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Author:	B.J. Vogel

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Supervisor:	Dr. ir. H. Veeke
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Subject: **Planning of production Applied approach for reducing planning nervousness and increasing flexibility**

Several different kinds of Miracoli Dinner kits are produced on Line 4 in Oud-Beijerland. The current method of planning of production is not sufficient in terms of product availability and planning nervousness. A new method of Most-Urgent-First planning is proposed and a simulation is run to measure the performance in order to see if another method of planning is preferable.

Supervisors,

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Preface

Working on this research has thought me many things and provided me with the possibility to bring my knowledge into practice and contribute to a place where real life operations take place. Mars Oud-Beijerland has been a welcoming place and I am grateful to all people working there who all made an effort to make me feel at home. The opportunity to work besides a team with expert knowledge on logistics as well as years of experience at the company has helped me enormously in my understanding of logistics.

My work was performed under the supervision of Florus Plaizier, and when I express my gratitude towards my friends and colleagues at Mars, I cannot help but think that Florus enabled and empowered the people he works with to be as helpful as they were. For this, and for the many times Florus helped me with my research, I want to express my sincere gratitude to him.

At the TU Delft, Hans Veeke has found the energy and enthusiasm to help me with my graduation project as one of his final students. His experience and his ability to remain calm and see the bigger picture have helped me finish the race rather than sprint to premature conclusions, for which I want to thank him.

Finally, professor Negenborn has managed to both set the bar for my research high, as well as help me reach it. This challenging combination has led to the results I present in this research and makes me proud to have studied in Delft.

Delft, July 2019

Abstract

Mars Incorporated is an American multibillion company with a wide variety of products. The most commonly known are the candy Mars and Snickers candy bars from the chocolate segment. Next to Chocolate, there are five other segments, among which is Mars Food. Mars Food has several manufacturing sites throughout the world, and one of them is in Oud-Beijerland in the Netherlands. Here sauces for several brands are produced as well as Dinner Kits. It is the production, and especially the planning of production, of these dinner kits that this research is about.

The Miracoli Dinner Kits are boxes that contain Pasta, sauce, herbs and in some cases cheese. They are designed to be able to cook a complete meal from one box for 2 to five persons. Different pasta's, sizes and sauces lead to a variety of different boxes that are all produced on a single production line in the Oud-Beijerland plant. Changing for producing different items takes between 20 minutes and 3 hours, depending on the changeover. With 120 hours of production per week, it is impossible to satisfy the complete demand of a week, within one week. Too much time would be lost on changeovers, thus production for several weeks is grouped. This has led to a system where the production is not capacity constrained.

The production of these boxes is planned ahead in time and the goal is to ensure clients demand can be met. Currently, this is done by producing to stock in order to find a profitable balance between holding costs and production set-up costs. This has led to varying production frequencies, depending on the item. For each production, a lot size is determined by aggregating the forecast demands up until the next production. This allows the suppliers of raw materials and packaging materials to ensure their components are available when production commences.

It was found that the current method of planning production leads to situations where the stock of items combined with the planned production is not enough to satisfy the demand. This causes a risk of going out of stock. When such a risk occurs the logistics department of Mars Oud-Beijerland goes into crisis mode and prioritizes preventing going out of stock. Changing the planning and adding or removing the production of an item is one way to prevent going out of stock. When such a change is made, the supply of raw-, and packaging materials is strained, the operators in that are at the line of the production facility are confused as their plans need to change, and the expedition out-bound plan needs to be changed. It is therefore that changes in the production planning are undesired. These changes are called planning nervousness.

When changes in the production planning are not possible, or not sufficient, the risk of out-of-stock manifests into an actual out-of-stock situation. This leads to the situation where one or more customers do not get all the items they ordered. The percentage of ordered items that are fulfilled is called the Customer Service Level. Mars Inc. has set the acceptable Customer Service Level for the Oud-Beijerland plant at 98.5%. A percentage that was not met in recent years.

Objective and method

Further analyses of the current method of planning of production has led to the findings that for 2018 23% of all production plannings is changed in the week before the execution. Furthermore, with the lower than acceptable Customer Service Level it was decided that the planning of production is a good candidate for improvement. From literature it was found that decreasing the planning horizon and freezing the planning horizon can reduce nervousness. Furthermore, it was found that the current lot-sizing-technique to determine the size of production is already the method that causes the least nervousness. These facts have led to the believe that another method of planning might be able to reduce nervousness and still

might be able to increase the customer service level. Two implementations of a new planning method were formed and compared with the current method of planning on three indicators in several different scenarios. This is done to find an answer to the question:

How should planning and scheduling of the production of Miracoli Dinnerkits be organized in order to lower nervousness and increase the customer service level?

This research question provides two important performance indicators. Nervousness and Customer Service Level. Nervousness is defined as the difference between expected production, and executed production. Customer Service Level is the percentage of Demand that is available to the customer and Cost is the estimated cost of production and storage of items in order to be able to deliver them on demand.

Performance indicator:	Equation:
NervousnessEquation 6	$\pi_s = 1 - \frac{E\left[\left|\delta(Q_1) - \delta(\hat{Q}_1)\right|\right]}{max_{\mathcal{R},F_D} E\left[\left|\delta(Q_1) - \delta(\hat{Q}_1)\right|\right]}$
Customer Service Level	$\gamma = 1 - \frac{\text{Sum of all negative stocks}}{\text{Sum of all demands}}$
Cost	$C = \sum_t \sum_i H_{i,t} I_{i,t} + \sum_t \sum_i S_{i,t} Y_{i,t}$

Scenarios

The industry of fast-moving consumer goods appears to be moving toward more volatile demand and less accurate forecasts of the demand. Furthermore, the volume of production is unstable as the market for dinner kits is competitive. Lastly, there is the believe that seasonality effects, where demand is perceived to be higher during a specific part of the year, can occur in the food industry. This has led to four parameters of external influence that are varied to see how the different methods perform. The parameters are:

- Average demand
- Standard deviation of demand
- Standard deviation of forecast
- Seasonality of demand

Techniques:

As mentioned, two implementations of a newly formed technique were formed and they are compared against the current method of planning. To describe the new techniques, it helps to describe the current method of planning first. The current method of planning is done in several steps.

Current Method

First, the yearly demand per item is determined. Together with the cost of keeping stock and the cost for each production set-up, the optimal order quantity is determined with the EOQ method.

Secondly, with this optimum order quantity, and the yearly demand, the order frequency is determined. This is the period between productions under constant demand with the optimum production quantity. This period is then rounded to the nearest viable production interval. Viable production intervals are 1.3, 2, 4 and 8, where the interval is the time in weeks between productions. The period of 1.3 means the item is produced in 3 out of 4 weeks. Since all intervals fit into two four-week periods, a fixed production schedule is made for all items, wherein the order of production and the week or weeks of production are determined.

Now that the production interval is known, the demand forecast is used to determine the production quantity. The forecast demands between productions are summed and together with the stock determine the quantity that needs to be produced. Since the production schedule is fixed, this method is called ‘Fixed Schedule’.

Most Urgent First

Instead of predetermining the production moment for each item, the Most Urgent First methods accept that there is a discrepancy between forecast demand and actual demand that can lead to premature running out of stock. The Most Urgent First method focusses on the Items with the lowest estimate for remaining stock coverage period. These items are produced. The quantity of production is then determined by using the ideal order frequency to determine for how many weeks the forecast demand needs to be produced. To find out how many days of stock there are remaining, the demand forecast is used. As mentioned, two implementations of this method were formed.

The first implementation is called ‘Full & Empty weeks’. For this method the planner keeps updating the stock coverage length for all items. After each production run is complete, the next items is produced. When the stock coverage of an item is equal to, or higher than the production frequency, an extra week of forecast demand is added to the production quantity. This is endlessly repeated until the end of the week. With the larger production capacity than demand, this leads to a gradual build-up of stocks, until at the beginning of a week, all items have more than a week of stock as a reserve. At that moment the production is halted for a full week to save the start-up, and shutdown costs. This is where the name, ‘Full & Empty weeks’ comes from. Full weeks to build up stock. And empty weeks to save costs.

Alternatively, the second implementation is called ‘Short weeks’. In this implementation items are produced until the highest priority item has enough stock to cover the period up until the next week. This must lead to weeks where in general there is always time left to spare, as the capacity is higher than needed.

Simulation

To compare the different planning methods a simulation was performed. The methods were programmed to behave as desired. Input data was based on either historic data or the one of the parameters that is varied and the simulations were ran for at least 250 weeks virtual time. The results were saved as comma separated files resembling the production results available as historic data.

To see if the simulation provides viable results, a set of verification tests was performed. It was found that the simulation model provided valid data to compare the various methods of planning.

Using historic information on demand per item and forecast of demands, for each item the average demand, standard deviation and forecast accuracy was determined. Also based on historic data are the change-over times and production rates of each item. Lastly, a starting stock was set.

Results

In the normal situation, with 100% of regular demand, 100% of regular standard deviation of demand, 100% regular forecast standard deviation and no seasonality present, the following results were found.

KPI\Method	'Full & Empty weeks'	'Short weeks'	'Fixed schedule'
Nervousness	66.4%	2.0%	98.4%
Customer Service Level	99.7%	98.9%	90.4%
Cost [$x10^3$]	€ 417	€ 329	€ 257

Conclusion

The goal of this research is to find a method that is both less nervous and provides a higher level of demand satisfaction. In the current situation the 'Short weeks' implementation of the 'Most Urgent First' method is the best solution. It has no 'extra' productions and very little missed production. The 'Full & Empty weeks' implementation has a comparable low number of missed productions, but a significantly higher percentage of extra productions and therefore nervousness. The current method 'Fixed schedule' has almost every week missed productions and therefore significant levels of stress. The percentage of extra production is lower than that of the 'Full & Empty weeks' but still more than the 'Short weeks' method.

The high percentage of missed productions for the current method is related to the performance of delivering what is ordered. The current method of 'Fixed Schedule' planning leads to a high percentage of items that are not available. In the current situation this is overcome with an expensive safety stock model. Both the 'Short weeks' and the 'Full & Empty weeks' methods provide a better coverage of demand. 'Full & Empty weeks' scores a little better than 'Short weeks' but both score significantly better than 'Fixed schedule'.

As described, the high percentage of out of stock situations for the 'Fixed schedule' need to be solved by a significant safety stock. It was not researched how costly the safety stock would be but it is estimated that this brings the total cost for fulfillment for this method up significantly and perhaps even so that the method becomes competitive in terms of costs with either 'Short weeks' or even with the more costly 'Full & Empty weeks' methods.

Contents

1 Background of Mars

1.1 History

1.1.1 Mars Inc.

Frank C. Mars and his wife Ethel V. Mars started the Mar-O-Bar Co. in 1920 in Minneapolis, Minnesota. They made chocolate candy bars and introduced the Milky Way bar in 1923, which was an idea of his son, Forrest Mars, Sr. Forrest inherited the company in 1934, merged it with his own British Mars Food UK Limited and expanded the company. The Mars bar and M&M's were added to the portfolio and the company diversified by launching Uncle Ben's Rice and Pedigree dog food. Over time, ownership and leadership further transitioned to descendants of the company's founders. In 2008 the Wrigley Company was bought and the chewing gum company was added to the portfolio.

1.1.2 Mars Oud-Beijerland

Mars Oud-Beijerland was acquired by Mars Inc. in 1980. Before that it was a company owned by descendants of Koenraad Visser. Koenraad started in Oud-Beijerland in 1892 with selling fresh fish and smoked eel. In 1942, together with his suns, he started smoking salmon with his company Koen Visser VOF. In 1965 ready-to-make canned food was made and exported to 53 countries. In 1975 the brand Suzi Wan was introduced to sell oriental sauces. In 1982, two years after the takeover by Mars Inc, the packaging changed to glass pots instead of cans. In 1995 a new production facility was opened on a new location in Oud-Beijerland, the factory that is still used today, and where in 2012 a fourth production line was installed for the Miracoli Dinner kits.

1.2 Structure of the company

Mars has a broad portfolio of brands, categorized in 6 segments. The six segments are Chocolate, Wrigley, Drinks, Symbioscience, Food and Petcare. These brands generate a revenue of $ 35 billion and are sold in 78 countries worldwide. In Figure 1 the split of revenue per division is made visible. The company has over 100.000 associates who work on 421 sites around the world. In Figure 2 all brands that fall under Mars Inc. are represented next to their segment.

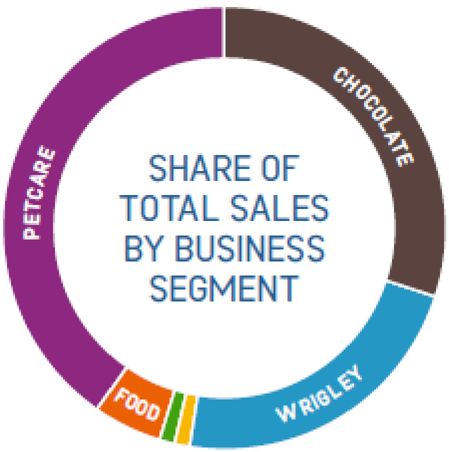

Figure 1 Total sales split by segment

Figure 2 Overview of brands within the six departments of Mars Incorporated

In the Netherlands there are two production sites. One for Mars Chocolate in Veghel, where candy bars are made and one for Mars Food in Oud-Beijerland where sauce is made for the brands Dolmio, Uncle Ben’s, Suzi Wan, Seeds of Change, Miracoli and MasterFoods. The majority of products made in Oud-Beijerland are shipped abroad. The market for Dutch products is relatively small.

The site in Oud-Beijerland is the focus of this research, therefore the following Table 1 has been formed with additional information on the OBL site.

Table 1 Key figures of the OBL site

Key figures on Mars OBL	Value
Annual production:	92 kilo tonnes
Employees:	250 persons
Nr. of products:	498 items
Nr. of containers:	14 sizes
Nr. of recipes:	110 recipes
Nr. of raw materials:	195 raw items

Nr. of packaging materials:	615 packaging materials
Nr. of destinations:	13 warehouses

1.3 Company philosophy

Knowing that we can always do a better job encourages us to challenge the status quo, and to believe that if we don't quite climb the mountain today, we will surely reach the top tomorrow.

Forrest Mars, Sr has implemented the five principles within Mars Inc. They are leading in the decision-making process. These principles provide moral guidelines and are strongly present throughout the company, in spirit and in writing. The five principles are:

Quality, Responsibility, Mutuality, Efficiency and Freedom. These will be briefly explained in the following sections:

1.3.1 Quality

"The consumer is our boss, quality is our work and value for money is our goal." Mars has grown to a multimillion company because of a large number of very small purchases of Mars products. It is believed that these purchases, of which many are repeating purchases, come from the quality of the products of Mars. Part of the quality of Mars products is the value for money they offer while another quality of the products is their availability. This motivates the drive to have a high customer support level as well as keeping the costs low.

1.3.2 Responsibility

"As individuals, we demand total responsibility from ourselves; as associates, we support the responsibilities of others." Mars invests in its employees in order to let them grow and strive for their full potential. In return it asks them to take responsibility for their work and their actions. As part of this principle each associate is responsible for an environment in which others thrive. This holds not only for Mars and its associates but also for the outside. It is seen as the company's responsibility to have associates who are honest and who have integrity. Part of this integrity is that when Mars accepts an order and promises to deliver it should follow up on that promise.

