784	4	11136	345	29208196	96,03	63,30	C

15103	5563	2	11126	346	29219322	96,07	63,49	C
1237	5516	2	11032	347	29230354	96,11	63,67	C
9210800H	3616	3	10848	348	29241202	96,14	63,85	C
1410502H	5380	2	10760	349	29251962	96,18	64,04	C
5030400	5367	2	10734	350	29262696	96,21	64,22	C
9410601	5348	2	10696	351	29273392	96,25	64,40	C
9410602	5348	2	10696	352	29284088	96,28	64,59	C
4020302	2121	5	10605	353	29294693	96,32	64,77	C
5020401	2121	5	10605	354	29305298	96,35	64,95	C
17205	5264	2	10528	355	29315826	96,39	65,14	C
17505	5264	2	10528	356	29326354	96,42	65,32	C
17108	10466	1	10466	357	29336820	96,46	65,50	C
17208	10466	1	10466	358	29347286	96,49	65,69	C
17308	10466	1	10466	359	29357752	96,52	65,87	C
2230604H	3437	3	10311	360	29368063	96,56	66,06	C
2410602	5015	2	10030	361	29378093	96,59	66,24	C
4420601	5015	2	10030	362	29388123	96,62	66,42	C
5410601	5015	2	10030	363	29398153	96,66	66,61	C
5081141	4868	2	9736	364	29407889	96,69	66,79	C
5081142	4868	2	9736	365	29417625	96,72	66,97	C
7500052	1380	7	9660	366	29427285	96,75	67,16	C
2210800H	3202	3	9606	367	29436891	96,78	67,34	C
4240500	2372	4	9488	368	29446379	96,82	67,52	C
4040601	3155	3	9465	369	29455844	96,85	67,71	C
9210400H	2363	4	9452	370	29465296	96,88	67,89	C
1410502	4715	2	9430	371	29474726	96,91	68,07	C
9070902	9357	1	9357	372	29484083	96,94	68,26	C
9020401	2328	4	9312	373	29493395	96,97	68,44	C
9020402	2328	4	9312	374	29502707	97,00	68,62	C
9210604H	3103	3	9309	375	29512016	97,03	68,81	C
729	835	11	9185	376	29521201	97,06	68,99	C
2040502	3047	3	9141	377	29530342	97,09	69,17	C
5050800	4564	2	9128	378	29539470	97,12	69,36	C
5020502	2271	4	9084	379	29548554	97,15	69,54	C
15024	3013	3	9039	380	29557593	97,18	69,72	C
329-60	1129	8	9032	381	29566625	97,21	69,91	C
4070902	8943	1	8943	382	29575568	97,24	70,09	C
5080901	8943	1	8943	383	29584511	97,27	70,28	C
1410402	4415	2	8830	384	29593341	97,30	70,46	C
9050400	4345	2	8690	385	29602031	97,33	70,64	C
4210604H	2896	3	8688	386	29610719	97,36	70,83	C
2210400H	2156	4	8624	387	29619343	97,38	71,01	C
15615	1431	6	8586	388	29627929	97,41	71,19	C
12311	1216	7	8512	389	29636441	97,44	71,38	C

1020401	2121	4	8484	390	29644925	97,47	71,56	C
5020402	2121	4	8484	391	29653409	97,50	71,74	C
13152	8174	1	8174	392	29661583	97,52	71,93	C
12302	1360	6	8160	393	29669743	97,55	72,11	C
4211000	2702	3	8106	394	29677849	97,58	72,29	C
2220600H	4048	2	8096	395	29685945	97,60	72,48	C
4220600H	4048	2	8096	396	29694041	97,63	72,66	C
251	4045	2	8090	397	29702131	97,66	72,84	C
252	4045	2	8090	398	29710221	97,68	73,03	C
15146	4042	2	8084	399	29718305	97,71	73,21	C
17118	7833	1	7833	400	29726138	97,74	73,39	C
2080902	7769	1	7769	401	29733907	97,76	73,58	C
3080902	7769	1	7769	402	29741676	97,79	73,76	C
12312	1553	5	7765	403	29749441	97,81	73,94	C
1230604	1925	4	7700	404	29757141	97,84	74,13	C
4230602	1925	4	7700	405	29764841	97,86	74,31	C
728BJ	1539	5	7695	406	29772536	97,89	74,50	C
2430601H	7685	1	7685	407	29780221	97,91	74,68	C
3430601H	7685	1	7685	408	29787906	97,94	74,86	C
4430601H	7685	1	7685	409	29795591	97,96	75,05	C
4430602H	7685	1	7685	410	29803276	97,99	75,23	C
9210400	1907	4	7628	411	29810904	98,01	75,41	C
5210500	1857	4	7428	412	29818332	98,04	75,60	C
232BJ	3691	2	7382	413	29825714	98,06	75,78	C
284TR	3660	2	7320	414	29833034	98,09	75,96	C
3230603H	2437	3	7311	415	29840345	98,11	76,15	C
4230603H	2437	3	7311	416	29847656	98,14	76,33	C
15825	7254	1	7254	417	29854910	98,16	76,51	C
596	1794	4	7176	418	29862086	98,18	76,70	C
2210604	2342	3	7026	419	29869112	98,21	76,88	C
4615	3511	2	7022	420	29876134	98,23	77,06	C
1211000H	3439	2	6878	421	29883012	98,25	77,25	C
2211000H	3439	2	6878	422	29889890	98,27	77,43	C
12102	1360	5	6800	423	29896690	98,30	77,61	C
9220600	3344	2	6688	424	29903378	98,32	77,80	C
17111	6461	1	6461	425	29909839	98,34	77,98	C
1430602	6456	1	6456	426	29916295	98,36	78,17	C
2430602	6456	1	6456	427	29922751	98,38	78,35	C
3430602	6456	1	6456	428	29929207	98,40	78,53	C
3210800H	3202	2	6404	429	29935611	98,42	78,72	C
4210800H	3202	2	6404	430	29942015	98,45	78,90	C
2020202	2121	3	6363	431	29948378	98,47	79,08	C
2020402	2121	3	6363	432	29954741	98,49	79,27	C
3040602	3155	2	6310	433	29961051	98,51	79,45	C

2220600	3137	2	6274	434	29967325	98,53	79,63	C
552	3135	2	6270	435	29973595	98,55	79,82	C
1374	6134	1	6134	436	29979729	98,57	80,00	C
5040501	3047	2	6094	437	29985823	98,59	80,18	C
5040502	3047	2	6094	438	29991917	98,61	80,37	C
2071141	5975	1	5975	439	29997892	98,63	80,55	C
2210603H	2896	2	5792	440	30003684	98,65	80,73	C
264BJ	5789	1	5789	441	30009473	98,67	80,92	C
2230604	1925	3	5775	442	30015248	98,69	81,10	C
15045	2882	2	5764	443	30021012	98,71	81,28	C
1410602H	5752	1	5752	444	30026764	98,72	81,47	C
2410601H	5752	1	5752	445	30032516	98,74	81,65	C
5410601H	5752	1	5752	446	30038268	98,76	81,83	C
5410602H	5752	1	5752	447	30044020	98,78	82,02	C
1362	5730	1	5730	448	30049750	98,80	82,20	C
532	2858	2	5716	449	30055466	98,82	82,39	C
1518	2833	2	5666	450	30061132	98,84	82,57	C
17112	5630	1	5630	451	30066762	98,86	82,75	C
17512	5630	1	5630	452	30072392	98,87	82,94	C
9210300	1862	3	5586	453	30077978	98,89	83,12	C
1236	5516	1	5516	454	30083494	98,91	83,30	C
3060600	2758	2	5516	455	30089010	98,93	83,49	C
5060600	2758	2	5516	456	30094526	98,95	83,67	C
263	5511	1	5511	457	30100037	98,97	83,85	C
264	5511	1	5511	458	30105548	98,98	84,04	C
1030500	5485	1	5485	459	30111033	99,00	84,22	C
3030500	5485	1	5485	460	30116518	99,02	84,40	C
1410501H	5380	1	5380	461	30121898	99,04	84,59	C
9230601H	2644	2	5288	462	30127186	99,05	84,77	C
15561	2621	2	5242	463	30132428	99,07	84,95	C
243BJ	5230	1	5230	464	30137658	99,09	85,14	C
3210800	2531	2	5062	465	30142720	99,11	85,32	C
2410601	5015	1	5015	466	30147735	99,12	85,50	C
3410602	5015	1	5015	467	30152750	99,14	85,69	C
4420602	5015	1	5015	468	30157765	99,15	85,87	C
1410401H	5011	1	5011	469	30162776	99,17	86,06	C
1240600	2441	2	4882	470	30167658	99,19	86,24	C
2240600	2441	2	4882	471	30172540	99,20	86,42	C
1230601H	2437	2	4874	472	30177414	99,22	86,61	C
4230604H	2437	2	4874	473	30182288	99,24	86,79	C
1081142	4868	1	4868	474	30187156	99,25	86,97	C
4081142	4868	1	4868	475	30192024	99,27	87,16	C
1410501	4715	1	4715	476	30196739	99,28	87,34	C
5410502	4715	1	4715	477	30201454	99,30	87,52	C

5420501	4715	1	4715	478	30206169	99,31	87,71	C
4210603	2342	2	4684	479	30210853	99,33	87,89	C
1314	4674	1	4674	480	30215527	99,34	88,07	C
15047	4591	1	4591	481	30220118	99,36	88,26	C
262BJ	4526	1	4526	482	30224644	99,37	88,44	C
1342	4521	1	4521	483	30229165	99,39	88,62	C
9210300h	2250	2	4500	484	30233665	99,40	88,81	C
1418	4450	1	4450	485	30238115	99,42	88,99	C
1410401	4415	1	4415	486	30242530	99,43	89,17	C
4420401	4415	1	4415	487	30246945	99,45	89,36	C
9230603	2132	2	4264	488	30251209	99,46	89,54	C
1020302	2121	2	4242	489	30255451	99,48	89,72	C
1020402	2121	2	4242	490	30259693	99,49	89,91	C
2020401	2121	2	4242	491	30263935	99,50	90,09	C
11871	2105	2	4210	492	30268145	99,52	90,28	C
11872	2105	2	4210	493	30272355	99,53	90,46	C
15023	4140	1	4140	494	30276495	99,55	90,64	C
12332	2066	2	4132	495	30280627	99,56	90,83	C
2210300H	2043	2	4086	496	30284713	99,57	91,01	C
543	4076	1	4076	497	30288789	99,59	91,19	C
544	4076	1	4076	498	30292865	99,60	91,38	C
5220600H	4048	1	4048	499	30296913	99,61	91,56	C
2230603	1925	2	3850	500	30300763	99,63	91,74	C
4230601	1925	2	3850	501	30304613	99,64	91,93	C
4230604	1925	2	3850	502	30308463	99,65	92,11	C
3210500	1857	2	3714	503	30312177	99,66	92,29	C
231BJ	3691	1	3691	504	30315868	99,67	92,48	C
1400	3435	1	3435	505	30319303	99,69	92,66	C
1210300	1655	2	3310	506	30322613	99,70	92,84	C
2210200	1655	2	3310	507	30325923	99,71	93,03	C
9240800	3238	1	3238	508	30329161	99,72	93,21	C
1040601	3155	1	3155	509	30332316	99,73	93,39	C
2040601	3155	1	3155	510	30335471	99,74	93,58	C
9210603H	3103	1	3103	511	30338574	99,75	93,76	C
1210603H	2896	1	2896	512	30341470	99,76	93,94	C
1210604H	2896	1	2896	513	30344366	99,77	94,13	C
5210603H	2896	1	2896	514	30347262	99,78	94,31	C
5210604H	2896	1	2896	515	30350158	99,79	94,50	C
9230604H	2644	1	2644	516	30352802	99,80	94,68	C
15581	2621	1	2621	517	30355423	99,80	94,86	C
15582	2621	1	2621	518	30358044	99,81	95,05	C
929-60	1285	2	2570	519	30360614	99,82	95,23	C
15025	2549	1	2549	520	30363163	99,83	95,41	C
9210603	2549	1	2549	521	30365712	99,84	95,60	C