1.3.3 Mutuality

"A mutual benefit is a shared benefit; a shared benefit will endure" It is believed that by ensuring both parties of an agreement actually benefit from the agreement, this strengthens the relationship between parties. This limits the incentive for short term profit but ensures long term durable growth. It is also the key principle driving the corporate responsibility of Mars of returning a fair benefit to local communities and to respect the environment. Furthermore it underlines the importance of returning profit to investors. Within the planning and scheduling, requiring more flexibility from employees and suppliers can mean handing off responsibility as a sign of mutuality.

1.3.4. Efficiency

"We use resources to the full, waste nothing and do only what we can do best." This principle of mars defines efficiency as: 'the ability to organize all our assets – physical, financial and human – for maximum productivity.' This means the Return On Total Assets (ROTA) is a driving measurement of performance in making decisions. It ensures focus on the core business of Mars. Furthermore, waste and environmental impact are to be minimized. By

increasing flexibility in production, this opens the possibility to produce with resources that risk exceeding their allowable shelf-life.

1.3.5 Freedom

"We need freedom to shape our future; we need profit to remain free." The financial independence of a privately-owned corporation is valued highly. It gives the freedom to unilateral make decisions on risk, investments, and acquisitions. This freedom exists as long as it is profitable and should not be taken lightly. Opportunities that come from this freedom include the possibility to make long-term investments and to ensure the well-being of its associates. Fundamentally, making the planning and scheduling more flexible, thus less restricted, can be seen as giving the organization more freedom.

2. Introduction

In this chapter the scope and boundaries of the research are defined in the first section.

2.1 Scope and system boundaries

2.1.1 Planning and scheduling

The terms planning and scheduling are used throughout this report and to prevent confusion they are defined here. Planning is the operation to determine when what should be produced. Currently the planning is made on a week basis. That is to say, a product that needs to be produced in the future, might be planned to be produced in a certain week, but it is never specified at what day that might be.

Scheduling is the determination of the production order, and it attributes the production times and changeover times. In a schedule all productions of a line are defined in a production order and production size. Between productions there is a time reserved for changeover of materials and equipment for the new product. As the order of production is determined, all specific change-overs can be estimated based on the complexity of the change-over. With knowledge on the start-up and shut-down of the production line it is now possible to make a Gant-chart of production where it is possible to be specific up until the minute for each start and stop of production. This schedule encompasses one week of production.

Every week a schedule for the next week is made. In that next week the items are produced that need to be delivered to customers in the week after that. In other words, every Tuesday a schedule is formed to fulfill the demand for two weeks later. Since the lead time for raw materials and packaging materials can be longer than two weeks, forecast data is used to order materials in advance, based on planned production further ahead.

2.1.2 Line 4 dinner kits:

Out of the four production lines at Mars Oud-Beijerland, this research focusses on the logistics around line 4. On that line Miracoli dinner kits are made. Because of the different container of products for this line there is no transfer of production between other lines and line 4. Furthermore, there are ten items produced on line 4 so the required number of raw-, and packaging materials is limited. However, there are shared resources for different products produced on the line and the forecast and actual demand are presented similarly as with other production lines.

2.1.3 Materials

For production on Line 4, a limited number of raw materials is needed. In general, these materials can be grouped in the following way:

Raw materials

Tomatoes, frozen vegetables and onions are used for the production of the sauce of the dinner kits.

Pasta

All dinner kits contain a type of pasta. The amount and type of pasta is dependent on the specific kit.

Herbs and spices

To produce a sauce spices and herbs are added as well as sugar and salt.

Packaging

Every product needs to be packaged. There are pouches for the sauce, plastic bags for the pasta, boxes to contain it all, and cases to hold multiple boxes in order to be shipped to customers.

2.1.4 Demand

Mars has the goal to fulfill at least 98.5% of the demands from the clients. Clients place orders at Mars for delivery of a specified amount of products in a certain week. When possible, clients communicate their expected orders in advance. Especially when there are promotional campaigns for certain products, and the orders will be significantly higher in certain weeks, it is of great importance for Mars to know in advance that there is an increased demand. This way Mars can anticipate on this disturbance in regular demand. Furthermore, the forecast data is never perfect. The actual demand can and does alter from the demand that was forecast earlier for that week. The research in this report is limited and does not go into the possibility of improving the forecast. It is seen as a given that the forecast is not perfect and Mars needs to be able to handle this. Normally, a fluctuating demand can be mitigated by the safety stock. This is the stock that is kept on top of stock that is expected to be used between productions. The size of the safety stock is determined by the SMI model of Mars. This model determines the size of the safety stock based on production frequency and demand and their variability. The size of this stock is seen as a given size and altering the size is seen as out of the scope of this research.

2.2 Problem description

2.2.1 Current situation: Disturbances occur and need to be solved by planning and logistics

When the mismatch between forecast and actual demand is given, and the fact that safety stock is at times not enough to prevent out-of-stock situations, the remaining solution to prevent running out of stock is to alter production. Currently, altering production is done ad-hoc and without much structure. This leads to stress in the organization because actors on multiple levels are presented with changing requirements of production planning. Despite the efforts to handle disturbances and the use of safety stock, the Customer Service Level for 2018 was 98.4%.

2.2.2 Flexibility

In this research the capability of handling disruptions is called ‘flexibility’. In the Oxford dictionary it is defined as: (Definition of flexibility in English by Oxford Dictionaries, 2019)

1. ‘The quality of bending easily without breaking.’
2. ‘The ability to be easily modified.’
3. ‘Willingness to change or compromise.’

Within planning and scheduling, flexibility is considered the ability to be easily modified, while in the organization flexibility is the willingness to change or compromise. That is because for planning and scheduling there are hard constraints that are either met or not but cannot be compromised. For the organization however, flexibility might be required when a production schedule changes and the work people have to perform becomes different from what they expected.

2.2.3 Nervousness

In contrast to flexibility there is stability, or robustness. Flexible schedules make changes easy and thus allow to react on changing circumstances. However, when the planning or schedule is actually changed this demands that actors that rely on the planning or schedule, handle the change. In their eyes this is a disruption. How well this is perceived is depending on how flexible the subsequent parties are, but in general changes are not desirable. The more changes occur, the more disruptions are encountered. This effect is called ‘Nervousness’, while the ability to handle changing circumstances without changing the schedule is called robustness of the schedule.

“Nervousness is defined as frequent changes in both the timing and quantity of orders.” (Sridharan & Lawrence LaForge, 1989). They state, based on Hayes and Clark 1985, that these changes lead to confusion, and with that, reduced productivity at the shop floor.

Demirel Et al. (Demirel, Özelkan, & Lim, 2018) come to a similar observation and attribute the nervousness to uncertainty in the demand forecast. Furthermore, they note the following effects resulting from anxiety/nervousness in the production environment: adverse effect on labor and inventory levels, *“increases in production and inventory/shortage costs, reduced productivity, lower customer service levels, and a general state of confusion on the shop floor.”*

Carlson et al., (Carlson, Jucker, & Kropp, 1979) make the bold statement that *“Many managers would rather live with nonoptimal but stable plans [than change their previous planning]”* and they argue that it is not reasonable to avoid nervousness at all costs. They propose quantifying the costs of changing a planning based on how far in the future the change takes place.

The schedule for Line 4 at Mars Oud-Beijerland was changed 23% of the times in 2018. This was measured by comparing the planned production schedule for 1 week ahead with the actual production of that week. Only if all items that were planned for production were actually produced, and no other items a week was counted as executed according to plan. Changes in quantity were not taken into account.

2.3 Research relevance and objective

There are several techniques developed to reduce nervousness and improve stability in production schedules. For all techniques it holds that a balance is sought between flexibility and robustness and cost. Different approaches were found in literature and a selection of commonly found methods is presented here.

2.3.1 Lot sizing techniques

Jeunet et al., compare several lot-sizing algorithms on different aspects of stability.

Wagner-Whitin algorithm (WW)

The wagner-Whitin algorithm is a simple method to calculate the optimal production sizes for in a situation where demand is known. It uses the fact that in a specific period there can either be production or not. When there is production, exactly the amount should be produced to satisfy all demand until the next production. Although this method provides cost optimality, it needs complete information to achieve this. That means that it can be used as a cost benchmark, but not on a running model. (Wagner & Whitin, 1958)

Economic order quantity (EOQ)

Under constant demand, an optimal production quantity can be found by balancing the cost of inventory and the cost of set-up. The total cost of production for one year can be expressed as a function of the order size. This leads to the total cost being the sum of the number of orders times the ordering cost, and the average inventory size times the holding cost for inventory: (Harris, 1913)

Equation 1: Cost as a function of the order quantity as by (Harris, 1913)

$$TC = \frac{DK}{Q} + \frac{hQ}{2}$$

With:

$Q =$ order quantity
$D =$ annual demand quantity
$K =$ cost per order set up
$h =$ annual holding cost per unit of inventory

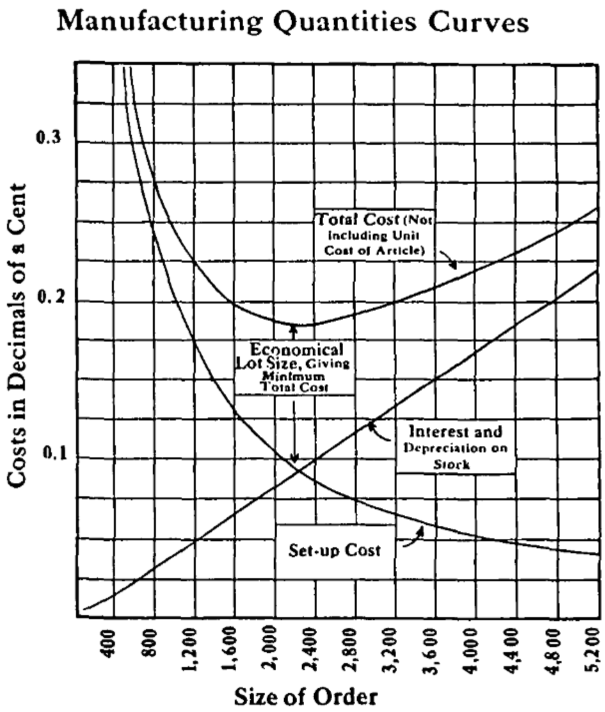

Figure 3: Graph showing Set-up Cost, Inventory Cost and Total Cost as functions of the Order Size. By (Harris, 1913)

The minimum for this formula is where the derivative over order size of the previous function equals zero. The optimum quantity $Q^*$where this happens is found by the following equation:

Equation 2: Economic Order Quantity as by (Harris, 1913)

$$Q^* = \sqrt{\frac{2DK}{h}}$$

This method works only for constant demand and constant inventory prices and constant set up prices. When demand is varying this method does not give an optimum result. Jeunet et al., found that EOQ fails to be robust and found that it has significantly higher costs than other methods analyzed. (Jeunet & Jonard, 2000)

Periodic order quantity (POQ)

Contrary to the economic order quantity, the periodic order quantity was found to be very robust, scoring at the robust end for all measures of (in)stability. (Jeunet & Jonard, 2000) However, it also scored high on the cost measure. The method works by using the economic order quantity to determine the ordering interval period. At any moment where an order is made, the forecast data is used to order enough until the next ordering point, based on the forecast demand data available.

Least unit cost method (LUC)

The least unit cost method works by determining at each production moment the amount to be produced, based on the forecast, to as much as where the cost per unit for the total production starts increasing. This method scores below, or equal to the periodic order quantity on terms of stability and cost. (Jeunet & Jonard, 2000)

Part-period algorithm (PPA)

For each production the size is determined by adding future demands until the carrying costs for such a future demand are equal-, or more than creating a new order. This method scores consistently just below the Least Unit Cost method on all stability measures, whilst also being slightly more cost effective. (Jeunet & Jonard, 2000)

Incremental part-period algorithm (IPPA)

Instead of only evaluating the additional carrying costs of additional demand periods, the incremental part-period algorithm only adds periods until the combined carrying costs are equal or more than the production set-up costs. IPPA scores below the regular Part-Period Algorithm on costs and all measures of stability. (Jeunet & Jonard, 2000)

Silver-Meal algorithm (SM)

The Silver-Meal algorithm includes periods until the cost of set up and holding cost combined-, and averaged over the number of periods, starts to increase. This method scores below or equal to the (regular) Part-Period Algorithm on the stability measurements, whilst being equally cost-efficient as PPA. It does, however, score better on both costs and stability than the Incremental Part-Period Algorithm. (Jeunet & Jonard, 2000)

Minimum demand technique (MINS)

The MINS algorithm works by starting with attributing a production to each period with demand, and then repeatedly checking whether it is economic to add the period with the lowest production to the previous production period, until this is no longer feasible. (Zhu, Heady, & Lee, 1994) This method was found to score high on cost effectiveness, scoring only below the optimum Wagner-Whithin algorithm and the Technique for Order Placement and Sizing. On stability, however, together with the Economic Order Quantity method it scores the lowest. (Jeunet & Jonard, 2000)

Technique for Order Placement and Sizing (TOPS)

TOPS, or Technique for Order Placement and Sizing, is a four-step improvement over the regular Incremental Part-Period Algorithm. It starts by forming a regular IPPA production schedule, then it places a new ‘artifical’ production period between existing production periods. It runs a second IPPA pass from that artificial production period and lastly it compares the two series and checks if it is feasible to shift to the artificial set of periods. (Coleman & McKnew, 1990) This method scores only second to the Wagner-Whitin optimum on costs and scores similar to the Incremental Part-Period Algorithm and the Wagner-Whitin algorithm on all measures of stability by Jeunet et al. (Jeunet & Jonard, 2000)

Lot-for-lot policy

Lot-for-lot scheduling constitutes a specific production run for each period of demand for an item. Thus, requiring a set up for each period there is demand. Under uncertain demand forecast, the size of production runs is also uncertain and the method is proven to be both instable and cost-ineffective. (Blackburn, Kropp, & Millen, MRP system nervousness: Causes and cures, 1985)

2.3.2 Other techniques for decreasing nervousness of a production schedule

The way production schedules are made is not the only parameter that contributes to more or less nervousness. By altering other parameters, the stability of a schedule can be increased. The methods that were found in literature are presented here:

Freezing the MPS

A simple method to reduce nervousness or instability is by not allowing it. Once scheduled, a production order can become fixed, or 'frozen'. This can be done for the entire horizon in which production is scheduled, allowing a next schedule to only 'change', or in this case create new-, production for periods that roll within the horizon. Another possibility is to freeze part of the horizon, for example the part where orders for raw materials and packaging already were done. This allows for some freedom in production further towards the horizon but prevents instability, and its negative consequences, closer towards the present. Forecast errors, however, can cause for stockouts and thus it was suggested to only use this method in combination with safety stocks. (Blackburn & Millen, A Methodology for Predicting Single-Stage Lot-Sizing Performance: Analysis and Experiments, 1985) Further research into this method of avoiding instability has come to the conclusion that both the length of the frozen period is important, as can be seen in Figure 4, but also the method of freezing productions in the MPS. (Sridharan, Berry, & Udayabhanu, 1988)