1230603H	2437	1	2437	522	30368149	99,85	95,78	C
1230604H	2437	1	2437	523	30370586	99,85	95,96	C
2230601H	2437	1	2437	524	30373023	99,86	96,15	C
2230602H	2437	1	2437	525	30375460	99,87	96,33	C
5230604H	2437	1	2437	526	30377897	99,88	96,51	C
1210603	2342	1	2342	527	30380239	99,89	96,70	C
4210604	2342	1	2342	528	30382581	99,89	96,88	C
3210500H	2335	1	2335	529	30384916	99,90	97,06	C
5210500H	2335	1	2335	530	30387251	99,91	97,25	C
1512	2310	1	2310	531	30389561	99,92	97,43	C
3020501	2271	1	2271	532	30391832	99,92	97,61	C
3020502	2271	1	2271	533	30394103	99,93	97,80	C
1210400H	2156	1	2156	534	30396259	99,94	97,98	C
2020301	2121	1	2121	535	30398380	99,95	98,17	C
4020201	2121	1	2121	536	30400501	99,95	98,35	C
2210200H	2043	1	2043	537	30402544	99,96	98,53	C
1230602	1925	1	1925	538	30404469	99,97	98,72	C
3230602	1925	1	1925	539	30406394	99,97	98,90	C
3751	633	3	1899	540	30408293	99,98	99,08	C
12131	1524	1	1524	541	30409817	99,98	99,27	C
728	1466	1	1466	542	30411283	99,99	99,45	C
5500061	1329	1	1329	543	30412612	99,99	99,63	C
3760	1152	1	1152	544	30413764	100,00	99,82	C
12101	1050	1	1050	545	30414814	100,00	100,00	C

8.2 Aggregte Prodution Planning model

8.2.1 No hire/fire strategy

DATA_File:

```
# Data
# Aggregated Production Planning
#

data;
param periods := 12;
set products :=
par11850
par293
par295
par285
par573
par283
par284
par521
par384
par221BJ
par222BJ
par294
par394
par11820
par383
par564
par563
par393
par522
par398
par159
par283TR
par572
par292
par221
par11800
par510
par282
par11870
par11851
par397
par382
;
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par382
;
param demand:
    par11850  par293  par295  par285  par573  par283  par284  par521  par384  par221BJ  par222BJ  par294  par394  par11820  par383  par564  par563  par393  par522  par398  par159  par283TR
1   6         2       15      15      2       11      22      13      17      0         0         23      8       0         13      0       0       5       0       0       2       0
2   5         6       4       5       0       13      32      0       13      0         0         5       8       10        5       0       0       0       0       0       11      0
3   0         0       5       6       0       3       3       5       8       5         0         2       10      0         1       0       0       3       0       0       11      0
4   1         2       1       0       1       2       0       0       15      2         0         1       15      2         0       0       0       0       0       0       13      0
5   1         42      39      77      0       39      12      0       9       0         0         11      9       9         9       0       0       11      0       25      3       0
6   0         25      0       0       44      19      16      48      8       0         32        32      49      10        58      6       0       63      0       26      39      0
7   6         0       0       0       0       0       0       0       6       0         0         0       6       0         44      0       0       22      0       0       6       0
8   9         38      12      10      0       39      4       0       39      0         0         3       24      3         18      0       0       9       1       3       7       0
9   3         73      6       12      32      23      26      0       15      0         0         7       17      1         23      36      36      24      0       5       24      41
10  2         19      22      22      4       17      13      40      2       0         2         22      2       10        4       1       2       0       0       1       4       0
11  36        3       7       7       0       3       0       26      0       33        0         0       0       0         1       4       0       1       19      2       16      0
12  0         63      3       3       3       6       4       1       11      0         0         4       0       0         4       0       0       0       0       0       29      0
;


par572  par292  par221  par11800  par510  par282  par11870  par11851  par397  par382 :=
0       2       2       2         0       1       0         1         0       8
0       3       3       0         0       7       0         2         0       2
0       6       5       6         8       8       0         0         0       5
0       0       5       0         0       0       0         0         0       0
0       4       3       0         0       6       16        2         6       8
9       8       0       19        8       6       0         0         18      8
0       0       0       0         0       0       0         0         8       0
0       4       1       0         0       6       0         1         0       7
22      21      2       0         0       11      0         0         0       11
0       9       0       0         14      8       0         6         0       5
0       1       0       2         0       0       0         2         0       1
0       3       0       0         0       3       0         2         0       2


param days :=
1  20
2  19
3  22
4  22
5  20
6  22
7  22
8  21
9  21
10 21
11 19
12 22;


param production_rate :=
par11850      7
par293        7
par295        7
par285        7
par573        7
par283        7
par284        7
par521        3
par384        7
par221BJ      3
par222BJ      3
par294        7
par394        7
par11820      7
par383        7
par564        6
par563        6
par393        7
par522        6
par398        18
par159        12
par283TR      7
par572        7
par292        8
par221        3
par11800      6
par510        6
par282        8
par11870      9
par11851      6
par397        18
par382        8
;


param salary := 1275; # 170*7.5=1500 (170 NOK each hour)
param hiring_cost := 5304;
param firing_cost := 0;
param carrying_cost :=
par11850       710            #
par293         710
par295         710
par285         710
par573         710
par283         710
par284         710
par521         710
par384         710
par221BJ       710
par222BJ       710
par294         710
par394         710
par11820       710
par383         710
par564         710
par563         710
par393         710
par522         710
par398         710
par159         710
par283TR       710
par572         710
par292         710
par221         710
par11800       710
par510         710
par282         710
par11870       710
par11851       710
par397         710
par382         710
;
```

```
param production_cost :=
par11850            5064      # 48 %
par293              1225
par295              2039
par285              1901
par573              2616
par283              1140
par284              1522
par521              3137
par384              947
par221BJ            4272
par222BJ            4272
par294              1631
par394              853
par11820            3195
par383              709
par564              2159
par563              2159
par393              641
par522              3137
par398              1309
par159              396
par283TR            1316
par572              1744
par292              815
par221              4071
par11800            2671
par510              2292
par282              761
par11870            1797
par11851            2670
par397              1322
par382              473


;


param initial_inventory := 0;
param end_inventory := 0;
param initial_workforce := 3;

param fired_workers := 0;
```

MODEL_File

```
# Model
# Aggregated Production Planning
#

# Parameters
param periods > 0;                                  # Time periods in time horizon
set products;                                       # Number of products
param demand {1..periods, products} >= 0;           # Forecasted number of units demanded for product in periods
param days {1..periods} >= 0;                       # Number of working days in periods
param production_rate {products};                   # Number of product units that can be made by one worker a day.
param salary;                                       # One worker dayly salary
param hiring_cost;                                  # One worker hiring cost
param firing_cost;                                  # One worker firing cost
param carrying_cost {products};                     # Cost of carrying one unit in inventory in one period
param production_cost {products};                   # Production cost of one item of each product
param initial_inventory;                            # Number of units in initial inventory
param end_inventory;                                # Number of units in end inventory
param initial_workforce;                            # Number of workers in initial period
param Salary_costs;                                 # Total salary costs
param Hiring_costs;                                 # Total hiring costs
param Firing_costs;                                 # Total firing costs
param Production_costs{1..periods, products};       # Total production costs
param Carrying_costs{1..periods, products};         # Total holding costs
param fired_workers;                                # Number of workers allowed to fire

# Variables
var Workforce {0..periods} >= 0 integer;            # Number of workers available in periods
var Hired {1..periods} >= 0;                        # Number of workers hired in periods
var Fired {1..periods} >= 0;                        # Number of workers fired in periods
var Inventory {0..periods, products} >= 0 integer;  # Number of held units in inventory in periods
var Production {1..periods, products} >= 0 integer; # Number of units produced in periods


# Model
minimize Total_costs:
sum {t in 1..periods} (salary*days[t]*Workforce[t] + hiring_cost*Hired[t] + firing_cost*Fired[t]
       + sum {p in products} (production_cost[p]*Production[t,p] + carrying_cost[p]*Inventory[t,p]));

subject to Production_capacity {t in 1..periods}:
sum {p in products}((1/production_rate[p])*Production[t,p]) <= days[t]*Workforce[t];

subject to Workforce_capacity {t in 1..periods}:
Workforce[t] = Workforce[t-1] + Hired[t] - Fired[t];

subject to Inventory_balance {t in 1..periods, p in products}:
Inventory[t-1,p] + Production[t,p] = demand[t,p] + Inventory[t,p];

subject to Initial_inventory {p in products}:
Inventory[0,p] = initial_inventory;

subject to Initial_workforce:
Workforce[0] = initial_workforce;

subject to End_inventory {p in products}:
Inventory[6,p] = end_inventory;

subject to Fired_workers {t in 1..periods}:           # Uncomment this copnstraint if you want to hire/fire workers
Fired[t] = fired_workers;
```