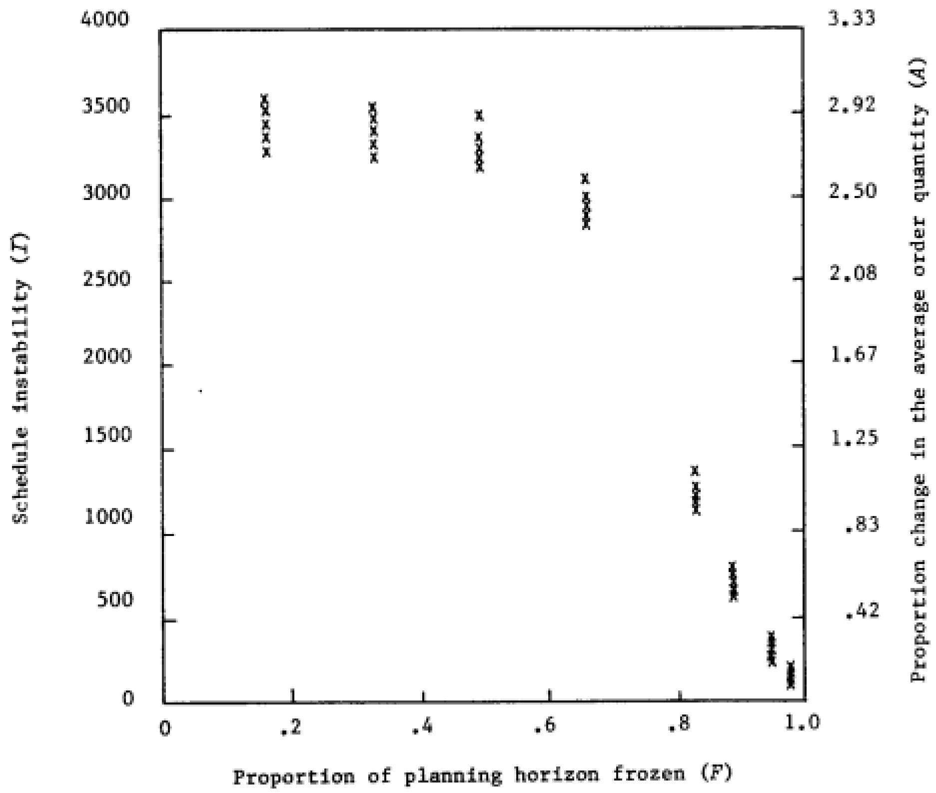

Figure 4: Effect of frozen horizon length on schedule instability by (Sridharan, Berry, & Udayabhanu, 1988)

Buffer stocks

During a normal cycle consisting of production and one or more periods without production for a particular item, stock is kept to ensure demand can be met in periods without production. Any stock in this situation is made to be used in a demand situation and this stock is called cycle stock. On top of this stock that has a clear purpose, an extra amount of stock can be kept. This extra stock is there for unforeseen shortages of stock and is the buffer stock. An important parameter for buffer stock is the size of the buffer stock. It provides more freedom for the scheduler to not change planned productions when the forecast changes, but depending on the holding cost of stock, it can be at a considerable cost. Its usage has been studied extensively and the level of success in reducing instability varies with its size, as does the cost performance. (Blackburn, Kropp, & Millen, MRP system nervousness: Causes and cures, 1985)

Forecast beyond the planning horizon

Another method of improving stability of the MPS is by minimizing the rolling-horizon-effect. This is the effect where every new period, a new future period with forecast demands presents itself at the horizon, and where this new period can cause a change in MPS because in the previous MPS all inventories inevitably end up at zero at the end of the period. If the forecast is extended beyond the planning horizon, this ripple effect of new demand periods presenting themselves occurs mainly outside of the production schedule. It was found that this strategy achieved slight improvements and is mainly effective in short planning horizon situations. (Blackburn, Kropp, & Millen, MRP system nervousness: Causes and cures, 1985)

Increasing cost of alterations

Many production planning systems optimize the schedule by balancing production set-ups and cost of keeping stock. When doing so in a systematic manner, the ideal production plan changes only if the input, which is usually the forecast demand, changes. This change can be an update of expected demands or an increase in planning horizon length or both. If the updated production plan is different than the previous plan, extra costs can be attributed to that difference. This reduces the chance that the optimal plan is different than the previous plan and thus forces more stability. Important in this aspect is that the cost attributed to schedule changes needs to be high enough to have effect, but also not so high that it fails to allow any changes. In literature, cost is attributed to set-up changes. When a schedule plans a new production moment costs occur, and when a schedule removes a set-up costs occur. Alterations in the size of production are not considered. Any algorithm that is influenced this way in order to reduce nervousness, is not optimal in terms of cost of stock and set-up. The further one is willing to deviate from optimal cost, the more stable a schedule becomes. It was found that the method is reasonably cost effective and reduces the number of unplanned orders. (Blackburn, Kropp, & Millen, MRP system nervousness: Causes and cures, 1985)

Planning horizon length

(Sridharan, Berry, & Udayabhanu, 1988) have found that increasing the planning horizon length has a positive effect on the stability of a production planning from a starting length of 5 times the natural product cycle. Before 5 times the products natural cycle the inverse is true. Decreasing the planning horizon length increases the schedule stability, as can be seen in Figure 5.

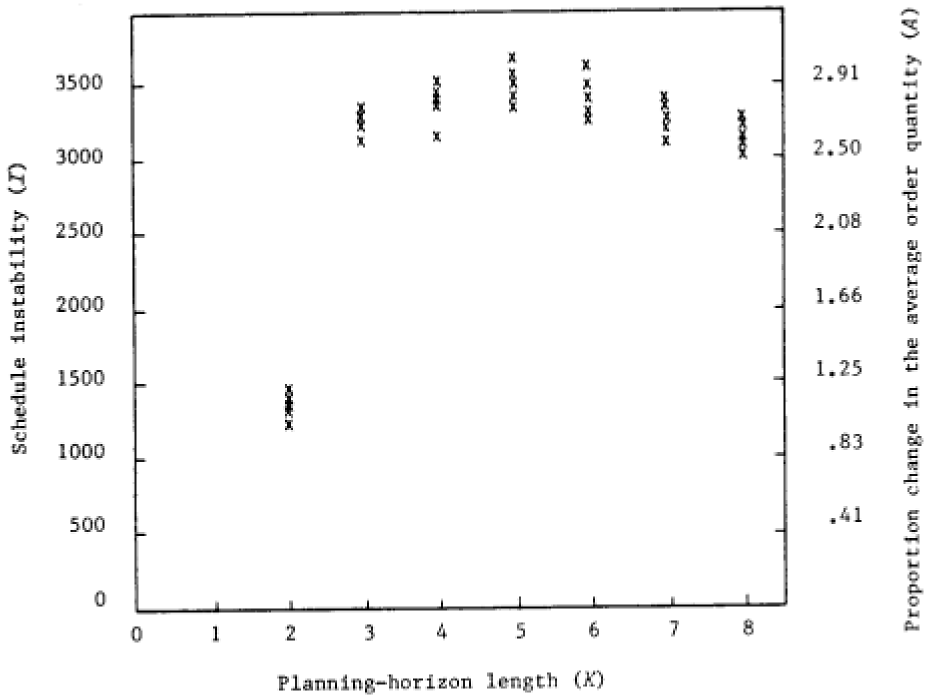

Figure 5: Effect of planning horizon length on schedule instability by (Sridharan, Berry, & Udayabhanu, 1988)

2.3.3 Relevance of the research

It is clear that a stable system is desirable but the trade-off of less flexibility or higher costs seems inevitable. The current lot-sizing technique, Periodic order quantity (POQ), is found to be the most stable technique whilst not being the most cost-effective. Within the organization it is believed that a further increase in safety stock level is not the most cost-effective method of improving the customer service level and literature confirms this by concluding that increasing safety stock becomes cost-ineffective after a certain point.

Furthermore, it was found that decreasing the planning horizon length can increase stability and similarly increasing the forecast horizon relative to the planning horizon can increase stability. It was suggested that these factors are worthwhile investigating further as a combination, decreasing the planning horizon whilst keeping the forecast horizon equal achieves both. It decreases the planning horizon and it increases the forecast-, to planning horizon ratio.

In practice this would mean that with a shorter production planning horizon, changes are not registered as such because there is no fixed schedule. Furthermore, it reduces the complexity of planning, allowing for operators on the factory floor to take on this responsibility. Within the company philosophy, this is one of the key principles. 1.3.2 Responsibility

Within Mars Oud-Beijerland the possibility of becoming more customer oriented, and focusing on fulfilling the demands of the customer is actively pursued. Practical problems that might arise are of subordinate importance if the goals of less nervousness, and higher customer service level can be met.

This results in the objective of this research as follows:

Determine how planning and scheduling of the production of Miracoli Dinnerkits must be organized to lower nervousness and increase the customer service level.

To do so, first the current system is analyzed and then a research question is proposed, with supporting sub questions.

2.4 Outline of the report

The structure of the report is as follows:

Chapter 1: Background of Mars Inc.

Chapter 2: Introduction to the research

Chapter 3: Analyses of the current system

Chapter 4: Requirements and limitation for production

Chapter 5: Input to the system

Chapter 6: Method

Chapter 7: Results

Chapter 8: Conclusion and Recommendations

3 Analyses of the current system

In order to make improvements in the current Planning and Scheduling process it is necessary to analyze the current system. First the Environment is analyzed, and then the Planning and Scheduling are analyzed. From these analyses a research question follows.

3.1 Environment

3.1.1 Production

Mars is in the supply chain of pots of sauce and dinner boxes to the consumer. Mars needs a supply of goods and materials to be able to make pots of sauce, and a distribution system to bring them to the consumers. In Figure 6, a schematic overview of this supply chain is given. Here it can be seen that raw materials like vegetables, tomatoes and unions are transported to either Mars directly, or a warehouse that stocks for Mars. Similarly, packaging is transported from the supplier to either Mars directly, or a Mars warehouse. Anything that is transported to the Raws & Packs stock warehouse will be transported to the Mars OBL production site. Here the sauce is made, put into pots or dinner kits, and packaged for distribution. This can happen by transporting the finished products to a Mars distribution center directly, or, for smaller markets, the products are sent to a central distribution center of Mars, to be bundled with other Mars products, and then send to a Mars distribution center. From the Mars distribution centers the products are distributed to supermarket distribution centers, which in turn distribute to supermarkets. In the supermarket consumers can buy the products.

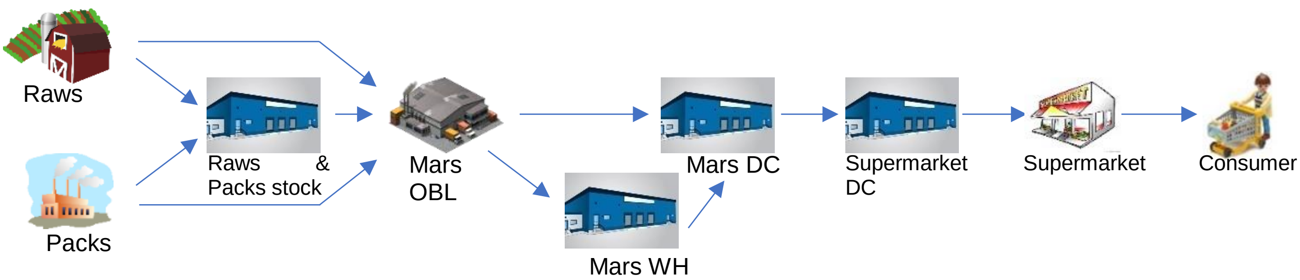

Figure 6 Product stream from supplier to consumer for Mars OBL

3.1.2 Order stream

In order to know who should produce what, and at what time it is necessary to place orders. The direction of orders is opposite of that of the product stream. As can be seen in Figure 7, a supermarket distribution center orders at Mars. Mars in turn orders at its suppliers the raw- and packaging materials needed to produce. For this order stream yellow arrows are used. Since both the suppliers of Mars, as Mars itself not always send their produced goods directly to the client, but also to warehouses first, there is also an order stream to the warehouses that can order the goods to be send further down the product stream. These release orders are in green.

3.1.3 Key logistic process

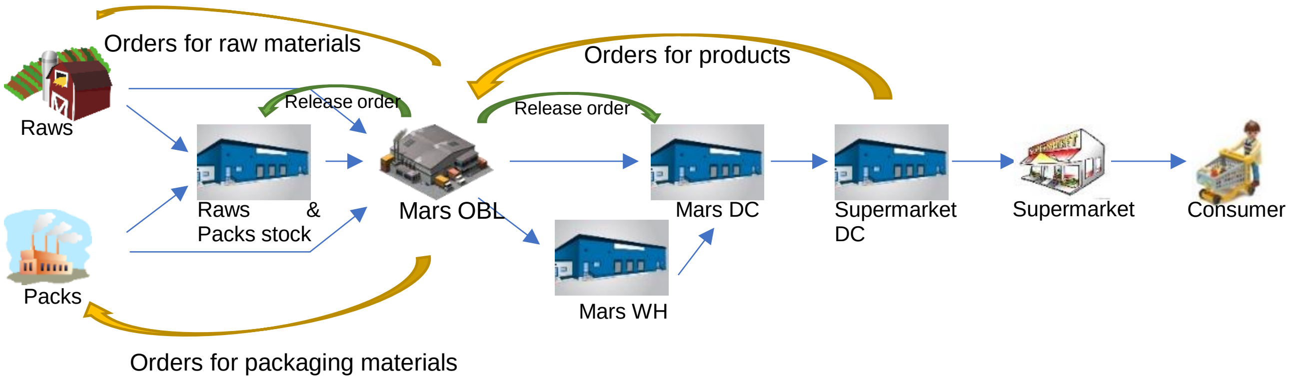

Figure 7 Product stream for Mars OBL with corresponding order stream

Mars is responsible for a specific part of this chain of processes. If the parts where Mars is not responsible are left out, the following figure remains:

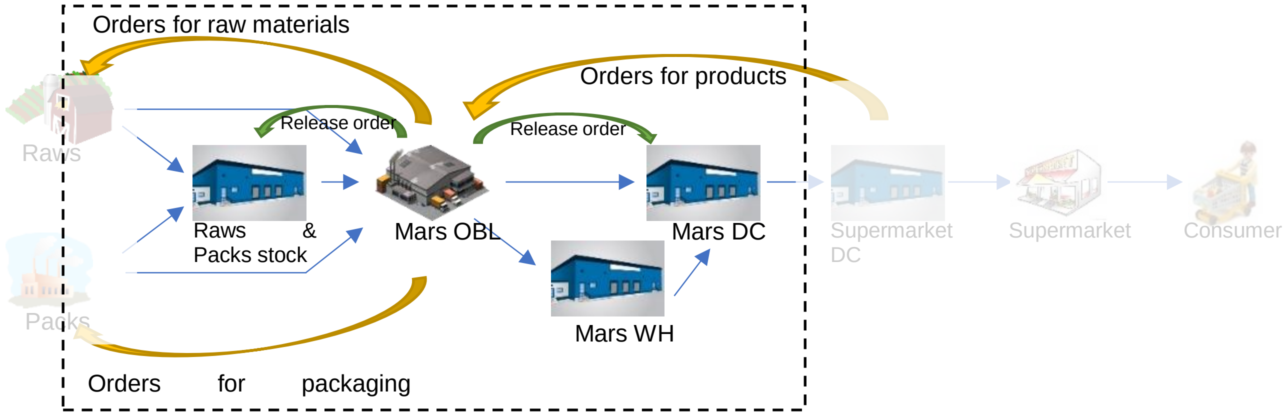

Figure 8 Product stream that falls under Mars' responsibility

If this picture is then further formalized into a PROPER model, as described by Veeke, et al., the following figure is formed in Figure 9 (Hans P.M. Veeke, 2008). Here it can be seen that raw materials and packaging materials come into the system, are transformed by the production aspect stream into Produced goods. It is done so by using the available resources like production lines and storage space. It does so based on the orders from market. In Figure 9 the PROPER model for production in the OBL plant is given.