RUN-File

```
# Run
# Aggregated Production Planning
#
#option solver "c:\temp\AMPLcml\cplexamp";
option solver cplexamp;
model APPmax.mod;
data APPmax.dat;
option solution_round 9;
solve;
display Total_costs > APPmax.sol;
display Workforce, Hired, Fired > APPmax.sol;
display demand, Production, Inventory > APPmax.sol;
let Salary_costs:= sum {t in 1..periods} salary*days[t]*Workforce[t];
let Hiring_costs:= sum {t in 1..periods} hiring_cost*Hired[t];
let Firing_costs:= sum {t in 1..periods} firing_cost*Fired[t];
let {t in 1..periods, p in products} Production_costs[t,p] := production_cost[p]*Production[t,p];
let {t in 1..periods, p in products} Carrying_costs[t,p] := carrying_cost[p]*Inventory[t,p];
display {t in 1..periods} salary*days[t]*Workforce[t] > APPmax.sol;
display Salary_costs > APPmax.sol;
display Hiring_costs > APPmax.sol;
display Firing_costs > APPmax.sol;
display Carrying_costs > APPmax.sol;
display sum{t in 1..periods, p in products} carrying_cost[p]*Inventory[t,p] > APPmax.sol;
display Production_costs > APPmax.sol;
display sum{t in 1..periods, p in products} production_cost[p]*Production[t,p] > APPmax.sol;
```

SOL-File

```
Total_costs = 5379550

:  Workforce Hired Fired    :=
0       3       .     .
1       3       0     0
2       3       0     0
3       3       0     0
4       3       0     0
5       3       0     0
6       3       0     0
7       3       0     0
8       3       0     0
9       3       0     0
10      3       0     0
11      3       0     0
12      3       0     0
;


salary*days[t]*Workforce[t] [*] :=
 1  76500
 2  72675
 3  84150
 4  84150
 5  76500
 6  84150
 7  84150
 8  80325
 9  80325
10  80325
11  72675
12  84150
;

Salary_costs = 960075

Hiring_costs = 0

Firing_costs = 0
```

Productino plan

Month	Products	Demand	Product	Stock	Month	Products	Demand	Productio	Stock	Month	Products	Demand	Productio	Stock
1	par11800	2	2	0	2	par11800	0	0	0	3	par11800	6	6	0
1	par11820	0	0	0	2	par11820	10	10	0	3	par11820	0	0	0
1	par11850	6	6	0	2	par11850	5	5	0	3	par11850	0	0	0
1	par11851	1	1	0	2	par11851	2	2	0	3	par11851	0	0	0
1	par11870	0	0	0	2	par11870	0	0	0	3	par11870	0	0	0
1	par159	2	2	0	2	par159	11	11	0	3	par159	11	11	0
1	par221	2	2	0	2	par221	3	3	0	3	par221	5	5	0
1	par221BJ	0	0	0	2	par221BJ	0	0	0	3	par221BJ	5	5	0
1	par222BJ	0	0	0	2	par222BJ	0	0	0	3	par222BJ	0	0	0
1	par282	1	1	0	2	par282	7	7	0	3	par282	8	8	0
1	par283	11	11	0	2	par283	13	13	0	3	par283	3	3	0
1	par283TR	0	0	0	2	par283TR	0	0	0	3	par283TR	0	0	0
1	par284	22	22	0	2	par284	32	32	0	3	par284	3	3	0
1	par285	15	15	0	2	par285	5	5	0	3	par285	6	6	0
1	par292	2	2	0	2	par292	3	3	0	3	par292	6	6	0
1	par293	2	2	0	2	par293	6	6	0	3	par293	0	0	0
1	par294	23	23	0	2	par294	5	5	0	3	par294	2	2	0
1	par295	15	15	0	2	par295	4	4	0	3	par295	5	5	0
1	par382	8	8	0	2	par382	2	2	0	3	par382	5	5	0
1	par383	13	13	0	2	par383	5	5	0	3	par383	1	1	0
1	par384	17	17	0	2	par384	13	13	0	3	par384	8	8	0
1	par393	5	5	0	2	par393	0	0	0	3	par393	3	3	0
1	par394	8	8	0	2	par394	8	8	0	3	par394	10	10	0
1	par397	0	0	0	2	par397	0	0	0	3	par397	0	0	0
1	par398	0	0	0	2	par398	0	0	0	3	par398	0	0	0
1	par510	0	0	0	2	par510	0	0	0	3	par510	8	8	0
1	par521	13	13	0	2	par521	0	0	0	3	par521	5	5	0
1	par522	0	0	0	2	par522	0	0	0	3	par522	0	0	0
1	par563	0	0	0	2	par563	0	0	0	3	par563	0	0	0
1	par564	0	0	0	2	par564	0	0	0	3	par564	0	0	0
1	par572	0	0	0	2	par572	0	0	0	3	par572	0	0	0
1	par573	2	2	0	2	par573	0	0	0	3	par573	0	0	0

Month	Products	Demand	Product	Stock	Month	Products	Demand	Productio	Stock	Month	Products	Demand	Productio	Stock
4	par11800	0	0	0	5	par11800	0	0	0	6	par11800	19	19	0
4	par11820	2	2	0	5	par11820	9	9	0	6	par11820	10	10	0
4	par11850	1	1	0	5	par11850	1	1	0	6	par11850	0	0	0
4	par11851	0	0	0	5	par11851	2	2	0	6	par11851	0	0	0
4	par11870	0	0	0	5	par11870	16	16	0	6	par11870	0	0	0
4	par159	13	13	0	5	par159	3	3	0	6	par159	39	39	0
4	par221	5	5	0	5	par221	3	3	0	6	par221	0	0	0
4	par221BJ	2	2	0	5	par221BJ	0	0	0	6	par221BJ	0	0	0
4	par222BJ	0	0	0	5	par222BJ	0	19	19	6	par222BJ	32	13	0
4	par282	0	0	0	5	par282	6	6	0	6	par282	6	6	0
4	par283	2	2	0	5	par283	39	39	0	6	par283	19	19	0
4	par283TR	0	0	0	5	par283TR	0	0	0	6	par283TR	0	0	0
4	par284	0	0	0	5	par284	12	12	0	6	par284	16	16	0
4	par285	0	0	0	5	par285	77	77	0	6	par285	0	0	0
4	par292	0	0	0	5	par292	4	4	0	6	par292	8	8	0
4	par293	2	2	0	5	par293	42	42	0	6	par293	25	25	0
4	par294	1	1	0	5	par294	11	11	0	6	par294	32	32	0
4	par295	1	1	0	5	par295	39	39	0	6	par295	0	0	0
4	par382	0	0	0	5	par382	8	8	0	6	par382	8	8	0
4	par383	0	0	0	5	par383	9	9	0	6	par383	58	58	0
4	par384	15	15	0	5	par384	9	9	0	6	par384	8	8	0
4	par393	0	0	0	5	par393	11	11	0	6	par393	63	63	0
4	par394	15	15	0	5	par394	9	9	0	6	par394	49	49	0
4	par397	0	0	0	5	par397	6	6	0	6	par397	18	18	0
4	par398	0	0	0	5	par398	25	25	0	6	par398	26	26	0
4	par510	0	0	0	5	par510	0	0	0	6	par510	8	8	0
4	par521	0	24	24	5	par521	0	24	48	6	par521	48	0	0
4	par522	0	0	0	5	par522	0	0	0	6	par522	0	0	0
4	par563	0	0	0	5	par563	0	0	0	6	par563	0	0	0
4	par564	0	0	0	5	par564	0	0	0	6	par564	6	6	0
4	par572	0	0	0	5	par572	0	0	0	6	par572	9	9	0
4	par573	1	1	0	5	par573	0	0	0	6	par573	44	44	0

Month	Products	Demand	Product	Stock	Month	Products	Demand	Productio	Stock	Month	Products	Demand	Productio	Stock
7	par11800	0	0	0	8	par11800	0	0	0	9	par11800	0	0	0
7	par11820	0	0	0	8	par11820	3	3	0	9	par11820	1	1	0
7	par11850	6	6	0	8	par11850	9	9	0	9	par11850	3	3	0
7	par11851	0	0	0	8	par11851	1	1	0	9	par11851	0	0	0
7	par11870	0	0	0	8	par11870	0	0	0	9	par11870	0	0	0
7	par159	6	6	0	8	par159	7	7	0	9	par159	24	24	0
7	par221	0	0	0	8	par221	1	3	2	9	par221	2	0	0
7	par221BJ	0	0	0	8	par221BJ	0	0	0	9	par221BJ	0	0	0
7	par222BJ	0	0	0	8	par222BJ	0	0	0	9	par222BJ	0	0	0
7	par282	0	0	0	8	par282	6	6	0	9	par282	11	11	0
7	par283	0	0	0	8	par283	39	39	0	9	par283	23	23	0
7	par283TR	0	0	0	8	par283TR	0	0	0	9	par283TR	41	41	0
7	par284	0	0	0	8	par284	4	4	0	9	par284	26	26	0
7	par285	0	0	0	8	par285	10	10	0	9	par285	12	12	0
7	par292	0	0	0	8	par292	4	4	0	9	par292	21	21	0
7	par293	0	0	0	8	par293	38	38	0	9	par293	73	73	0
7	par294	0	0	0	8	par294	3	3	0	9	par294	7	7	0
7	par295	0	0	0	8	par295	12	12	0	9	par295	6	6	0
7	par382	0	0	0	8	par382	7	7	0	9	par382	11	11	0
7	par383	44	44	0	8	par383	18	18	0	9	par383	23	23	0
7	par384	6	6	0	8	par384	39	39	0	9	par384	15	15	0
7	par393	22	22	0	8	par393	9	9	0	9	par393	24	24	0
7	par394	6	6	0	8	par394	24	24	0	9	par394	17	17	0
7	par397	8	8	0	8	par397	0	0	0	9	par397	0	0	0
7	par398	0	0	0	8	par398	3	3	0	9	par398	5	5	0
7	par510	0	0	0	8	par510	0	0	0	9	par510	0	0	0
7	par521	0	0	0	8	par521	0	0	0	9	par521	0	0	0
7	par522	0	0	0	8	par522	1	1	0	9	par522	0	0	0
7	par563	0	0	0	8	par563	0	0	0	9	par563	36	36	0
7	par564	0	0	0	8	par564	0	19	19	9	par564	36	17	0
7	par572	0	0	0	8	par572	0	0	0	9	par572	22	22	0
7	par573	0	0	0	8	par573	0	0	0	9	par573	32	32	0