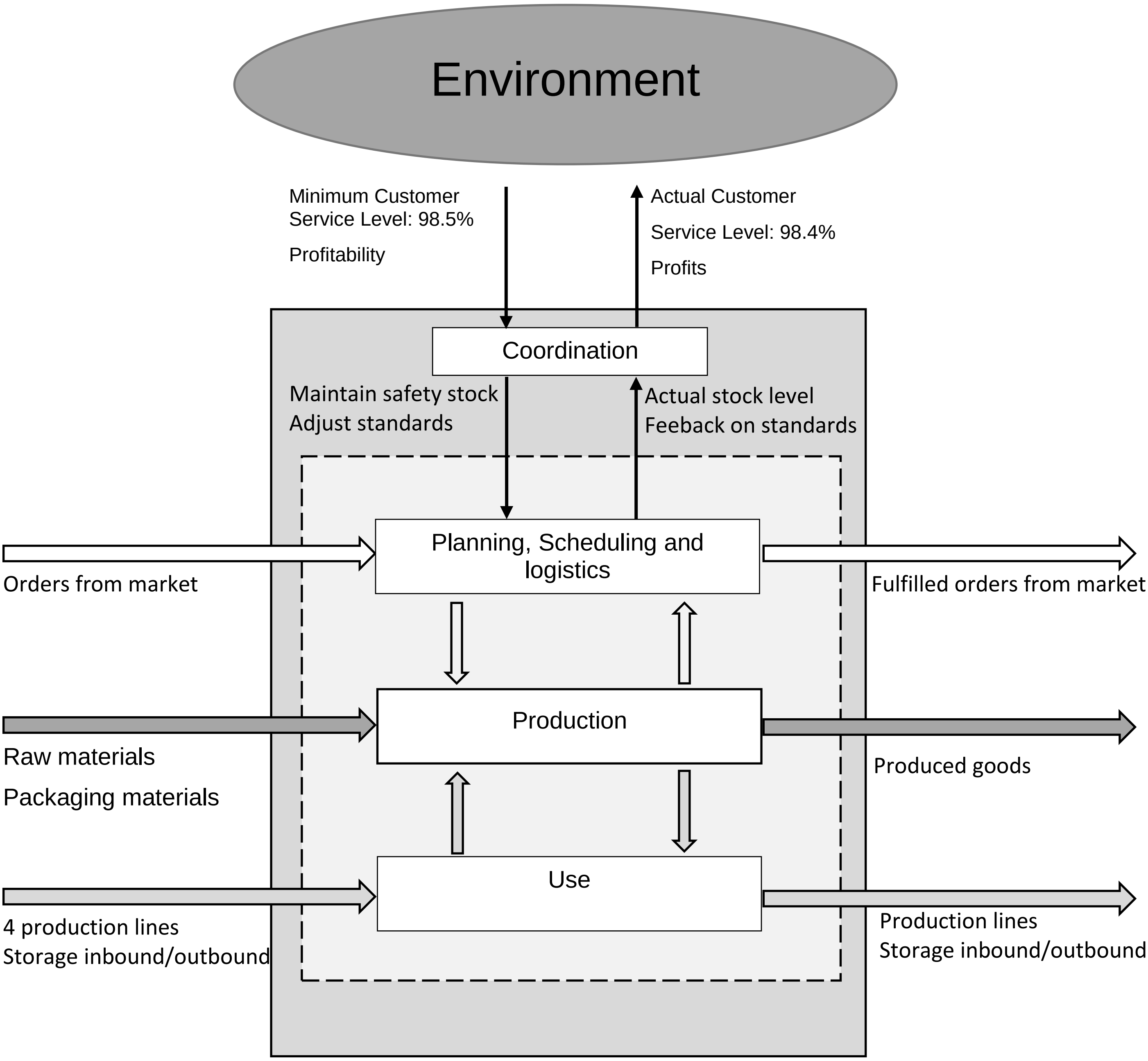

Figure 9 PROPER model for the Mars OBL plant

The orders from clients lead to the planning and scheduling of the production in the product process stream. Production uses the resources available in the resource stream.

3.2 Planning

Planning is the process of determining what should be produced in what week and how much of it, based on a forecast. At Mars this is done in order to maintain specified stock levels. Produce to stock. Over time, the stocks deplete because of orders from the market. By producing items that have depleting stocks, the stocks are replenished. As straight forward as this might seem, it should be noticed that there is a minimum required time between deciding to produce and replenishing stocks. Raw materials need to be sourced and delivered, the production process takes some time and once production is finished, the product needs to be transported to the warehouse where the stock is kept. Furthermore, there is a limited production capacity on the production line so it might not be able to produce as soon as the raw materials come in. To deal with this lag in time between deciding to produce and replenishing stock, production is planned for the future. To do this, a specific method is used by Mars.

3.2.1 ICB

First the *Ideal COGs Balance* is determined. COGs stands for Cost of Goods sold. These costs include the cost of keeping stock and the cost of starting production runs. Here the ideal amount for production is determined, based on the yearly demand for the product, the cost of keeping stock for the product, and the cost of starting a production run. For the yearly demand, the demand of the past year is used or if this is not available, an estimate is made. The cost of keeping stock is a function of the production size and calculated by multiplying half of the production size with the cost of keeping stock per unit per year. The total cost of starting production runs is also a function of the production size and is calculated by dividing the annual production by the production size, and multiplying this with the cost of starting a production run.

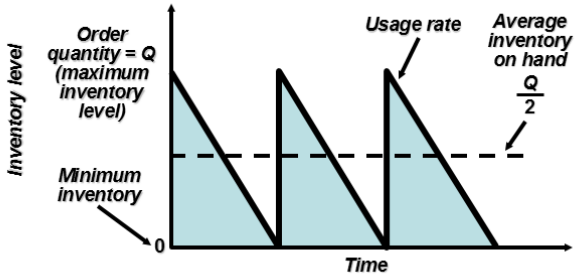

Figure 11 Average inventory

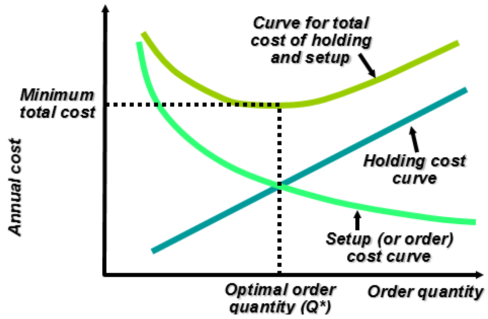

Figure 10 Annual cost of setup, holding and combined for varying order quantity

- TC = total annual cost of goods sold as a function of production run size
- Q = production run size
- Q* = optimal production run size
- D = total annual production
- K = setup cost per production run
- h = annual holding cost per unit

Equation 3 Cost calculation of stock and production

$$TC_{(Q)} = D \cdot \frac{K}{Q} + h \cdot \frac{Q}{2}$$

To find the optimal production run size the derivative of the total costs is equal to zero:

Equation 4 Optimal production run size calculation

$$Q^* = \sqrt{\frac{2 \cdot D \cdot K}{h}}$$

3.2.2 MFI

With the optimal production run size, a *manufacturing frequency index* can be made. This is done by dividing the total annual production by the optimal production run size, and rounding the result to the nearest possible production frequency. The possible production frequencies are; thrice per four weeks, once every two weeks, once every four weeks and once every eight weeks.

For the regular products on line 4 this yields the following manufacturing frequencies:

Table 2 EOQ and MFI for various products on Line 4. Note: for certain products the MFI is not based on historic data. MFI is the MFI rounded to possible production frequencies.*

Family	Ton/yr	E/setup	E/ton/yr	EOQ [ton]	EOQ [SKU]	MFI	MFI*
MKK	478	€ 1.031,54	€ 692,12	28,5	3780	3,10	2
MTK	508	€ 1.611,47	€ 658,94	37,6	3595	3,85	4
MUK	371	€ 850,25	€ 764,97	21,6	3445	3,03	4
MIK	2647	€ 966,76	€ 558,48	71,8	9043	1,41	1,3
MGK	4520	€ 1.132,80	€ 516,31	106,2	9308	1,22	1,3
MCH	272	€ 1.162,27	€ 940,10	19,4	3660	3,72	4
MRK	145	€ 1.380,41	€ 708,17	17,1	3226	6,12	8
MFK	109	€ 1.254,31	€ 667,75	14,5	2385	6,93	8
MEK	357	€ 924,08	€ 495,91	26,2	3456	3,81	4
MQK	487	€ 1.542,92	€ 421,58	42,9	3766	4,58	4
MSC	325	€ 1.295,91	€ 797,45	24,5	5213	3,92	4
MPA							4

3.2.3 Week plan

There are items that are produced weekly, bi-weekly, once every 4 weeks and once every 8 weeks. It is thus possible to make a repeating plan of 8 weeks. This is done by starting with adding the weekly items to all 8 weeks. Then a selection is made of items that are produced bi-weekly for the even week numbers and a selection for the uneven week numbers. By grouping items that are similar in composition, the expected cost of changing from one recipe to another is kept low. A special exception is made for items that have an ideal MFI between once every 1 and 2 weeks. Here an intermediate frequency of once every 1.3 weeks can be assigned. In this case every 4 weeks there are 3 production runs. These runs fall within a combination of 3 weeks, resulting in an unequal interval between production runs. Below, in Table 3 an overview of production runs per week is given. For each item in the first column the product family it belongs to-, and the cycle it is in is given. The cycle information given is the MFI frequency, and the week or weeks in which there is production are given.

Table 3 MFI table and assigned weeks for items on line 4

WK1		
Items	**Family**	**Cycle**
CA86P (CH) &CA87P (GER) & CA88E (DK)	OBL_L04_MIK_3PB	MFI 1.3 wk 1+2+4
CA87D (BE)	OBL_L04_MEK_3PB	MFI 4 wk 1
CA87M (GER)	OBL_L04_MUK_2PA	MFI 4 wk 1
CA88G (GER) & CA88R (DK)	OBL_L04_MGK_5PD	MFI 1.3 wk 1+3+4

WK2		
Items	**Family**	**Cycle**
CA86V (GER) & CA86X (DK)	OBL_L04_MCH_3PB	MFI 4 wk 2

CA87B (BE)	OBL_L04_MFK_3PB	MFI 8 wk 2
CB11D (BE) & CB16D (GER via NOMI)	OBL_L04_MSC_3PG	MFI 4 wk 2
CA86Y (BE)	OBL_L04_MRK_3PE	MFI 8 wk 2
CA87H (GER)	OBL_L04_MKK_3PC	MFI 2 wk 2+4
CA86P (CH & CA87P (GER) & CA88E (DK)	OBL_L04_MIK_CPL	MFI 1.3 wk 1+2+4

WK3		
Items	**Family**	**Cycle**
CA87K (GER)	OBL_L04_MTK_5PD	MFI 4 wk 3
CA87F (BE)	OBL_L04_MQK_5PD	MFI 4 wk 3
CA88G (GER) & CA88R (DK)	OBL_L04_MGK_5PD	MFI 1.3 wk 1+3+4

WK4		
Items	**Family**	**Cycle**
CB09X (BE) & CB11X (DK) & CB16F (GER via NOMI)	OBL_L04_MPA_3PG	MFI 4 wk 4
CA86P (CH & CA87P (GER) & CA88E (DK)	OBL_L04_MIK_CPL	MFI 1.3 wk 1+2+4
CA87H (GER)	OBL_L04_MKK_3PC	MFI 2 wk 2+4
CA88G (GER) & CA88R (DK)	OBL_L04_MGK_5PD	MFI 1.3 wk 1+3+4

3.2.4 Production quantities

Now that it is determined in what week what is to be produced the question of quantity remains. When an item is produced, enough should be produced to fulfill all the demand up until the next production. The demand forecast is used to determine the production quantity. Furthermore, every product has a minimum production quantity and per item the quantity grows with discrete steps because certain resources come in specific quantities and are deemed too valuable to let go to waste.

3.3 Scheduling

3.3.1 Order determination

When it is known what should be produced in a specific week, the next task is to form a schedule. This schedule contains the information of what to produce given the current solution and in what order, and the amounts that need to be produced. As the quantities are determined in the planning, the question for scheduling is in what order these quantities should be produced. To determine the order, the change-over time between items is compared. The change-over times are not symmetrical, i.e. changing from producing a product with a red sauce to a product with white sauce takes longer than going from white sauce to tomato sauce, as the machines need to be cleaned more thorough to prevent the white sauce from becoming pink because of tomato residue. To find the optimal sequence order the problem is translated into an asymmetric traveling salesman problem, where the change-over time is seen as the distance, or cost, between cities, and the production of an item is seen as a city. For determining the order of visits, or production, it does not matter how long the visit to the city, or production of an item, takes. As can be seen in Table 3, the most diverse weeks (2 and 4) have 6 different items that need to be produced. That means that there are $6! = 720$ possible orders for those weeks. However, it should be noted that this number significantly lowers when certain operational preferences are taken into account. The last production item is always either MGK or MIK. This is because these have the biggest volumes and highest production frequencies, so if the production is cut short, it can simply be produced in the next week. The following table is a change-over table for the products of Line 4. On this table the time every change over takes is represented, as well as the startup and shut down times that are required to start or stop the production.

Table 4 Change over time matrix for items on Line 4. Changeover is in minutes [min]

SOP	To	**MCH**	**MEK**	**MFK**	**MGK**	**MIK**	**MKK**	**MPA**	**MQK**	**MRK**	**MSC**	**MTK**	**MUK**	SD
From	Box	3PB	3PB	3PB	5PD	3PB	3PC	3PG	5PD	3PE	3PG	5PD	2PA	
SU		60	195	120	195	195	195	195	195	120	120	195	195	
MCH	3PB		30	20	90	30	30	30	90	30	30	90	30	240
MEK	3PB	20		60	180	20	30	120	180	30	60	180	60	480
MFK	3PB	20	60		90	60	60	120	90	60	30	90	60	480
MGK	5PD	90	180	90		180	180	180	20	90	90	20	180	480
MIK	3PB	20	20	60	180		30	120	180	30	60	180	60	480
MKK	3PC	30	30	60	180	30		120	180	30	60	180	60	480
MPA	3PG	30	120	120	180	120	120		180	120	120	180	120	480
MQK	5PD	90	180	90	20	180	180	180		90	90	20	180	480
MRK	3PE	30	30	60	90	30	30	120	90		60	90	60	480
MSC	3PG	30	60	30	90	60	60	120	90	60		90	60	480
MTK	5PD	90	180	90	20	180	180	180	20	90	90		180	480
MUK	2PA	30	60	60	180	60	60	120	180	60	60	180		480

3.3.2 Production schedule

Now that both the sequence and the quantities are known, the final production schedule can be made. Starting at the beginning of the week, the startup, production and change-overs are scheduled. To determine the duration of a production time, the production quantity is divided by the production rate. The production rate can differ for the same recipe but different container types, as is shown in Table 5.

Table 5 Production rates per product

Recipe code	**Size**	**Plan rate**	**SOC (jars/min)**	**CaseCount**	**Cases/min**
MCH	CPL	55%	97,9	20	4,90
MCH	3PB	55%	97,9		
MEK	CPL	60%	106,8	20	5,34
MEK	3PB	60%	106,8		
MFK	CPL	54%	96,12	20	4,81
MFK	3PB	54%	96,12		
MGK	FAM	54%	96,12	18	5,34
MGK	5PD	55%	97,9		
MIK	CPL	58%	103,24	20	5,16
MIK	3PB	58%	103,24		
MKK	CPL	55%	97,9	20	4,90
MKK	3PC	55%	97,9		
MPA	3PG	40%	71,2	20	3,56
MQK	FAM	53%	94,34	18	5,24

MQK	5PD	55%	97,9		
MRK MRK	CPL 3PE	48% 48%	85,44 85,44	20	4,27
MSC MSC	CPL 3PG	45% 45%	80,1 80,1	16	5,01
MTK MTK	FAM 5PD	45% 45%	80,1 80,1	18	4,45
MUK MUK	TPP 2PA	54% 54%	96,12 96,12	22	4.37

Item	Omschrijving		Recept	Tonn.	Size	Packs CRP	Packs CP	Case	Verpakkingen	Cases	Pallets	Markt	ZO-N	MA-O	MA-M	MA-N	DI-O	DI-M	DI-N	WO-O	WO-M	WO-N	DO-O	DO-M	DO-N	VR-O	VR-M	VF
CA87B	MR DB SPAGH CHEESE 20X304G BE	-	MFK		3PB	86400	86400	20	86400	4320	60,00	BES	1370	2307	643													
CB11D	MR DB S MACARONI CHEESE 14X294G BE	-	MSC		3PG	132048	132048	14	30240	2160	30,00	BES			1638	522												
CB16D	MR DB S MACARONI CHEESE 14X294G DE	-	MSC		3PG			14	101808	7272	101,00	N...				2110	2746	2416										
CA87H	MR DB MACARONI TOMATO 18X360G DE	-	MKK		3PC	41472	41472	18	41472	2304	48,00	D							2304									
CA87P	MR DB SPAGH TOMATO 20X380G DE	-	MIK		3PB		189120	20	45120	2256	47,00	D							176	2080								
CA88E	MR DB SPAGH TOMATO 20X380G DK	-	MIK		3PB			20	28800	1440	20,00	DK								295	1145							
CA86P	MR DB SPAGH NAPOLI 20X380G CH	-	MIK		3PB			20	43200	2160	30,00	CH									1230	930						
CA87D	MR DB SPAGH ITALIANO 20X370G BE	-	MEK		3PB	72000		20	72000	3600	50,00	BES										1494	2106					
CA87K	MR DB MACARONI TOMATO 18X563G DE	-	MTK		5PD		109512	18	35640	1980	55,00	D												1716	264			
CA88G	MR DB SPAGH TOMATO 18X616G DE	-	MGK		5PD	73872		18	73872	4104	114,00	D													2179	1925		
CB09X	MR DB PENNE ARRABIATA 14X360G BE	-	MPA		3PG	33264	33264	14	10080	720	10,00	BES															720	
CB16F	MR DB PENNE ARRABIATA 14X360G DE	-	MPA		3PG			14	23184	1656	23,00	N...															1345	

Figure 12 Screenshot of Mars weekplan for production on Line 4

3.4 Checking the feasibility of the planning

When planning is made, the schedule is made to fulfill the forecasted demand. However, when there is more forecast demand than can actually be produced in one week, the remaining production need to be scheduled elsewhere. Since production for a specific demand is generally planned as late as possible, this means there is no production date after the production that that appears to have insufficient production time available. In this case production needs to be scheduled earlier. Preferably this change in planning is done by increasing an existing planned production run. This is only possible if there is a production run planned before the week with the shortage in capacity.

The decision of what item needs to be moved forward is done based on the outcome of the shift. The outcome that has the least days of lower than desired stock is moved forward.

3.5 Research question

After analyzing the current state of production planning, it becomes apparent that the process of planning of production has potential for improvement. This results in the proposition of the following research question:

How should planning and scheduling of the production of Miracoli Dinnerkits be organized in order to lower nervousness and increase the customer service level?

To find an answer to this question, the following sub questions need to be answered:

1. What is the current process for planning and scheduling of production?
    a. What is the process for creating a planning?
    b. How is a schedule made after a planning is made?
2. What are the requirements and limitations for production?
    a. What raw materials do the produced items need and what is their lead-time?
    b. What other resources are needed?
    c. What are limiting properties for these raw materials and other resources?
3. What characteristics do the demands for the products have?
    a. What information does historic data give?
    b. What information does forecast data give?
4. How should the performance of the methods be measured?
    a. What KPI’s can be used?
5. What alternative methods of planning and scheduling can be proposed?
6. What other effects will alternative methods for planning and scheduling have in the fulfillment stream?

The answers to these questions are used to answer the main research question.

4 Requirements and limitations for production

For production of the Miracoli Dinner kits on Line 4, several things are needed. Off course time on the production line is needed but also the ingredients that together form the food for the people who buy the dinner kits. And to keep the ingredients in good condition packaging material is needed. Furthermore, the food is sold as a ‘dinner kit’, which means that there is a single box containing the ingredients for the dinner. That box, and the case in which the box is delivered to supermarkets is also needed to start production. In this chapter an analysis of what is needed for production is made.

4.1 People

To operate the production line, people are needed. Depending on the type of dinner box there are people needed to do the work. Furthermore, there are people who work in the factory to handle incoming freight or outgoing deliveries and these are not attributed to Line 4 because they are necessary for all production. People whore are always needed to specifically operate Line 4 are:

- Team leader Dinner Boxes
- 2 people who place pasta in the boxes
- A person operating the boxes’ carton unfolding machine
- A person operating the machine that puts boxes into trays
- A person that handles the logistics of Line 4
- A person that handles the robot that fills the boxes
- A person that handles the outgoing stream of goods and checks the quality

Furthermore, depending on what is being made on Line 4 there are either 6 temporary employees needed to manually add spices to dinner boxes, or there are 5 persons needed who perform various tasks. Only one role for these persons is for a temporary employee: checking the quality. Other tasks that require employees with certified skills are:

- A person that prepares tomatoes to make sauce with
- A person that operates the cheese or spices filler machine
- A person that operates the tomato filler machine

All in all, to operate Line 4 there are either 12 or 13 persons needed with varying skills and positions at Mars OBL.

4.2 Raw and packaging materials

On Line4 there are 12 recipes produced in 16 stock keeping units. For these units there are 28 raw materials needed, and there are 38 packaging materials needed. The average amount of components per SKU is 13, so there is some overlap. When plotting the number of SKU’s that use a specific raw or packaging material the graph from Figure 13 is found. Here it can be seen that a distinction can be made between raw and packaging materials that are used in 1, 2 or 3 items and raw and packaging materials that are used in more than 3 items. 10 raw and packaging materials are used in 7 or more items. This means these raw and packaging materials are suitable to keep as a general stock, instead of a dedicated stock.

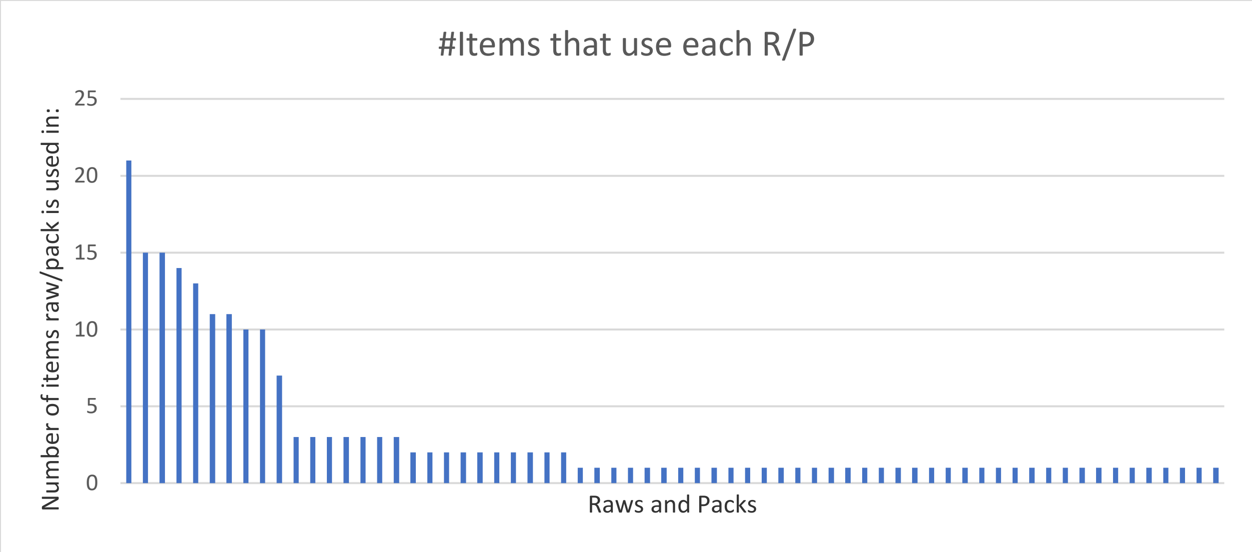

Figure 13 Graph showing distribution of raws and packs multi-usability

When looking at the specific SKU's, it can be distinguished that 3 to 5 raw and packaging materials are unique for every recipe. Often these contain the box and tray packaging materials, and the sauce and pasta raw ingredients. Commonly shared materials are a *Carton divider*, *Pallet stretch foil* to wrap around a pallet, a *label* for each pallet and the *Spice Mix Original*.

4.3 Other resources

To make sauce from the tomato paste, not only spices are added but also water. This water is regular drinking water that is readily available at the production site through its connection to the fresh water grid. Furthermore, the machines are powered by electro motors and controlled by computers running on electricity. The electricity is readily available and sourced from the national electricity net. For heating of the sauce natural gas is used that is also readily available and comes from the gas net.

4.4 Limiting properties

There are three raw materials that have a significantly short maximum shelf life to be mentioned. *Spice Mix Original*, *Dry Mix Cheese 55 g* and *Dry Mix Cheese And Herb 65 g* have best-before lifespans of 13 months. Since the products these materials are used in need to have best-before dates of at least 1 year, this results in a permissible shelf-life of 1 month.

5 Input to the system

Planning and scheduling is the process of determining what is produced when and in what quantity. To do this it is necessary to know how much must be produced, this production quantity is based on the demand of clients. Clients place orders at Mars OBL for items they need in a specific week. This can be in the future but also for the next week. Because clients are of sufficient size, e.g. national supermarket chains, there is structural demand. The amount of demand for each week changes depending on the product. There are products with significant fluctuation throughout the year, products with relatively stable demand and products with stable demand distorted by peaks of multiple times the regular demand.

5.1 Historic data

All weekly sales of products on line 4 in 2018 have been stored and this data is accessible though the Mars QlikView application. A table was made with the sales per week per item, and by combining items that have the same recipe the yearly sales can be determined. Besides the sales that actually took place, the deleted (parts of) orders can be retrieved. By adding these to the sales the demand can be constructed. It is important to add the missed sales, or deleted orders, to the actual sales because these deletions often occur when the demand is irregular. When the production and planning is not flexible it fails to handle peaks in the demand. The actual sales then will not be as high as the actual demand. The goal of this research is to develop a method of planning and scheduling that is capable of handling disruptions, including disruptions in demand. It is therefore imperative to analyze the incoming demand and not just the actual sales. Below, in Figure 14, the sales and on top of that the missed sales are plotted for the item MTK in 2018. Instead of the time labels, the reason codes for the deletions are plotted on the horizontal axis. Here it can be seen that where the missed sales are most prominently available, the reason is often ‘Above forecast’.

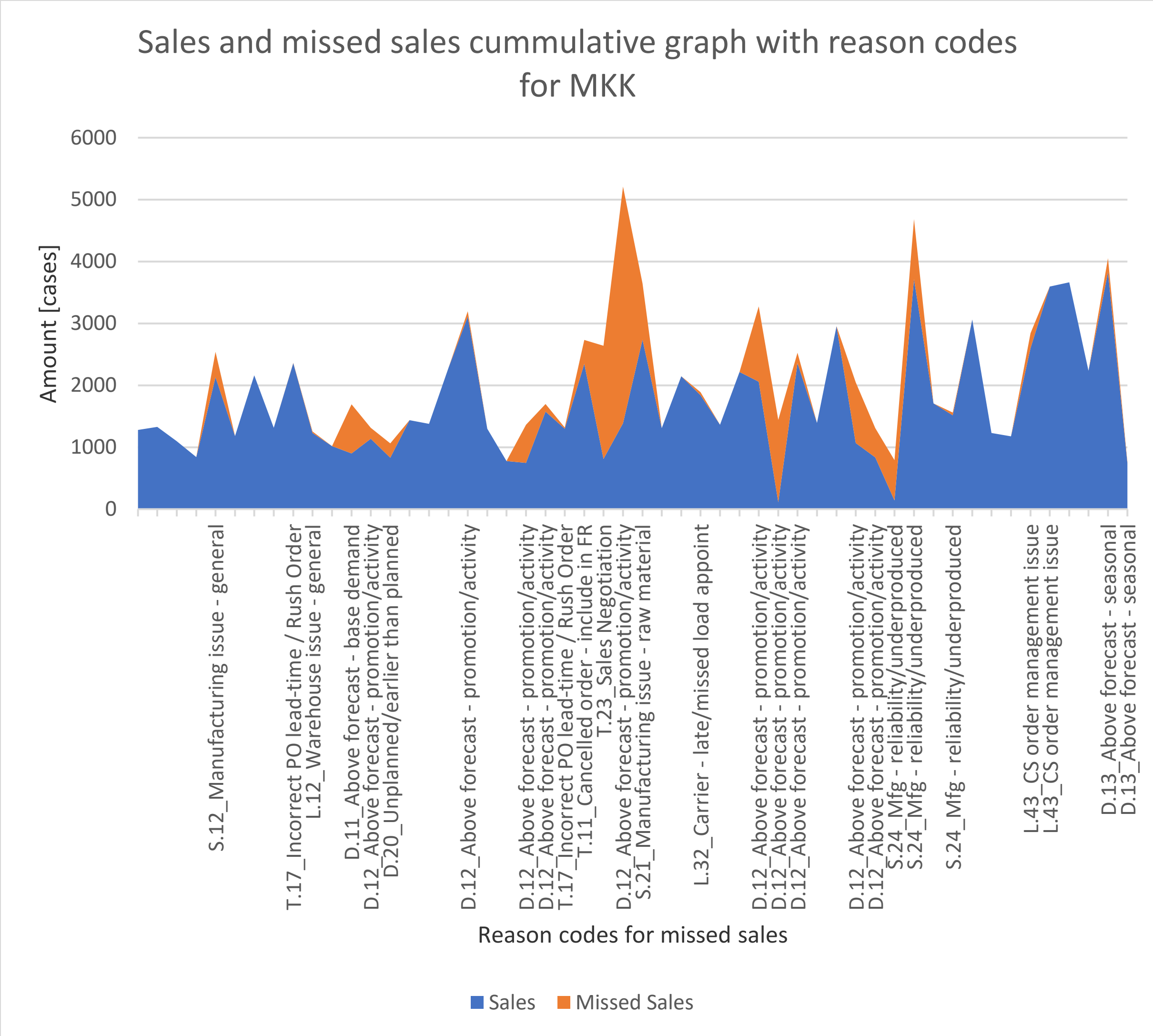

Figure 14 Graph showing the missed sales on top of the actual sales throughout 2018 for the MKK item. Underneath the time axis the reason codes for deleted orders are presented.