Month	Products	Demand	Product	Stock	Month	Products	Demand	Productio	Stock	Month	Products	Demand	Productio	Stock
10	par11800	0	0	0	11	par11800	2	2	0	12	par11800	0	0	0
10	par11820	10	10	0	11	par11820	0	0	0	12	par11820	0	0	0
10	par11850	2	2	0	11	par11850	36	36	0	12	par11850	0	0	0
10	par11851	6	6	0	11	par11851	2	2	0	12	par11851	2	2	0
10	par11870	0	0	0	11	par11870	0	0	0	12	par11870	0	0	0
10	par159	4	4	0	11	par159	16	16	0	12	par159	29	29	0
10	par221	0	0	0	11	par221	0	0	0	12	par221	0	0	0
10	par221BJ	0	0	0	11	par221BJ	33	33	0	12	par221BJ	0	0	0
10	par222BJ	2	2	0	11	par222BJ	0	0	0	12	par222BJ	0	0	0
10	par282	8	8	0	11	par282	0	0	0	12	par282	3	3	0
10	par283	17	17	0	11	par283	3	3	0	12	par283	6	6	0
10	par283TR	0	0	0	11	par283TR	0	0	0	12	par283TR	0	0	0
10	par284	13	13	0	11	par284	0	0	0	12	par284	4	4	0
10	par285	22	22	0	11	par285	7	7	0	12	par285	3	3	0
10	par292	9	9	0	11	par292	1	1	0	12	par292	3	3	0
10	par293	19	19	0	11	par293	3	3	0	12	par293	63	63	0
10	par294	22	22	0	11	par294	0	0	0	12	par294	4	4	0
10	par295	22	22	0	11	par295	7	7	0	12	par295	3	3	0
10	par382	5	5	0	11	par382	1	1	0	12	par382	2	2	0
10	par383	4	4	0	11	par383	1	1	0	12	par383	4	4	0
10	par384	2	2	0	11	par384	0	0	0	12	par384	11	11	0
10	par393	0	0	0	11	par393	1	1	0	12	par393	0	0	0
10	par394	2	2	0	11	par394	0	0	0	12	par394	0	0	0
10	par397	0	0	0	11	par397	0	0	0	12	par397	0	0	0
10	par398	1	1	0	11	par398	2	2	0	12	par398	0	0	0
10	par510	14	14	0	11	par510	0	0	0	12	par510	0	0	0
10	par521	40	40	0	11	par521	26	26	0	12	par521	1	1	0
10	par522	0	0	0	11	par522	19	19	0	12	par522	0	0	0
10	par563	2	2	0	11	par563	0	0	0	12	par563	0	0	0
10	par564	1	1	0	11	par564	4	4	0	12	par564	0	0	0
10	par572	0	0	0	11	par572	0	0	0	12	par572	0	0	0
10	par573	4	4	0	11	par573	0	0	0	12	par573	3	3	0

Inventory cost

:	1	2	3	4	5	6	7	8	9	10	11	12 :=
par11800	0	0	0	0	0	0	0	0	0	0	0	0
par11820	0	0	0	0	0	0	0	0	0	0	0	0
par11850	0	0	0	0	0	0	0	0	0	0	0	0
par11851	0	0	0	0	0	0	0	0	0	0	0	0
par11870	0	0	0	0	0	0	0	0	0	0	0	0
par159	0	0	0	0	0	0	0	0	0	0	0	0
par221	0	0	0	0	0	0	0	1420	0	0	0	0
par221BJ	0	0	0	0	0	0	0	0	0	0	0	0
par222BJ	0	0	0	0	13490	0	0	0	0	0	0	0
par282	0	0	0	0	0	0	0	0	0	0	0	0
par283	0	0	0	0	0	0	0	0	0	0	0	0
par283TR	0	0	0	0	0	0	0	0	0	0	0	0
par284	0	0	0	0	0	0	0	0	0	0	0	0
par285	0	0	0	0	0	0	0	0	0	0	0	0
par292	0	0	0	0	0	0	0	0	0	0	0	0
par293	0	0	0	0	0	0	0	0	0	0	0	0
par294	0	0	0	0	0	0	0	0	0	0	0	0
par295	0	0	0	0	0	0	0	0	0	0	0	0
par382	0	0	0	0	0	0	0	0	0	0	0	0
par383	0	0	0	0	0	0	0	0	0	0	0	0
par384	0	0	0	0	0	0	0	0	0	0	0	0
par393	0	0	0	0	0	0	0	0	0	0	0	0
par394	0	0	0	0	0	0	0	0	0	0	0	0
par397	0	0	0	0	0	0	0	0	0	0	0	0
par398	0	0	0	0	0	0	0	0	0	0	0	0
par510	0	0	0	0	0	0	0	0	0	0	0	0
par521	0	0	0	17040	34080	0	0	0	0	0	0	0
par522	0	0	0	0	0	0	0	0	0	0	0	0
par563	0	0	0	0	0	0	0	0	0	0	0	0
par564	0	0	0	0	0	0	0	13490	0	0	0	0
par572	0	0	0	0	0	0	0	0	0	0	0	0
par573	0	0	0	0	0	0	0	0	0	0	0	0

Production cost

	1	2	3	4	5	6	7	8	9	10	11	12
par11800	5342	0	16026	0	0	50749	0	0	0	0	5342	0
par11820	0	31950	0	6390	28755	31950	0	9585	3195	31950	0	0
par11850	30384	25320	0	5064	5064	0	30384	45576	15192	10128	182304	0
par11851	2670	5340	0	0	5340	0	0	2670	0	16020	5340	5340
par11870	0	0	0	0	28752	0	0	0	0	0	0	0
par159	792	4356	4356	5148	1188	15444	2376	2772	9504	1584	6336	11484
par221	8142	12213	20355	20355	12213	0	0	12213	0	0	0	0
par221BJ	0	0	21360	8544	0	0	0	0	0	0	140976	0
par222BJ	0	0	0	0	81168	55536	0	0	0	8544	0	0
par282	761	5327	6088	0	4566	4566	0	4566	8371	6088	0	2283
par283	12540	14820	3420	2280	44460	21660	0	44460	26220	19380	3420	6840
par283TR	0	0	0	0	0	0	0	0	53956	0	0	0
par284	33484	48704	4566	0	18264	24352	0	6088	39572	19786	0	6088
par285	28515	9505	11406	0	146377	0	0	19010	22812	41822	13307	5703
par292	1630	2445	4890	0	3260	6520	0	3260	17115	7335	815	2445
par293	2450	7350	0	2450	51450	30625	0	46550	89425	23275	3675	77175
par294	37513	8155	3262	1631	17941	52192	0	4893	11417	35882	0	6524
par295	30585	8156	10195	2039	79521	0	0	24468	12234	44858	14273	6117
par382	3784	946	2365	0	3784	3784	0	3311	5203	2365	473	946
par383	9217	3545	709	0	6381	41122	31196	12762	16307	2836	709	2836
par384	16099	12311	7576	14205	8523	7576	5682	36933	14205	1894	0	10417
par393	3205	0	1923	0	7051	40383	14102	5769	15384	0	641	0
par394	6824	6824	8530	12795	7677	41797	5118	20472	14501	1706	0	0
par397	0	0	0	0	7932	23796	10576	0	0	0	0	0
par398	0	0	0	0	32725	34034	0	3927	6545	1309	2618	0
par510	0	0	18336	0	0	18336	0	0	0	32088	0	0
par521	40781	0	15685	75288	75288	0	0	0	0	125480	81562	3137
par522	0	0	0	0	0	0	0	3137	0	0	59603	0
par563	0	0	0	0	0	0	0	0	77724	4318	0	0
par564	0	0	0	0	0	12954	0	41021	36703	2159	8636	0
par572	0	0	0	0	0	15696	0	0	38368	0	0	0
par573	5232	0	0	2616	0	115104	0	0	83712	10464	0	7848

8.2.2 Hybrid strategy

DATA_File

```
# Data
# Aggregated Production Planning
#

data;
param periods := 12;
set products :=
par11850
par293
par295
par285
par573
par283
par284
par521
par384
par221BJ
par222BJ
par294
par394
par11820
par383
par564
par563
par393
par522
par398
par159
par283TR
par572
par292
par221
par11800
par510
par282
par11870
par11851
par397
par382
;
```

```
par382
;
param demand:
    par11850  par293  par295  par285  par573  par283  par284  par521  par384  par221BJ  par222BJ  par294  par394  par11820  par383  par564  par563  par393  par522  par398  par159  par283TR
1   6         2       15      15      2       11      22      13      17      0         0         23      8       0         13      0       0       5       0       0       2       0
2   5         6       4       5       0       13      32      0       13      0         0         5       8       10        5       0       0       0       0       0       11      0
3   0         0       5       6       0       3       3       5       8       5         0         2       10      0         1       0       0       3       0       0       11      0
4   1         2       1       0       1       2       0       0       15      2         0         1       15      2         0       0       0       0       0       0       13      0
5   1         42      39      77      0       39      12      0       9       0         0         11      9       9         9       0       0       11      0       25      3       0
6   0         25      0       0       44      19      16      48      8       0         32        32      49      10        58      6       0       63      0       26      39      0
7   6         0       0       0       0       0       0       0       6       0         0         0       6       0         44      0       0       22      0       0       6       0
8   9         38      12      10      0       39      4       0       39      0         0         3       24      3         18      0       0       9       1       3       7       0
9   3         73      6       12      32      23      26      0       15      0         0         7       17      1         23      36      36      24      0       5       24      41
10  2         19      22      22      4       17      13      40      2       0         2         22      2       10        4       1       2       0       0       1       4       0
11  36        3       7       7       0       3       0       26      0       33        0         0       0       0         1       4       0       1       19      2       16      0
12  0         63      3       3       3       6       4       1       11      0         0         4       0       0         4       0       0       0       0       0       29      0
;
```

```
par572  par292  par221  par11800  par510  par282  par11870  par11851  par397  par382 :=
0       2       2       2         0       1       0         1         0       8
0       3       3       0         0       7       0         2         0       2
0       6       5       6         8       8       0         0         0       5
0       0       5       0         0       0       0         0         0       0
0       4       3       0         0       6       16        2         6       8
9       8       0       19        8       6       0         0         18      8
0       0       0       0         0       0       0         0         8       0
0       4       1       0         0       6       0         1         0       7
22      21      2       0         0       11      0         0         0       11
0       9       0       0         14      8       0         6         0       5
0       1       0       2         0       0       0         2         0       1
0       3       0       0         0       3       0         2         0       2
```

```
param days :=
1  20
2  19
3  22
4  22
5  20
6  22
7  22
8  21
9  21
10 21
11 19
12 22;
```

```
param production_rate :=
par11850     7
par293       7
par295       7
par285       7
par573       7
par283       7
par284       7
par521       3
par384       7
par221BJ     3
par222BJ     3
par294       7
par394       7
par11820     7
par383       7
par564       6
par563       6
par393       7
par522       6
par398       18
par159       12
par283TR     7
par572       7
par292       8
par221       3
par11800     6
par510       6
par282       8
par11870     9
par11851     6
par397       18
par382       8
;
```

```
param salary := 1275; # 170*7.5=1500 (170 NOK each hour)
param hiring_cost := 5304;
param firing_cost := 0;
param carrying_cost :=
par11850        710            #
par293          710
par295          710
par285          710
par573          710
par283          710
par284          710
par521          710
par384          710
par221BJ        710
par222BJ        710
par294          710
par394          710
par11820        710
par383          710
par564          710
par563          710
par393          710
par522          710
par398          710
par159          710
par283TR        710
par572          710
par292          710
par221          710
par11800        710
par510          710
par282          710
par11870        710
par11851        710
par397          710
par382          710
;


param production_cost :=
par11850           5064      # 48 %
par293             1225
par295             2039
par285             1901
par573             2616
par283             1140
par284             1522
par521             3137
par384             947
par221BJ           4272
par222BJ           4272
par294             1631
par394             853
par11820           3195
par383             709
par564             2159
par563             2159
par393             641
par522             3137
par398             1309
par159             396
par283TR           1316
par572             1744
par292             815
par221             4071
par11800           2671
par510             2292
par282             761
par11870           1797
par11851           2670
par397             1322
par382             473


;


param initial_inventory := 0;
param end_inventory := 0;
param initial_workforce := 3;

param fired_workers := 0;
```