Besides the single graph for MTK, the other items of line 4 are plotted as well and on top of each other in Figure 15.

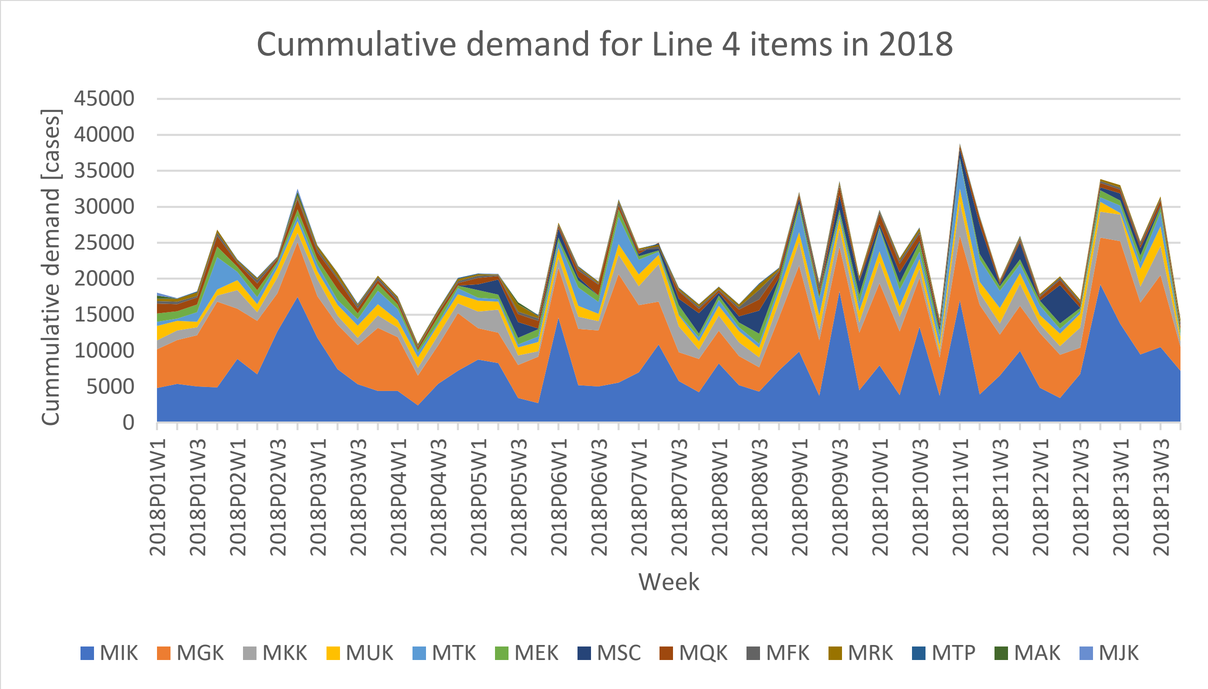

Figure 15 Stacked demands for all items of Line 4 for 2018

5.2 Formalizing the historic demand

At first glance the historic demand of Line 4 is a combination of different items with different averages and standard deviations. However, when analyzing all demand profiles, it becomes apparent that there are different types of demand, and that they not only change in average and variance.

To illustrate this, the demand profiles of two items are plotted in Figure 16 and Figure 17. An item with a high volume, MGK and an item with a more moderate volume, MUK were chosen to compare.

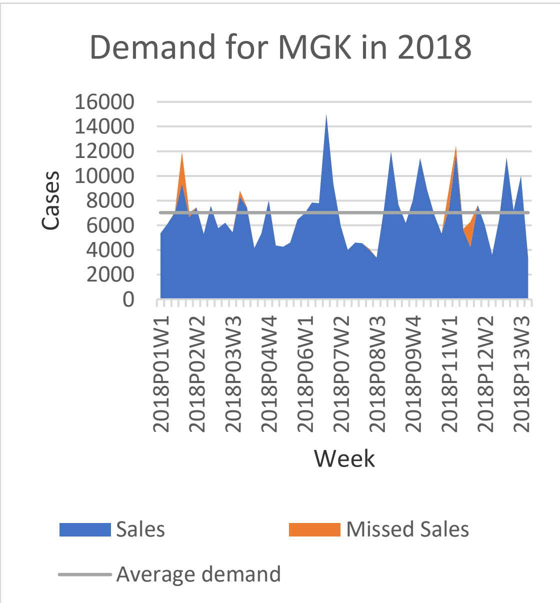

Figure 16 Demand profile for MGK in 2018 and the average demand

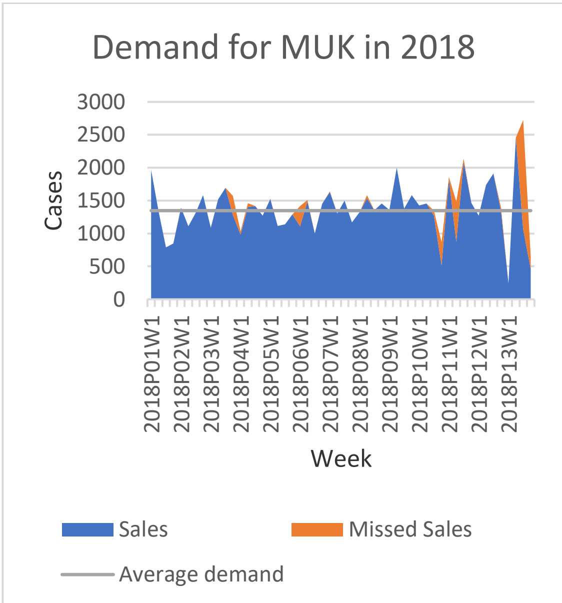

Figure 17 Demand profile for MUK in 2018 and the average demand

It can be seen that MGK has a much bigger volume of 7021 cases per week on average, while MUK only has 1421 cases. Furthermore, the lowest weekly demand for MGK is 3322 cases, while that is 238 for the MUK. Besides the difference in size, the shape of the demands is also quite different. MGK looks a lot more volatile, while MUK adheres more to the average. This is represented by the standard deviation of the two items. 2528 and 408 respectively.

Another way of looking at the demand for these two products is to organize the demand ascending according to size instead of chronologically. In this way the distribution of demands becomes more apparent, as can be seen in Figure 18 and Figure 19.

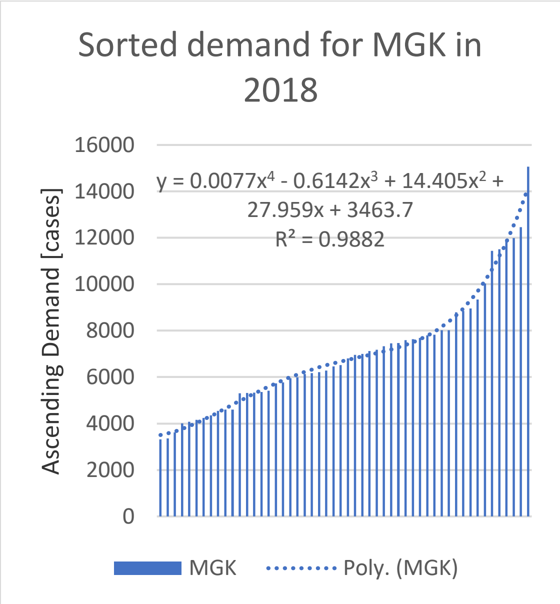

Figure 18 ascendingly sorted demand for MGK in 2018 and 4th polynomial trend line

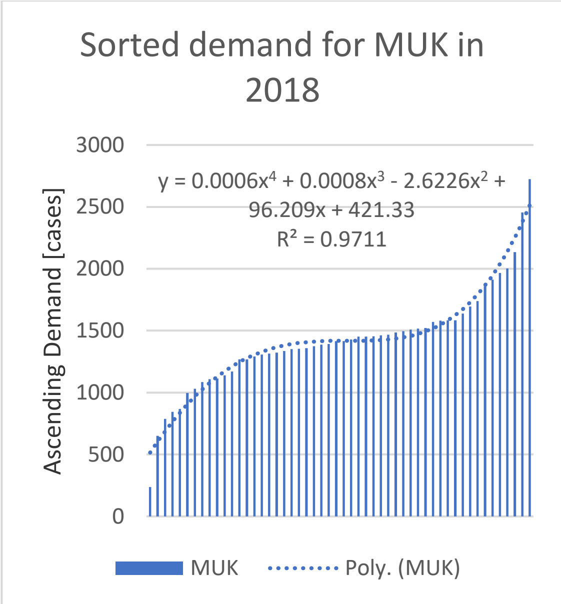

Figure 19 ascendingly sorted demand for MUK in 2018 and 4th polynomial trend line

For both graphs the trend line for a 4th order polynomial has also been added. Interestingly, these graphs have a quite different shape. The MGK graph starts out sloped upward and gradually increases in steepness, while the MUK starts out steep, flattens and then increases again. When the demands are categorized into 11 categories of equal size and with each categories' center distributed evenly over the range of all the demand of a specific item, the following distributions of demand patterns are found:

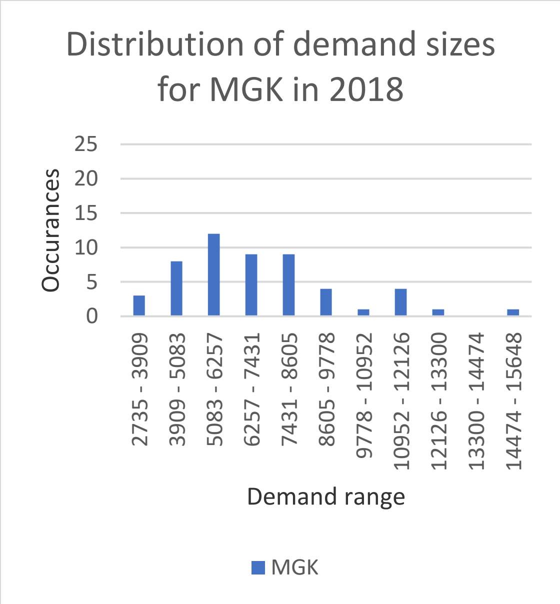

Figure 20 Demand distribution in 11 cohorts for MGK in 2018

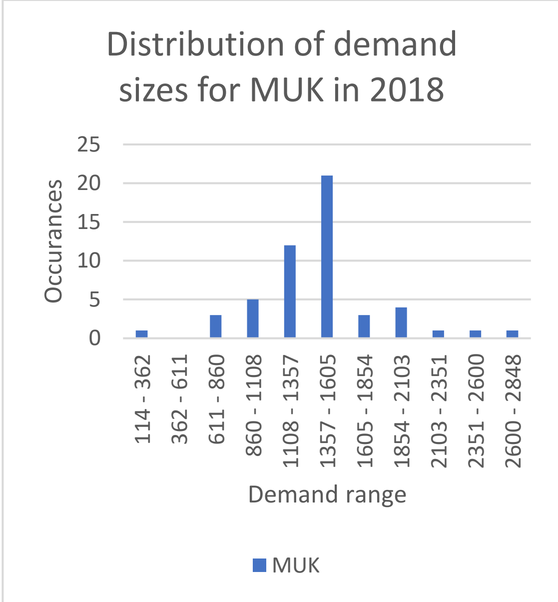

Figure 21 Demand distribution in 11 cohorts for MUK in 2018

The figures found appear to correspond with a lognormal and normal distribution. This means that what the demand is each week, can be expressed as a stochastic function with specific shape and parameters that can be defined for each item.

5.3 Autocorrelation

If the demand is truly a stochastic function, this means that there is no relation between consecutive weeks. For the demand the relation between other weeks of demand of the same product was analyzed by calculating the autocorrelation with the following formula:

Equation 5 Formula to calculate autocorrelation

$$r_k = \frac{\sum_{i=1}^{N-k}(Y_i - \bar{Y})(Y_{i+k} - \bar{Y})}{\sum_{i=1}^{N}(Y_i - \bar{Y})^2}$$

Where r_k is the autocorrelation for lag k, N is the number of data points, in this case 52, Y_i is the demand at week i and $\bar{Y}$ is the average demand.

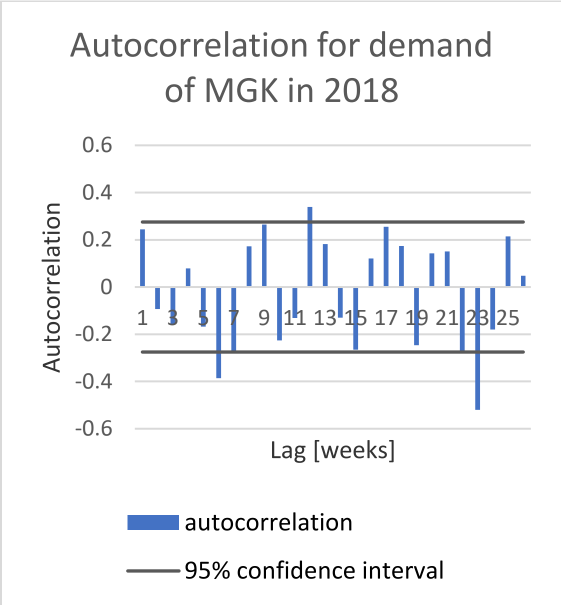

Figure 22 Autocorrelation graph for MGK in 2018

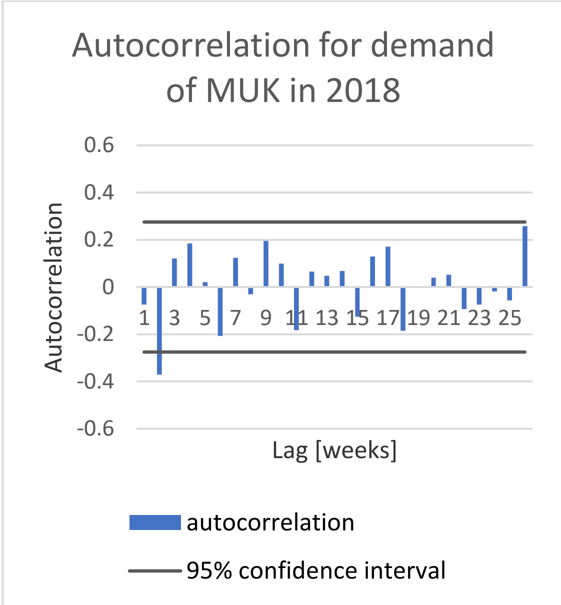

Figure 23 Autocorrelation graph for MUK in 2018

In Figure 22 and Figure 23 it can be seen that there is no insignificant correlation for certain amounts of lag for a 95% confidence interval. However, it is difficult to distinguish a pattern in either one of the correlograms. Furthermore, it could be reasoned that weeks that are close together are strongly related if the demand is seasonal or follows a trend, or that if there is a periodicity it would be based on 4 weeks per period. Since no qualitative explanation for the significant autocorrelations could be found, and since they are very limited in number, the demand profiles are assumed not-auto correlated. The demand is therefore considered serially independent.

5.4 Demand forecast

Every week a certain demand is put forward by the market. This is done based on the aggregate of orders from the clients. As explained in the previous sections, this demand fluctuates over time. However, with the use of historic data, and with information provided by the clients, it is possible to estimate future demand. This is done with a forecast model that is outside the scope of this research but some observation can be made.

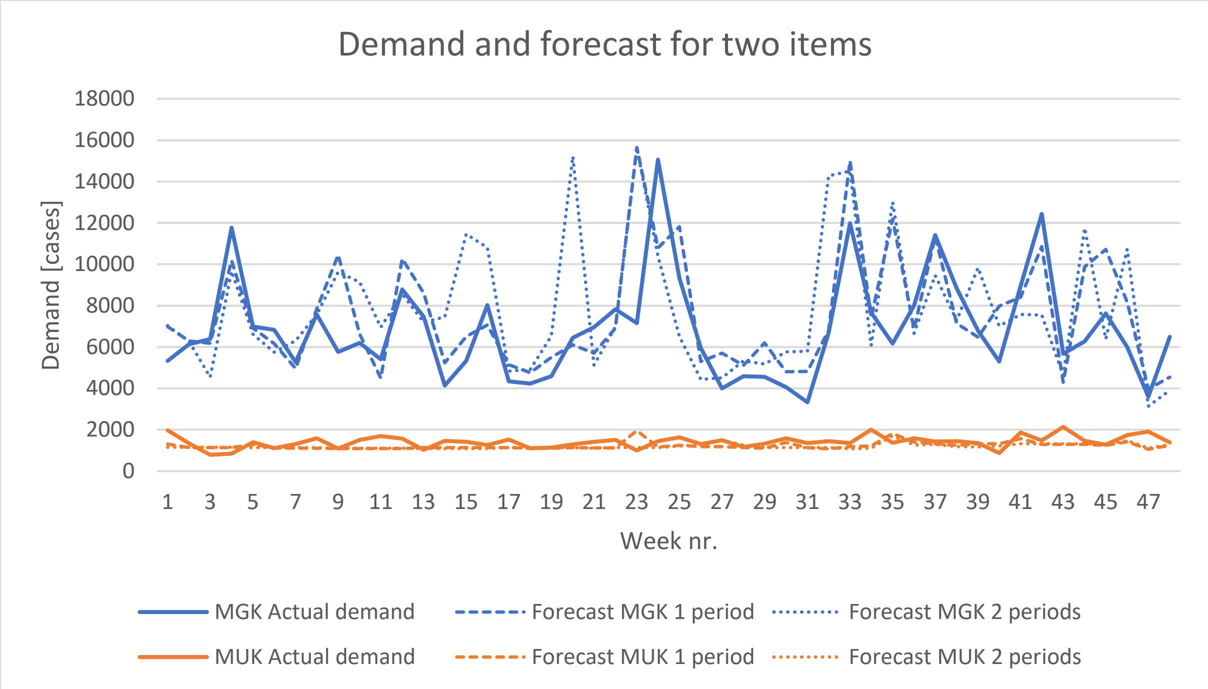

Figure 24 Graph showing demand and forecast for MGK and MUK

When comparing the forecast demand of a specific week with the actual sales, the percentage the forecast is off can be calculated. For the items MGK and MUK in 2018 this has yielded the following results:

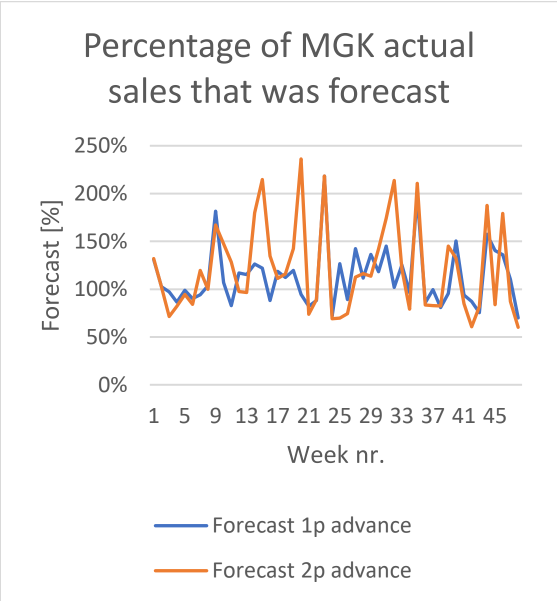

Figure 25 Accuracy graph of forecast for MGK

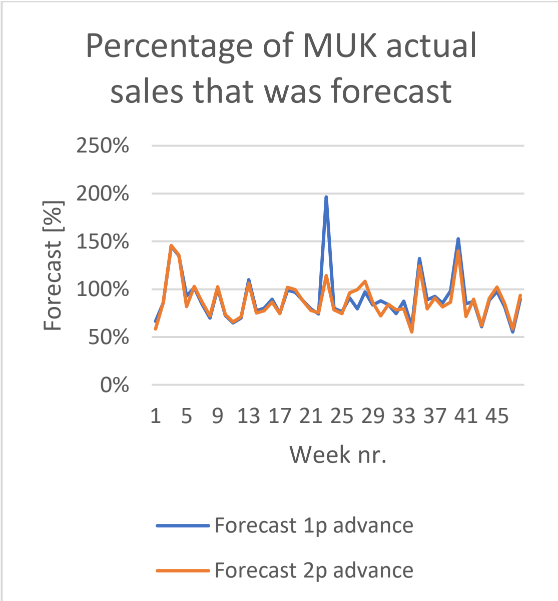

Figure 26 Accuracy graph of forecast for MUK

As can be seen in Figure 25 and Figure 26, the forecast accuracy is not always 100%. For MGK, an item with a large volume, the forecast 2 periods in advance is heavily fluctuating and also the forecast 1 period in advance is still fluctuating although less. For the MUK item however, the forecast 1 period or 2 periods in advance are almost identical and the fluctuations are smaller. When looking closely at what sales are forecast and what sales are not, a scatter plot can provide additional insight. Here, in Figure 27, it can be seen that for MGK there is a wide range of actual sales and wide ranges of forecast sales for both 1 period ahead and 2 periods ahead. Interestingly, the forecast of 1 period in advance much better corresponds to the best fit linear trend line than the 2 period ahead forecast.

In Figure 28 however, it can be seen that for the MUK, the actual sales are spread out over quite a range, while the forecasts concentrate on a much smaller range around 1200 cases. For this item both trend lines are nearly horizontal and both do not correspond much to the actual data points. Interestingly, due to forecast spike 1 period ahead in the week 23, the trend line for the 1 period forecast is even less accurate than that of forecast for 2 periods ahead.

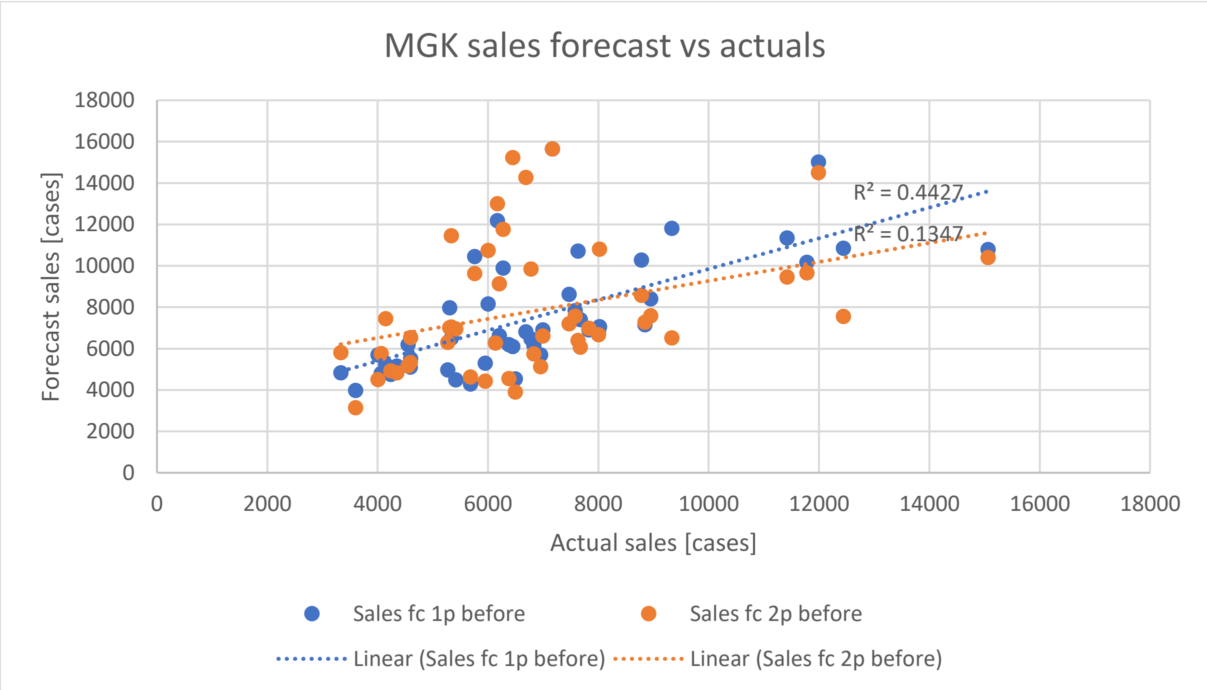

Figure 27 Forecast sales plotted against actual sales for MGK

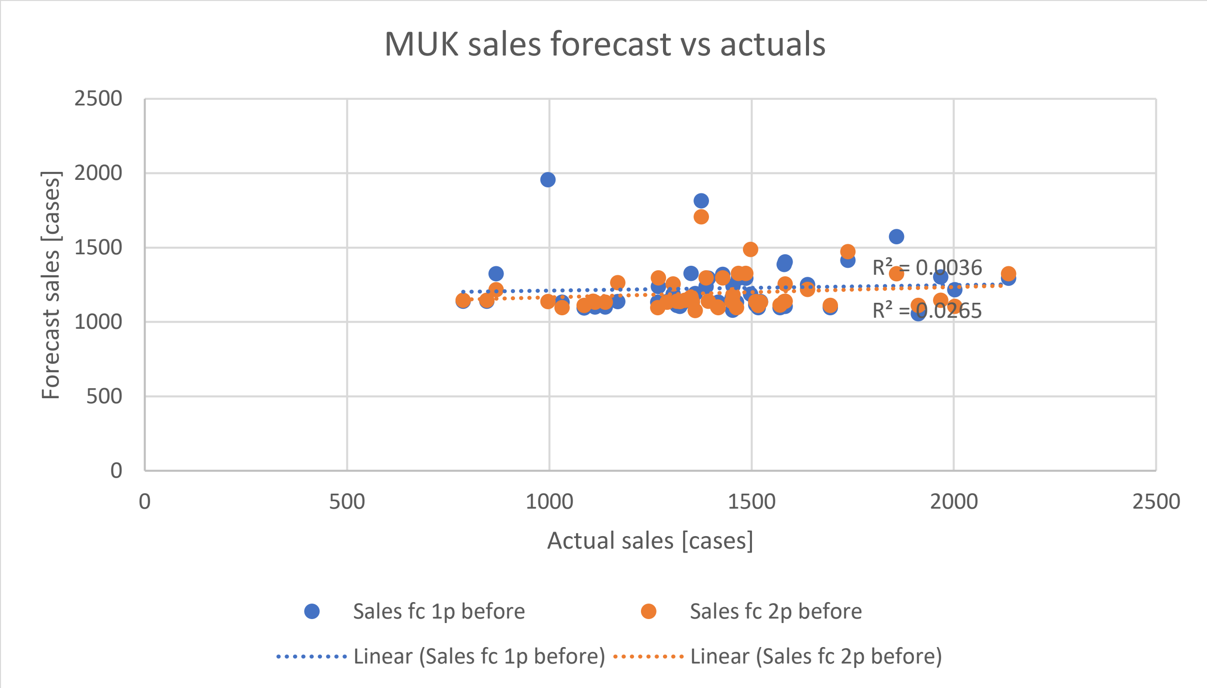

Figure 28 Forecast sales plotted against actual sales for MUK

The accuracy of the predictions can be plotted in graphs as well. Here it can be seen that there is somewhat of a normal distribution apparent. For the items MGK and MUK, for a 1 period advance forecast, the means are 113% and 91% respectively, and the standard deviations are: 31% and 25%. For a 2 period advance forecast the means are 121% and 88% with standard deviations of 47% and 20%. This means that for the MGK, the bigger volume item, the forecast becomes better with a shorter horizon. For the MUK however, the forecast decreases in accuracy and the standard deviation increases with a shorter horizon. This is counter intuitive as one expects forecast accuracy to increase with a shorter horizon rather than decrease, since at least the same, and probably more information is available when making the short-term forecast. In the following graphs the distribution of accuracies is presented:

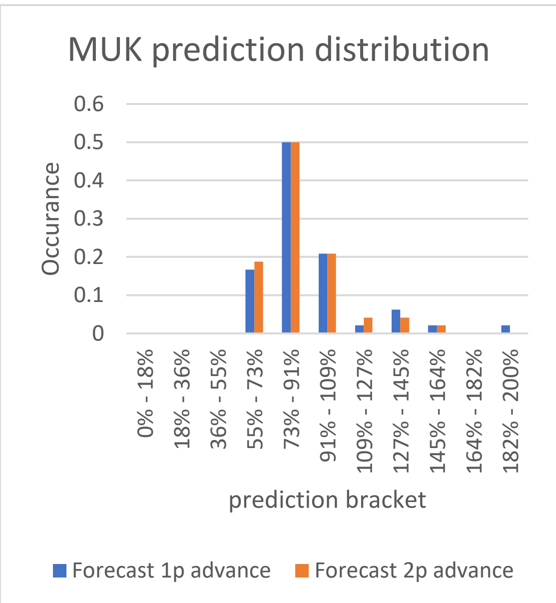

Figure 29 Distribution of accuracies for MUK

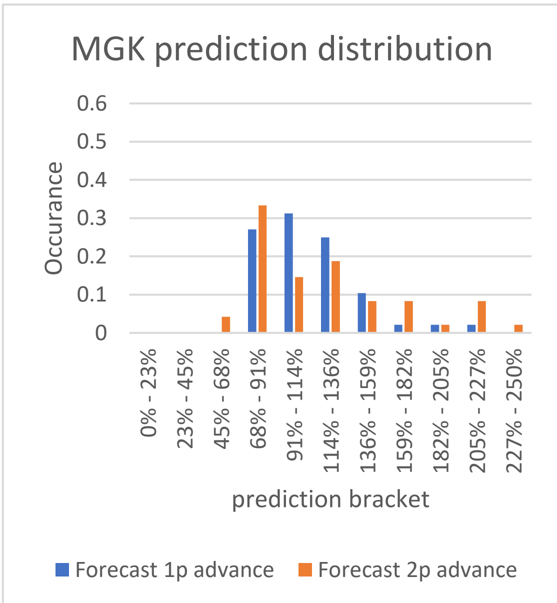

Figure 30 Distribution of accuracies for MGK

As can be seen in Figure 29 Distribution of accuracies for MUK and Figure 30 Distribution of accuracies for MGK, the accuracy of the forecast is distributed over a range of accuracies. For the MUK this has the shape of a normal distribution for both 1 period advance and 2 periods advance. For MGK however, the normal distribution shape is harder to distinguish.