MODEL_FILE

```
# Model
# Aggregated Production Planning
#

# Parameters
param periods > 0;                                    # Time periods in time horizon
set products;                                         # Number of products
param demand {1..periods, products} >= 0;             # Forecasted number of units demanded for product in periods
param days {1..periods} >= 0;                         # Number of working days in periods
param production_rate {products};                     # Number of product units that can be made by one worker a day.
param salary;                                         # One worker dayly salary
param hiring_cost;                                    # One worker hiring cost
param firing_cost;                                    # One worker firing cost
param carrying_cost {products};                       # Cost of carrying one unit in inventory in one period
param production_cost {products};                     # Production cost of one item of each product
param initial_inventory;                              # Number of units in initial inventory
param end_inventory;                                  # Number of units in end inventory
param initial_workforce;                              # Number of workers in initial period
param Salary_costs;                                   # Total salary costs
param Hiring_costs;                                   # Total hiring costs
param Firing_costs;                                   # Total firing costs
param Production_costs{1..periods, products};         # Total production costs
param Carrying_costs{1..periods, products};           # Total holding costs
param fired_workers;                                  # Number of workers allowed to fire

# Variables
var Workforce {0..periods} >= 0 integer;              # Number of workers available in periods
var Hired {1..periods} >= 0;                          # Number of workers hired in periods
var Fired {1..periods} >= 0;                          # Number of workers fired in periods
var Inventory {0..periods, products} >= 0 integer;    # Number of held units in inventory in periods
var Production {1..periods, products} >= 0 integer;   # Number of units produced in periods
```

```
# Model
minimize Total_costs:
sum {t in 1..periods} (salary*days[t]*Workforce[t] + hiring_cost*Hired[t] + firing_cost*Fired[t]
        + sum {p in products} (production_cost[p]*Production[t,p] + carrying_cost[p]*Inventory[t,p]));

subject to Production_capacity {t in 1..periods}:
sum {p in products}((1/production_rate[p])*Production[t,p]) <= days[t]*Workforce[t];

subject to Workforce_capacity {t in 1..periods}:
Workforce[t] = Workforce[t-1] + Hired[t] - Fired[t];

subject to Inventory_balance {t in 1..periods, p in products}:
Inventory[t-1,p] + Production[t,p] = demand[t,p] + Inventory[t,p];

subject to Initial_inventory {p in products}:
Inventory[0,p] = initial_inventory;

subject to Initial_workforce:
Workforce[0] = initial_workforce;

subject to End_inventory {p in products}:
Inventory[6,p] = end_inventory;

#### subject to Fired_workers {t in 1..periods}:  ####          # Uncomment this copnstraint if you want to hire/fire workers
#### Fired[t] = fired_workers;                     ####
```

RUN-File

```
# Run
# Aggregated Production Planning
#
#option solver "c:\temp\AMPLcml\cplexamp";
option solver cplexamp;
model APPmax.mod;
data APPmax.dat;
option solution_round 9;
solve;
display Total_costs > APPmax.sol;
display Workforce, Hired, Fired > APPmax.sol;
display demand, Production, Inventory > APPmax.sol;
let Salary_costs:= sum {t in 1..periods} salary*days[t]*Workforce[t];
let Hiring_costs:= sum {t in 1..periods} hiring_cost*Hired[t];
let Firing_costs:= sum {t in 1..periods} firing_cost*Fired[t];
let {t in 1..periods, p in products} Production_costs[t,p] := production_cost[p]*Production[t,p];
let {t in 1..periods, p in products} Carrying_costs[t,p] := carrying_cost[p]*Inventory[t,p];
display {t in 1..periods} salary*days[t]*Workforce[t] > APPmax.sol;
display Salary_costs > APPmax.sol;
display Hiring_costs > APPmax.sol;
display Firing_costs > APPmax.sol;
display Carrying_costs > APPmax.sol;
display sum{t in 1..periods, p in products} carrying_cost[p]*Inventory[t,p] > APPmax.sol;
display Production_costs > APPmax.sol;
display sum{t in 1..periods, p in products} production_cost[p]*Production[t,p] > APPmax.sol;
```

SOL-File

```
Total_costs = 4994090

:  Workforce Hired Fired    :=
0       3      .     .
1       2      0     1
2       1      0     1
3       1      0     0
4       1      0     0
5       3      2     0
6       4      1     0
7       1      0     3
8       2      1     0
9       3      1     0
10      2      0     1
11      2      0     0
12      1      0     1
;


salary*days[t]*Workforce[t] [*] :=
 1    51000
 2    24225
 3    28050
 4    28050
 5    76500
 6   112200
 7    28050
 8    53550
 9    80325
10    53550
11    48450
12    28050
;

Salary_costs = 612000

Hiring_costs = 26520

Firing_costs = 0
```

Production plan

Month	Product	demand	Production	Inventory	Month	Product	demand	Productio	Inventory	Month	Product	demand	Productio	Inventory
1	par11800	2	2	0	2	par11800	0	0	0	3	par11800	6	6	0
1	par11820	0	0	0	2	par11820	10	10	0	3	par11820	0	0	0
1	par11850	6	6	0	2	par11850	5	5	0	3	par11850	0	0	0
1	par11851	1	1	0	2	par11851	2	2	0	3	par11851	0	0	0
1	par11870	0	0	0	2	par11870	0	0	0	3	par11870	0	0	0
1	par159	2	2	0	2	par159	11	11	0	3	par159	11	11	0
1	par221	2	2	0	2	par221	3	3	0	3	par221	5	5	0
1	par221BJ	0	0	0	2	par221BJ	0	0	0	3	par221BJ	5	5	0
1	par222BJ	0	0	0	2	par222BJ	0	0	0	3	par222BJ	0	0	0
1	par282	1	1	0	2	par282	7	7	0	3	par282	8	8	0
1	par283	11	11	0	2	par283	13	13	0	3	par283	3	3	0
1	par283TR	0	0	0	2	par283TR	0	0	0	3	par283TR	0	0	0
1	par284	22	22	0	2	par284	32	32	0	3	par284	3	3	0
1	par285	15	15	0	2	par285	5	5	0	3	par285	6	6	0
1	par292	2	2	0	2	par292	3	3	0	3	par292	6	6	0
1	par293	2	2	0	2	par293	6	6	0	3	par293	0	0	0
1	par294	23	23	0	2	par294	5	5	0	3	par294	2	2	0
1	par295	15	15	0	2	par295	4	4	0	3	par295	5	5	0
1	par382	8	8	0	2	par382	2	2	0	3	par382	5	5	0
1	par383	13	13	0	2	par383	5	5	0	3	par383	1	1	0
1	par384	17	17	0	2	par384	13	13	0	3	par384	8	8	0
1	par393	5	5	0	2	par393	0	0	0	3	par393	3	3	0
1	par394	8	8	0	2	par394	8	8	0	3	par394	10	10	0
1	par397	0	0	0	2	par397	0	0	0	3	par397	0	0	0
1	par398	0	0	0	2	par398	0	0	0	3	par398	0	0	0
1	par510	0	0	0	2	par510	0	0	0	3	par510	8	8	0
1	par521	13	13	0	2	par521	0	0	0	3	par521	5	5	0
1	par522	0	0	0	2	par522	0	0	0	3	par522	0	0	0
1	par563	0	0	0	2	par563	0	0	0	3	par563	0	0	0
1	par564	0	0	0	2	par564	0	0	0	3	par564	0	0	0
1	par572	0	0	0	2	par572	0	0	0	3	par572	0	0	0
1	par573	2	2	0	2	par573	0	0	0	3	par573	0	0	0

Month	Product	demand	Production	Inventory	Month	Product	demand	Productio	Inventory	Month	Product	demand	Productio	Inventory
4	par11800	0	0	0	5	par11800	0	0	0	6	par11800	19	19	0
4	par11820	2	2	0	5	par11820	9	9	0	6	par11820	10	10	0
4	par11850	1	1	0	5	par11850	1	1	0	6	par11850	0	0	0
4	par11851	0	0	0	5	par11851	2	2	0	6	par11851	0	0	0
4	par11870	0	0	0	5	par11870	16	16	0	6	par11870	0	0	0
4	par159	13	13	0	5	par159	3	3	0	6	par159	39	39	0
4	par221	5	5	0	5	par221	3	3	0	6	par221	0	0	0
4	par221BJ	2	2	0	5	par221BJ	0	0	0	6	par221BJ	0	0	0
4	par222BJ	0	0	0	5	par222BJ	0	1	1	6	par222BJ	32	31	0
4	par282	0	0	0	5	par282	6	6	0	6	par282	6	6	0
4	par283	2	2	0	5	par283	39	39	0	6	par283	19	19	0
4	par283TR	0	0	0	5	par283TR	0	0	0	6	par283TR	0	0	0
4	par284	0	0	0	5	par284	12	12	0	6	par284	16	16	0
4	par285	0	0	0	5	par285	77	77	0	6	par285	0	0	0
4	par292	0	0	0	5	par292	4	4	0	6	par292	8	8	0
4	par293	2	2	0	5	par293	42	42	0	6	par293	25	25	0
4	par294	1	1	0	5	par294	11	11	0	6	par294	32	32	0
4	par295	1	1	0	5	par295	39	39	0	6	par295	0	0	0
4	par382	0	0	0	5	par382	8	8	0	6	par382	8	8	0
4	par383	0	0	0	5	par383	9	9	0	6	par383	58	58	0
4	par384	15	15	0	5	par384	9	9	0	6	par384	8	8	0
4	par393	0	0	0	5	par393	11	11	0	6	par393	63	63	0
4	par394	15	15	0	5	par394	9	9	0	6	par394	49	49	0
4	par397	0	0	0	5	par397	6	6	0	6	par397	18	18	0
4	par398	0	0	0	5	par398	25	25	0	6	par398	26	26	0
4	par510	0	0	0	5	par510	0	0	0	6	par510	8	8	0
4	par521	0	0	0	5	par521	0	0	0	6	par521	48	48	0
4	par522	0	0	0	5	par522	0	0	0	6	par522	0	0	0
4	par563	0	0	0	5	par563	0	0	0	6	par563	0	0	0
4	par564	0	0	0	5	par564	0	0	0	6	par564	6	6	0
4	par572	0	0	0	5	par572	0	0	0	6	par572	9	9	0
4	par573	1	1	0	5	par573	0	0	0	6	par573	44	44	0

Month	Product	demand	Production	Inventory	Month	Product	demand	Productio	Inventory	Month	Product	demand	Productio	Inventory
7	par11800	0	0	0	8	par11800	0	0	0	9	par11800	0	0	0
7	par11820	0	0	0	8	par11820	3	3	0	9	par11820	1	1	0
7	par11850	6	6	0	8	par11850	9	10	1	9	par11850	3	2	0
7	par11851	0	0	0	8	par11851	1	1	0	9	par11851	0	0	0
7	par11870	0	0	0	8	par11870	0	0	0	9	par11870	0	0	0
7	par159	6	6	0	8	par159	7	7	0	9	par159	24	24	0
7	par221	0	0	0	8	par221	1	3	2	9	par221	2	0	0
7	par221BJ	0	0	0	8	par221BJ	0	0	0	9	par221BJ	0	0	0
7	par222BJ	0	0	0	8	par222BJ	0	0	0	9	par222BJ	0	0	0
7	par282	0	0	0	8	par282	6	6	0	9	par282	11	11	0
7	par283	0	0	0	8	par283	39	39	0	9	par283	23	23	0
7	par283TR	0	0	0	8	par283TR	0	0	0	9	par283TR	41	41	0
7	par284	0	0	0	8	par284	4	4	0	9	par284	26	26	0
7	par285	0	0	0	8	par285	10	10	0	9	par285	12	12	0
7	par292	0	0	0	8	par292	4	4	0	9	par292	21	21	0
7	par293	0	0	0	8	par293	38	38	0	9	par293	73	73	0
7	par294	0	0	0	8	par294	3	3	0	9	par294	7	7	0
7	par295	0	0	0	8	par295	12	12	0	9	par295	6	6	0
7	par382	0	0	0	8	par382	7	7	0	9	par382	11	11	0
7	par383	44	44	0	8	par383	18	18	0	9	par383	23	23	0
7	par384	6	6	0	8	par384	39	39	0	9	par384	15	15	0
7	par393	22	22	0	8	par393	9	9	0	9	par393	24	24	0
7	par394	6	6	0	8	par394	24	24	0	9	par394	17	17	0
7	par397	8	8	0	8	par397	0	0	0	9	par397	0	0	0
7	par398	0	0	0	8	par398	3	3	0	9	par398	5	5	0
7	par510	0	0	0	8	par510	0	0	0	9	par510	0	0	0
7	par521	0	0	0	8	par521	0	0	0	9	par521	0	0	0
7	par522	0	0	0	8	par522	1	1	0	9	par522	0	0	0
7	par563	0	0	0	8	par563	0	0	0	9	par563	36	36	0
7	par564	0	0	0	8	par564	0	18	18	9	par564	36	18	0
7	par572	0	0	0	8	par572	0	0	0	9	par572	22	22	0
7	par573	0	0	0	8	par573	0	0	0	9	par573	32	32	0

Month	Product	demand	Production	Inventory	Month	Product	demand	Productio	Inventory	Month	Product	demand	Productio	Inventory
10	par11800	0	0	0	11	par11800	2	2	0	12	par11800	0	0	0
10	par11820	10	10	0	11	par11820	0	0	0	12	par11820	0	0	0
10	par11850	2	2	0	11	par11850	36	36	0	12	par11850	0	0	0
10	par11851	6	6	0	11	par11851	2	2	0	12	par11851	2	2	0
10	par11870	0	0	0	11	par11870	0	0	0	12	par11870	0	0	0
10	par159	4	4	0	11	par159	16	16	0	12	par159	29	29	0
10	par221	0	0	0	11	par221	0	0	0	12	par221	0	0	0
10	par221BJ	0	0	0	11	par221BJ	33	33	0	12	par221BJ	0	0	0
10	par222BJ	2	2	0	11	par222BJ	0	0	0	12	par222BJ	0	0	0
10	par282	8	8	0	11	par282	0	0	0	12	par282	3	3	0
10	par283	17	17	0	11	par283	3	3	0	12	par283	6	6	0
10	par283TR	0	0	0	11	par283TR	0	0	0	12	par283TR	0	0	0
10	par284	13	13	0	11	par284	0	0	0	12	par284	4	4	0
10	par285	22	22	0	11	par285	7	7	0	12	par285	3	3	0
10	par292	9	9	0	11	par292	1	1	0	12	par292	3	3	0
10	par293	19	19	0	11	par293	3	3	0	12	par293	63	63	0
10	par294	22	22	0	11	par294	0	0	0	12	par294	4	4	0
10	par295	22	22	0	11	par295	7	7	0	12	par295	3	3	0
10	par382	5	5	0	11	par382	1	1	0	12	par382	2	2	0
10	par383	4	4	0	11	par383	1	1	0	12	par383	4	4	0
10	par384	2	2	0	11	par384	0	0	0	12	par384	11	11	0
10	par393	0	0	0	11	par393	1	1	0	12	par393	0	0	0
10	par394	2	2	0	11	par394	0	0	0	12	par394	0	0	0
10	par397	0	0	0	11	par397	0	0	0	12	par397	0	0	0
10	par398	1	1	0	11	par398	2	2	0	12	par398	0	0	0
10	par510	14	14	0	11	par510	0	0	0	12	par510	0	0	0
10	par521	40	40	0	11	par521	26	26	0	12	par521	1	1	0
10	par522	0	0	0	11	par522	19	19	0	12	par522	0	0	0
10	par563	2	2	0	11	par563	0	0	0	12	par563	0	0	0
10	par564	1	1	0	11	par564	4	4	0	12	par564	0	0	0
10	par572	0	0	0	11	par572	0	0	0	12	par572	0	0	0
10	par573	4	4	0	11	par573	0	0	0	12	par573	3	3	0

Inventory cost

	1	2	3	4	5	6	7	8	9	10	11	12
par11800	0	0	0	0	0	0	0	0	0	0	0	0
par11820	0	0	0	0	0	0	0	0	0	0	0	0
par11850	0	0	0	0	0	0	0	710	0	0	0	0
par11851	0	0	0	0	0	0	0	0	0	0	0	0
par11870	0	0	0	0	0	0	0	0	0	0	0	0
par159	0	0	0	0	0	0	0	0	0	0	0	0
par221	0	0	0	0	0	0	0	1420	0	0	0	0
par221BJ	0	0	0	0	0	0	0	0	0	0	0	0
par222BJ	0	0	0	0	710	0	0	0	0	0	0	0
par282	0	0	0	0	0	0	0	0	0	0	0	0
par283	0	0	0	0	0	0	0	0	0	0	0	0
par283TR	0	0	0	0	0	0	0	0	0	0	0	0
par284	0	0	0	0	0	0	0	0	0	0	0	0
par285	0	0	0	0	0	0	0	0	0	0	0	0
par292	0	0	0	0	0	0	0	0	0	0	0	0
par293	0	0	0	0	0	0	0	0	0	0	0	0
par294	0	0	0	0	0	0	0	0	0	0	0	0
par295	0	0	0	0	0	0	0	0	0	0	0	0
par382	0	0	0	0	0	0	0	0	0	0	0	0
par383	0	0	0	0	0	0	0	0	0	0	0	0
par384	0	0	0	0	0	0	0	0	0	0	0	0
par393	0	0	0	0	0	0	0	0	0	0	0	0
par394	0	0	0	0	0	0	0	0	0	0	0	0
par397	0	0	0	0	0	0	0	0	0	0	0	0
par398	0	0	0	0	0	0	0	0	0	0	0	0
par510	0	0	0	0	0	0	0	0	0	0	0	0
par521	0	0	0	0	0	0	0	0	0	0	0	0
par522	0	0	0	0	0	0	0	0	0	0	0	0
par563	0	0	0	0	0	0	0	0	0	0	0	0
par564	0	0	0	0	0	0	0	12780	0	0	0	0
par572	0	0	0	0	0	0	0	0	0	0	0	0
par573	0	0	0	0	0	0	0	0	0	0	0	0

Production cost

	1	2	3	4	5	6	7	8	9	10	11	12
par11800	5342	0	16026	0	0	50749	0	0	0	0	5342	0
par11820	0	31950	0	6390	28755	31950	0	9585	3195	31950	0	0
par11850	30384	25320	0	5064	5064	0	30384	50640	10128	10128	182304	0
par11851	2670	5340	0	0	5340	0	0	2670	0	16020	5340	5340
par11870	0	0	0	0	28752	0	0	0	0	0	0	0
par159	792	4356	4356	5148	1188	15444	2376	2772	9504	1584	6336	11484
par221	8142	12213	20355	20355	12213	0	0	12213	0	0	0	0
par221BJ	0	0	21360	8544	0	0	0	0	0	0	140976	0
par222BJ	0	0	0	0	4272	132432	0	0	0	8544	0	0
par282	761	5327	6088	0	4566	4566	0	4566	8371	6088	0	2283
par283	12540	14820	3420	2280	44460	21660	0	44460	26220	19380	3420	6840
par283TR	0	0	0	0	0	0	0	0	53956	0	0	0
par284	33484	48704	4566	0	18264	24352	0	6088	39572	19786	0	6088
par285	28515	9505	11406	0	146377	0	0	19010	22812	41822	13307	5703
par292	1630	2445	4890	0	3260	6520	0	3260	17115	7335	815	2445
par293	2450	7350	0	2450	51450	30625	0	46550	89425	23275	3675	77175
par294	37513	8155	3262	1631	17941	52192	0	4893	11417	35882	0	6524
par295	30585	8156	10195	2039	79521	0	0	24468	12234	44858	14273	6117
par382	3784	946	2365	0	3784	3784	0	3311	5203	2365	473	946
par383	9217	3545	709	0	6381	41122	31196	12762	16307	2836	709	2836
par384	16099	12311	7576	14205	8523	7576	5682	36933	14205	1894	0	10417
par393	3205	0	1923	0	7051	40383	14102	5769	15384	0	641	0
par394	6824	6824	8530	12795	7677	41797	5118	20472	14501	1706	0	0
par397	0	0	0	0	7932	23796	10576	0	0	0	0	0
par398	0	0	0	0	32725	34034	0	3927	6545	1309	2618	0
par510	0	0	18336	0	0	18336	0	0	0	32088	0	0
par521	40781	0	15685	0	0	150576	0	0	0	125480	81562	3137
par522	0	0	0	0	0	0	0	3137	0	0	59603	0
par563	0	0	0	0	0	0	0	0	77724	4318	0	0
par564	0	0	0	0	0	12954	0	38862	38862	2159	8636	0
par572	0	0	0	0	0	15696	0	0	38368	0	0	0
par573	5232	0	0	2616	0	115104	0	0	83712	10464	0	7848

8.3 Material requirement Model

MRPII-model

(the red marked are the additionals data that is needed in MRPII)

DATA-File

```
# mrp.dat
# AMPL: Data for mrp

param M := 1000000 ;                              # Large number

param:
PP:                     LT :=                     # Items with Lead Times
# 4 days LT / 5 (average # of days in period (weeks)) = 0.8
par11850                   0.8
par293                     1.4
par295                     1.4
par285                     1.4
par573                     1.8
par283                     1.4
par284                     1.4
par521                     0.8
par384                     1.4
par221BJ                   2
par222BJ                   2
par294                     1.4
par394                     1.4
par11820                   1
par383                     1.4
par564                     2
par563                     2
par393                     1.4
par522                     0.8
par398                     0.6
par159                     1.4
```

```
par283TR                1.8
par572                  1.8
par292                  1.4
par221                  2
par11800                1
par510                  0.8
par282                  1.4
par11870                0.6
par11851                1
par397                  1.4
par382                  1.4
Sider                   0.004444444             # machinetime in min / hours per week * 60 min
Top                     0.004444444
Botn                    0.004444444
Hyller                  0.004074074
Toppplate               0.005703704
SideMidtside            0.006296296
Rygg                    0.004592593
Dorer                   0.007777778
Gror20mm                0.
Opphenglist             0
Korger                  0
;

set TT :=                                # Time Buckets
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
;

param R :                                # Number of i to produce one j
```

	Sider	Topp	Botn	Hyller	Topplat e	SiderMi	Rygg	Dorer	Gror20	Opphen glist	Korger
par 11850	0	1	1	4	0	3	1	10	0	0	0
par 293	0	0	0	0	1	6	1	0	5	0	0
par 295	0	0	0	0	1	4	1	0	5	0	0
par 285	0	0	1	1	1	6	0	0	1	5	0
par 573	0	0	0	9	1	4	0	0	0	0	0
par 283	0	1	1	3	0	4	0	0	3	3	0
par 284	0	0	1	1	0	5	0	0	2	4	0
par 521	0	1	1	1	0	3	1	2	0	0	5
par 384	0	1	1	0	0	6	0	0	1	0	0
par 221BJ	0	1	1	1	0	3	1	2	0	0	5
par 222BJ	0	1	1	1	0	3	1	2	0	0	5
par 294	0	0	0	0	1	3	1	0	5	0	0
par 394	0	0	0	0	1	3	1	0	5	0	0
par 11820	0	1	1	1	0	3	1	4	0	0	0
par 383	0	0	1	1	0	5	0	0	1	0	0
par 564	2	1	1	1	0	0	1	1	0	0	5
par 563	2	1	1	1	0	0	1	1	0	0	5
par 393	0	0	0	0	1	3	1	0	5	0	0
par 522	0	1	1	1	0	3	1	2	0	0	0
par 398	2	0	0	0	0	0	1	0	0	0	0
par 159	0	0	0	0	3	0	0	0	1	3	0
par 283TR	0	0	1	1	0	4	0	0	2	3	0
par 572	0	0	0	6	1	3	0	0	0	0	0
par 292	0	0	0	0	1	6	1	0	5	0	0
par 221	0	1	1	1	1	3	1	2	0	0	5
par 11800	0	1	1	2	0	3	1	2	0	0	0
par 510	0	1	1	1	0	2	1	2	1	0	0
par 282	0	1	1	2	0	2	0	0	2	2	0
par 11870	0	1	1	0	0	3	1	2	0	0	0
par 11851	0	1	1	4	0	2	1	5	0	0	0
par 397	2	0	0	0	0	0	1	0	0	0	0
par 382	0	1	1	0	0	4	0	0	1	0	0

```
param D:                                  # external demand for i in t
            1  2  3  4     5  6  7  8        9  10  11  12     13  14  15  16 :=
par11850    0  0  0  6     0  3  0  2        0  0   0   0      0   0   0   1
par293      0  0  0  2     0  2  4  0        0  0   0   0      2   0   0   0
par295      0  0  2  11    0  0  1  3        2  0   0   3      1   0   0   0
par285      0  0  0  15    0  2  0  3        0  2   1   3      0   0   0   0
par573      0  0  0  2     0  0  0  0        0  0   0   0      1   0   0   1
par283      0  0  0  11    3  5  0  5        1  0   2   0      0   0   2   0
par284      0  0  0  22    8  5  11 8        0  0   0   3      0   0   0   0
par521      0  0  0  13    0  0  0  0        2  1   0   2      10  6   3   5
par384      0  0  3  15    1  5  4  3        1  1   3   3      7   1   4   3
par221BJ    0  0  0  0     0  0  0  0        1  1   2   1      1   0   1   0
par222BJ    0  0  0  0     0  0  0  0        0  0   0   0      0   0   0   0
par294      0  0  2  20    0  5  0  0        0  0   0   2      0   1   0   0
par394      0  0  0  0     2  0  6  0        3  1   3   3      3   2   3   7
par11820    0  0  0  0     3  2  5  0        0  0   0   0      0   0   2   0
par383      0  0  0  13    0  3  2  0        0  0   0   1      0   0   0   0
par564      0  0  0  0     0  0  0  0        0  0   0   0      0   0   0   0
par563      0  0  0  0     0  0  0  0        0  0   0   0      0   0   0   0
par393      0  0  0  5     0  0  0  0        1  0   0   2      0   0   0   0
par522      0  0  0  0     0  0  0  0        0  0   0   0      0   0   0   0
par398      0  0  0  0     0  0  0  0        0  0   0   0      0   0   0   0
par159      0  0  2  0     0  2  5  4        4  1   3   3      4   2   4   3
par283TR    0  0  0  0     0  0  0  0        0  0   0   0      0   0   0   0
par572      0  0  0  0     0  0  0  0        0  0   0   0      0   0   0   0
par292      0  0  0  2     0  0  0  3        0  2   4   0      0   0   0   0
par221      0  0  0  2     0  1  2  0        1  0   1   3      2   1   0   2
par11800    0  0  0  2     0  0  0  0        1  0   5   0      0   0   0   0
par510      0  0  0  0     0  0  0  0        1  3   2   2      0   0   0   0
par282      0  0  0  1     2  1  0  4        3  2   3   0      0   0   0   0
par11870    0  0  0  0     0  0  0  0        0  0   0   0      0   0   0   0
par11851    0  0  0  1     0  0  2  0        0  0   0   0      0   0   0   0
par397      0  0  0  0     0  0  0  0        0  0   0   0      0   0   0   0
par382      0  0  0  8     0  0  0  2        0  3   0   2      0   0   0   0
```

```
Sider         0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
Top           0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
Botn          0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
Hyller        0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
Toppplate     0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
SideMidtside  0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
Rygg          0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
Dorer         0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
Gror20mm      0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
Opphenglist   0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
Korger        0  0  0  0      0  0  0  0       0  0  0  0      0  0  0  0
;

param I :=                                   # Beginning Inventory of SKU i
par11850          0
par293            0
par295            0
par285            0
par573            0
par283            0
par284            0
par521            0
par384            0
par221BJ          0
par222BJ          0
par294            0
par394            0
par11820          0
par383            0
par564            0
par563            0
par393            0
par522            0
par398            0
par159            0
par283TR          0
par572            0
par292            0
par221            0
par11800          0
par510            0
par282            0
par11870          0
par11851          0
par397            0
par382            0

Sider                 50
Top                   50
Botn                  50
Hyller                50
Toppplate             50
SideMidtside          50
Rygg                  50
Dorer                 50
Gror20mm              50
Opphenglist           50
Korger                50
;

param LS :=                                  # Lot Size
par11850        1
par293          1
par295          1
par285          1
par573          1
par283          1
par284          1
par521          1
par384          1
par221BJ        1
par222BJ        1
par294          1
par394          1
par11820        1
par383          1
par564          1
par563          1
par393          1
par522          1
par398          1
par159          1
par283TR        1
par572          1
par292          1
par221          1
par11800        1
par510          1
par282          1
par11870        1
par11851        1
par397          1
par382          1

Sider           50
Top             50
Botn            50
Hyller          50
Toppplate       50
SideMidtside    50
Rygg            50
Dorer           50
Gror20mm        50
Opphenglist     50
Korger          50
;

set KK :=                                    # Resources
M1_Cutting
M2_Glue
M3_Lipping
M4_Drilling
M5_Montage
;
```

```
param U :                                    # fraction of resource k needed by one i
               M1_Cutting   M2_Glue   M3_Lipping   M4_Drilling   M5_Montage :=

par11850       0.00000      0.00000   0.00000      0.00000       0.00519
par293         0.00000      0.00000   0.00000      0.00000       0.00519
par295         0.00000      0.00000   0.00000      0.00000       0.00889
par285         0.00000      0.00000   0.00000      0.00000       0.00889
par573         0.00000      0.00000   0.00000      0.00000       0.00444
par283         0.00000      0.00000   0.00000      0.00000       0.00667
par284         0.00000      0.00000   0.00000      0.00000       0.00741
par521         0.00000      0.00000   0.00000      0.00000       0.00889
par384         0.00000      0.00000   0.00000      0.00000       0.00519
par221BJ       0.00000      0.00000   0.00000      0.00000       0.00889
par222BJ       0.00000      0.00000   0.00000      0.00000       0.00889
par294         0.00000      0.00000   0.00000      0.00000       0.00519
par394         0.00000      0.00000   0.00000      0.00000       0.00519
par11820       0.00000      0.00000   0.00000      0.00000       0.00667
par383         0.00000      0.00000   0.00000      0.00000       0.00519
par564         0.00000      0.00000   0.00000      0.00000       0.00889
par563         0.00000      0.00000   0.00000      0.00000       0.00889
par393         0.00000      0.00000   0.00000      0.00000       0.00519
par522         0.00000      0.00000   0.00000      0.00000       0.00889
par398         0.00000      0.00000   0.00000      0.00000       0.00667
par159         0.00000      0.00000   0.00000      0.00000       0.00370
par283TR       0.00000      0.00000   0.00000      0.00000       0.00667
par572         0.00000      0.00000   0.00000      0.00000       0.00667
par292         0.00000      0.00000   0.00000      0.00000       0.00519
par221         0.00000      0.00000   0.00000      0.00000       0.00889
par11800       0.00000      0.00000   0.00000      0.00000       0.00519
par510         0.00000      0.00000   0.00000      0.00000       0.00889
par282         0.00000      0.00000   0.00000      0.00000       0.00889
par11870       0.00000      0.00000   0.00000      0.00000       0.00519
par11851       0.00000      0.00000   0.00000      0.00000       0.00519
par397         0.00000      0.00000   0.00000      0.00000       0.00519
par382         0.00000      0.00000   0.00000      0.00000       0.00519

Sider          0.00111      0.00111   0.00074      0.00148       0.00000
Top            0.00148      0.00074   0.00111      0.00111       0.00000
Botn           0.00148      0.00074   0.00111      0.00111       0.00000
Hyller         0.00111      0.00074   0.00111      0.00111       0.00000
Toppplate      0.00111      0.00185   0.00111      0.00126       0.00000
SideMidtside   0.00104      0.00126   0.00119      0.00104       0.00000
Rygg           0.00074      0.00000   0.00185      0.00126       0.00000
Dorer          0.00148      0.00148   0.00148      0.00222       0.00000
Gror20mm       0.00000      0.00000   0.00000      0.00000       0.00000
Opphenglist    0.00000      0.00000   0.00000      0.00000       0.00000
Korger         0.00000      0.00000   0.00000      0.00000       0.00000
;
```

MODEL-file

```
# mrp2.mod
# MRPII Model

set PP ordered;                 # Set of SKU Numbers
set TT ordered;                 # Set of Time Buckets

set KK ordered;                 # Set of Recources

param P integer := card(PP);    # Number of SKUs
param T integer := card(TT);    # Number of Time Buckets
param M  >= 0;                  # Large Number

param K integer := card(KK);    # Number of Recources

param I {PP} integer;           # Beginning Inventory
param LT {PP};                  # Lead Time
param R {PP, PP} integer;       # number of SKUs i to make one SKU j
param D {PP, TT} integer;       # Ext. Demand for an item in a period
param LS {PP} integer;          # Lot Size

param U {PP, KK} ;              # frac. of rec. k needed by one SKU i
param S {PP, KK} ;              # # frac. of rec. k used to changeover to SKU i.

var x {PP, TT} >=0 integer;     # number of SKUs to produce
var d {PP, TT} binary;          # production indicator

# ----------------------------------------------------------------

minimize objective:
sum {i in PP, t in TT} (T-ord(t)+1) * x[i,t];

# ----------------------------------------------------------------

subject to MaterialRequirement {i in PP, t in TT}:
(sum {s in TT: ord(s) <= ord(t)-LT[i] } x[i,s]) + I[i]
- sum {s in TT: ord(s)<=ord(t)} (D[i,s] + sum {j in PP} R[i,j]* x[j,s]) >= 0;

subject to Capacity {t in TT, k in KK}:
  sum {i in PP} U[i,k] * x[i,t] <= 1;


subject to LotSize {i in PP, t in TT}:
   x[i,t] - d[i,t]*LS[i] >= 0;

subject to ProductionIndicator {i in PP, t in TT}:
   d[i,t] - x[i,t]/M >=0;
```

RUN-File

```
# mrp2.run
# Batch-file to run mrp2.mod, mrp2.dat and solve
option solver "c:\temp\AMPLcml\cplexamp";
option solver cplexamp;
model mrp2.mod;
data mrp2.dat;
solve;

display x > mrp2.sol;
display d > mrp2.sol;
display {t in TT, k in KK} sum {i in PP} U[i,k] * x[i,t] > mrp2.sol;
```

SOL-File

```
x [*,*]
:              1     2     3     4     5     6    7    8     9    10   11   12   13  14  15  16 :=
par11850       0     0     6     0     3     0    2    0     0     0    0    0    0   0   1   0
par293         0     2     0     2     4     0    0    0     0     0    2    0    0   0   0   0
par295         2    11     0     0     1     3    2    0     0     3    1    0    0   0   0   0
par285         0    15     0     2     0     3    0    2     1     3    0    0    0   0   0   0
par573         0     2     0     0     0     0    0    0     0     0    1    0    0   1   0   0
par283         0    11     3     5     0     5    1    0     2     0    0    0    2   0   0   0
par284         0    22     8     5    11     8    0    0     0     3    0    0    0   0   0   0
par521         0     0    13     0     0     0    0    2     1     0    2   10    6   3   5   0
par384         3    15     1     5     4     3    1    1     3     3    7    1    4   3   0   0
par221BJ       0     0     0     0     0     0    1    1     2     1    1    0    1   0   0   0
par222BJ       0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
par294         2    20     0     5     0     0    0    0     0     2    0    1    0   0   0   0
par394         0     0     2     0     6     0    3    1     3     3    3    2    3   7   0   0
par11820       0     0     0     3     2     5    0    0     0     0    0    0    0   2   0   0
par383         0    13     0     3     2     0    0    0     0     1    0    0    0   0   0   0
par564         0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
par563         0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
par393         0     5     0     0     0     0    1    0     0     2    0    0    0   0   0   0
par522         0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
par398         0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
par159         2     0     0     2     5     4    4    1     3     3    4    2    4   3   0   0
par283TR       0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
par572         0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
par292         0     2     0     0     0     3    0    2     4     0    0    0    0   0   0   0
par221         0     2     0     1     2     0    1    0     1     3    2    1    0   2   0   0
par11800       0     0     2     0     0     0    0    1     0     5    0    0    0   0   0   0
par510         0     0     0     0     0     0    0    1     3     2    2    0    0   0   0   0
par282         0     1     2     1     0     4    3    2     3     0    0    0    0   0   0   0
par11870       0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
par11851       0     0     1     0     0     2    0    0     0     0    0    0    0   0   0   0
par397         0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
par382         0     8     0     0     0     2    0    3     0     2    0    0    0   0   0   0


Sider          0     0     0     0     0     0    0    0     0     0    0    0    0   0   0   0
Top            0    65     0     0     0    51    0    0     0    55    0    0    0   0   0   0
Botn          76     0    50     0    53     0    0   50     0    50    0    0    0   0   0   0
Hyller        55    66    60     0    78     0    0   59     0     0   50    0    0   0   0   0
Toppplate     50     0     0    63     0     0    0   50     0    58    0    0    0   0   0   0
SideMidtside 572   133   143   156   161    50   61   89   128    90   50   60   82   0   0   0
Rygg           0    50     0     0    50     0    0    0    72     0    0    0    0   0   0   0
Dorer          0    63     0    50    56     0    0   50     0     0   74    0    0   0   0   0
Gror20mm       0   305    50    64    88    81   71    0    57    70   61    0   70   0   0   0
Opphenglist    0   154    50    50    57   103    0   50     0    65    0    0    0   9   0   0
Korger         0     0    50     0     0     0    0   55     0     0   50   50   65   0   0   0

;
```

```
d [*,*]
:             1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16 :=
par11850      0   0   1   0   1   0   1   0   0   0   0   0   0   0   1   0
par293        0   1   0   1   1   0   0   0   0   0   1   0   0   0   0   0
par295        1   1   0   0   1   1   1   0   0   1   1   0   0   0   0   0
par285        0   1   0   1   0   1   0   1   1   1   0   0   0   0   0   0
par573        0   1   0   0   0   0   0   0   0   0   1   0   0   1   0   0
par283        0   1   1   1   0   1   1   0   1   0   0   0   1   0   0   0
par284        0   1   1   1   1   1   0   0   0   1   0   0   0   0   0   0
par521        0   0   1   0   0   0   0   1   1   0   1   1   1   1   1   0
par384        1   1   1   1   1   1   1   1   1   1   1   1   1   1   0   0
par221BJ      0   0   0   0   0   0   1   1   1   1   1   0   1   0   0   0
par222BJ      0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
par294        1   1   0   1   0   0   0   0   0   1   0   1   0   0   0   0
par394        0   0   1   0   1   0   1   1   1   1   1   1   1   1   0   0
par11820      0   0   0   1   1   1   0   0   0   0   0   0   0   1   0   0
par383        0   1   0   1   1   0   0   0   0   1   0   0   0   0   0   0
par564        0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
par563        0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
par393        0   1   0   0   0   0   1   0   0   1   0   0   0   0   0   0
par522        0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
par398        0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
par159        1   0   0   1   1   1   1   1   1   1   1   1   1   1   0   0
par283TR      0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
par572        0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
par292        0   1   0   0   0   1   0   1   1   0   0   0   0   0   0   0
par221        0   1   0   1   1   0   1   0   1   1   1   1   0   1   0   0
par11800      0   0   1   0   0   0   0   1   0   1   0   0   0   0   0   0
par510        0   0   0   0   0   0   0   1   1   1   1   0   0   0   0   0
par282        0   1   1   1   0   1   1   1   1   0   0   0   0   0   0   0
par11870      0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
par11851      0   0   1   0   0   1   0   0   0   0   0   0   0   0   0   0
par397        0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
par382        0   1   0   0   0   1   0   1   0   1   0   0   0   0   0   0


 Sider        0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
 Top          0   1   0   0   0   1   0   0   0   1   0   0   0   0   0   0
 Botn         1   0   1   0   1   0   0   1   0   1   0   0   0   0   0   0
 Hyller       1   1   1   0   1   0   0   1   0   0   1   0   0   0   0   0
 Toppplate    1   0   0   1   0   0   0   1   0   1   0   0   0   0   0   0
 SideMidtside 1   1   1   1   1   1   1   1   1   1   1   1   1   0   0   0
 Rygg         0   1   0   0   1   0   0   0   1   0   0   0   0   0   0   0
 Dorer        0   1   0   1   1   0   0   1   0   0   1   0   0   0   0   0
 Gror20mm     0   1   1   1   1   1   1   0   1   1   1   0   1   0   0   0
 Opphenglist  0   1   1   1   1   1   0   1   0   1   0   0   0   0   0   0
 Korger       0   0   1   0   0   0   0   1   0   0   1   1   1   0   0   0
 ;
```

```
sum{i in PP} U[i,k]*x[i,t] [*,*]
:  M1_Cutting   M2_Glue M3_Lipping M4_Drilling M5_Montage    :=
1    0.82391    0.91016   0.88159     0.80329    0.05113
2    0.43802    0.35776   0.48942     0.48659    0.84043
3    0.28932    0.26158   0.29227     0.27082    0.27492
4    0.30617    0.38711   0.32957     0.35262    0.21122
5    0.45234    0.38268   0.51238     0.50017    0.23863
6    0.12748    0.10074   0.11611     0.10861    0.28158
7    0.06344    0.07686   0.07259     0.06344    0.12003
8    0.36155    0.3593    0.3564      0.38755    0.11634
9    0.1864     0.16128   0.28552     0.22384    0.17413
10   0.31338    0.2984    0.28803     0.28323    0.23343
11   0.21702    0.20952   0.22452     0.27178    0.15264
12   0.0624     0.0756    0.0714      0.0624     0.12595
13   0.08528    0.10332   0.09758     0.08528    0.1267
14   0          0         0           0          0.12523
15   0          0         0           0          0.04964
16   0          0         0           0          0
;
```