6 Method

In order to reduce nervousness and improve service level, two alternative methods for planning were formed. Together with a simulation of the current method of planning, three situations can be compared. To do so a selection of performance indicators is made. The goals of selecting performance indicators is to be able to quantitatively compare the different methods of planning. The comparison is done on a variety of scenario's, to provide insight in the strengths, and weaknesses of the methods. In this chapter a description of the proposed methods is given, the performance indicators are selected, the working of the model is given and the different scenarios are presented.

6.1 Description of Alternative methods

To see if the current method of planning can be improved, two alternative methods were formed. These methods aim to overcome the downsides of the current method. In this chapter the working of these methods is explained in three sections. First the basic, shared principle of the alternative methods is explained. Then for each method a specific implementation of that principle is described in sections two and three.

6.1.1 Most Urgent First

In chapter *2.3.2 Other techniques for decreasing nervousness of a production schedule* it was described how decreasing the planning horizon can lead to more stability, increasing the proportion of the planning horizon that is frozen lead to more stability, and how keeping a far horizon for demand forecast beyond the planning horizon increases stability. Furthermore, inspiration was drawn from the findings of (Veeke, 1983). Here, emphasis is put on the necessity of freedom for the scheduler to be able to make decisions regarding production when the reality of the work floor is different from that of the predicted state by the planner. The difference in reality on the work floor form that of the planned state is a result of the stochastic nature of different processes in production.

The 'Most Urgent First' method aims to accept the uncertainty of reality and to give the work scheduler the freedom to make what is most necessary, rather than to force him or her to choose between adhering to the production plan, or preventing going out of stock. This is done by enabling the scheduler to schedule production for items that are urgent, and not only items that are planned to be produced. Instead of discouraging breaking a planning cycle and adding an ad-hoc extra production moment when an item goes out of stock, the 'Most Urgent First' method simply accepts that it is difficult to accurately predict how much stock will cover the period up until the next production and therefore it allows extra production moments. The planning horizon is much shorter, up till almost non-existent. The amount of demand that actually occurs is determining for the actual period an item can go without production.

In Figure 31 an example of demand is given for a 12-week period. The average demand is 100, but as can be seen, the demand per week fluctuates. Furthermore, a 30% deviation of the forecast demand is given, as a forecast is not completely accurate.

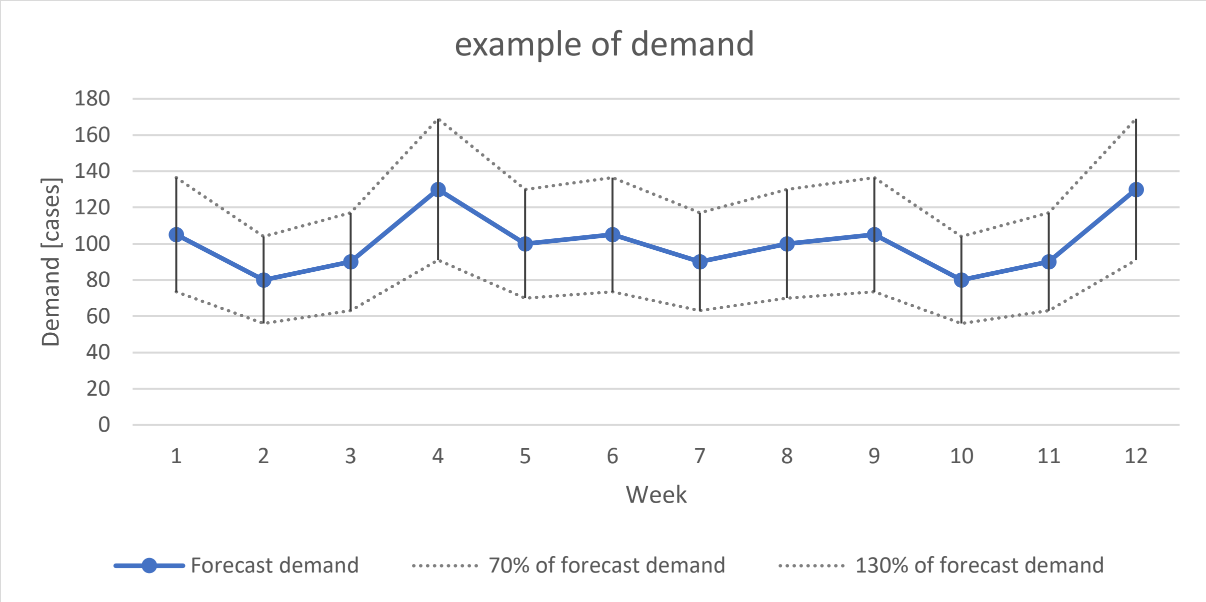

Figure 31 example of estimated demand and a 30% variation bandwidth thereof

In Figure 32 the cumulative demand for that same 12-week period is given, as are the 30% deviation bands. This graph shows that if this item is produced, and a quantity to cover 8 weeks is produced, a significant amount needs to be produced extra in order to be certain that demand can be met if the actual demand is different than the forecast. This is indicated by the red arrow in the figure. Alternatively, the moment production occurs can be made flexible. For higher than expected demand scenario's, the production needs to happen earlier (as indicated by the green arrow), and for situations where the actual demand is lower than expected the production can be pushed back, as the need to produce is lower.

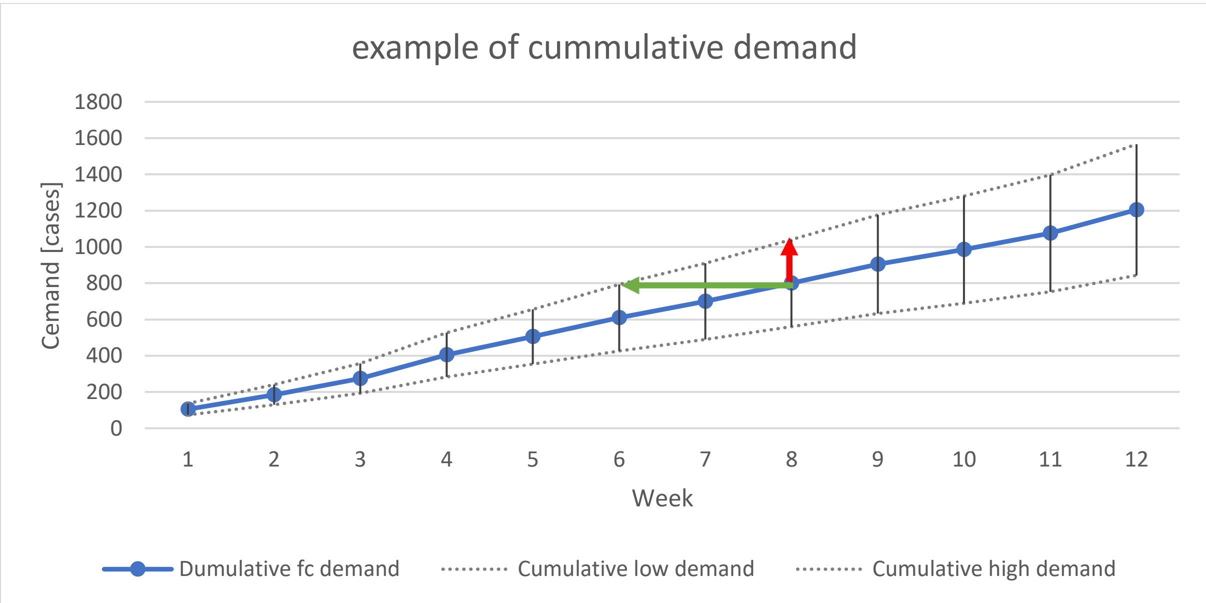

Figure 32 example of cumulated estimated demand and a 30% variation bandwidth thereof

In this situation it is no longer the planner that determines what item should be produced when, but rather the scheduler. The scheduler needs to have the information on what item is most urgent to make the decision on what to produce and the scheduler needs to know how much should be produced. To determine how much should be produced, both the current method and the 'Most Urgent First' methods can use the same lot sizing technique. For both methods the base production cycle length is used to determine how much demand is forecast until the next production moment. To determine what item is most urgent, the remaining days of stock is calculated for each item. This is done by estimating for how much time the current stock is enough to cover the expected demand. With the information on what item is most urgent, and how much should be made, the scheduler can decide what to make. To test the effectiveness of this method the Most Urgent First rule is applied hard, there are no exceptions to this rule.

6.1.2 Full & Empty weeks

At the beginning of the week, the demands for that week are subtracted from the stock. For all items a stock-cover period is determined and they are sorted according to the highest priority first. Production then starts with the highest priority item first and the method keeps repeating this until the week is finished and the machines are shut down. In the situation where the capacity of production is higher than the demand either the stocks are going to increase over time, or not all production time should be used. Uncontrolled increase of stock is not desirable so a limit on new production is formed. This is where the two versions of the Most Urgent First method come from. The first method keeps producing until at the start of a week, all items have enough stock to cover that week. In that case there is no need to start up that week and there will not be any production that week.

6.1.3 Short weeks

Alternatively, when all items have enough stock, instead of continuing production to enable 'free' weeks, it can also be decided to stop production. This leads to shorter weeks, where not all production capacity is used. The advantage of this method over full and empty weeks is that there is no extra stock buildup and the chance that the following week has more high priority items than that can be made is smaller.

6.2 Simulation Model Description

A model was formed to simulate different planning techniques. To work, the model needs specific input files. Then, a method to plan production can be selected. Finally, when the model runs it creates two output files that contain similar information as the historic data of the OBL plant.

6.2.1 Loaded files:

To import information that is specific to the simulated system files are imported containing information. The imported files are saved as comma separated files. Sometimes with a header to describe what information the file contains and underneath that a header for the name of the category. Two types of files are loaded into the simulation; files containing constant information that is equal throughout the simulation, and information that is time dependent. The files that contain information that is constant throughout the simulation are the production rates of all items, the starting stock level for all items, the predetermined economic order quantities, the manufacturing frequency index and the changeover times. Files that contain time-dependent information are the demands and forecast files.

Rates, Stocks and EOQs

The 'Rates.csv', 'Stocks.csv' and 'EOQs.csv' files contain a header to describe what is in the file and two columns. The first column has the items name on each row and the second column has the corresponding information in cases. For the production rates, that is in cases per hour, for the stocks and economic order quantities that is in cases total. The table that is used for the production rates is presented below in Table 6.

Table 6 table containing the information for the production rates

These are the production rates of the system.	
MEK	320
MFK	289
MGK	320
MIK	310
MKK	294
MQK	314
MRK	256
MSC	301
MTK	267
MUK	262

MFIs

The 'MFIs.csv' file contains more information than just the standard manufacturing frequency indexes. The header is still a single sentence describing the information but there are 10 columns containing information. The first column still contains the names of each item, the second column the manufacturing frequency index, but the third up to the tenth column contain 'the horizon up to the next manufacturing point'. This is used for a planning system with fixed planning moments and possibly extra production moments to bridge the time between the extra production period and the next planned production moment. This means that for example an item that is planned to be produced once every 4 weeks can have a planned production moment in week 3 and in week 7. (and then further on again in week 11, 15, … etc.). If the item is produced in week 3, it needs to produce for 4 weeks. However, if for some unforeseen reason the item is also planned in week 5, it only needs to produce for 2 weeks ahead. Especially for products with MFI 1.3 this table provides crucial information on how big production should be, as the production horizon is two times 1 period, and 1 time 2 periods. 2 items are produced once every 8 weeks so 8 weeks is the length of the production horizon table, as can be seen in Table 7.

Table 7 table containing the Manufacturing Frequency Index and production horizons for each item on each period

These are the Manufacturing Frequency Indexes for the system.									
MEK	4	4	3	2	1	4	3	2	1
MFK	8	1	8	7	6	5	4	3	2
MGK	1	2	1	1	1	2	1	1	1
MIK	1	1	2	1	1	1	2	1	1
MKK	2	1	2	1	2	1	2	1	2
MQK	5	2	1	4	3	2	1	4	3
MRK	11	5	4	3	2	1	8	7	6
MSC	7	1	4	3	2	1	4	3	2

MTK	3	2	1	4	3	2	1	4	3
MUK	2	4	3	2	1	4	3	2	1

Changeovers

The ChangeOvers.csv file contains a header describing the contents of the file, and a second header containing the items where the change-over is to. The first column contains the names of the items the changeover is from. The last row is for the start-up situation. The next columns are for the change over time from each item, to each item. The last column is the change over time from each item to the shut-down state. In Table 8 the changeover times are presented as they are saved in the file.

Table 8 change over table

These are all change-overtimes in minutes for the system.											
Item:	MEK	MFK	MGK	MIK	MKK	MQK	MRK	MSC	MTK	MUK	SD
MEK	0	60	180	20	30	180	30	60	180	60	480
MFK	60	0	90	60	60	90	60	30	90	60	480
MGK	180	90	0	180	180	20	90	90	20	180	480
MIK	20	60	180	0	30	180	30	60	180	60	480
MKK	30	60	180	30	0	180	30	60	180	60	480
MQK	180	90	20	180	180	0	90	90	20	180	480
MRK	30	60	90	30	30	90	0	60	90	60	480
MSC	60	30	90	60	60	90	60	0	90	60	480
MTK	180	90	20	180	180	20	90	90	0	180	480
MUK	60	60	180	60	60	180	60	60	180	0	480
SU	195	120	195	195	195	195	120	120	195	195	0

Demands

The ‘Demands.csv’ file is one of the files that is time dependent. It contains a header to describe the contents of the file and a header to describe the column below it. The first column are the items for which a demand is defined. After that, there is a column for every week where the demand for each item is defined. There are as many columns as there are weeks for which demand is defined.

Table 9 example of data in a demand file

These are all demands of the system.									
Item:	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9
MEK	1590	1179	1230	1333	591	716	576	539	-313
MFK	365	606	-18	644	349	-3	-92	164	417
MGK	5846	7439	6604	8961	7109	8633	11765	5606	11083

MIK	1418	7854	6610	13662	8424	8826	8149	20843	1055
MKK	2875	2182	5179	3389	2226	1768	739	2279	760
MQK	963	351	475	345	-281	949	1312	419	1706
MRK	640	123	485	1	236	69	330	404	332
MSC	-1224	793	-316	1100	431	-1548	988	-368	-323
MTK	2072	1499	307	1347	3149	-598	1958	2491	917
MUK	1816	1788	1943	1438	1990	2185	1441	1611	1619

Forecast

The last file, or better yet, 'files', are the forecast files. Since the forecast for each week is made for every week up to two years in advance of that specific week, there are three dimensions to this figure. There is the item the forecast is made for, the week the forecast is made in, and the week the forecast is made for. To overcome this extra dimension there is a limit of 7 weeks on how many weeks ahead is forecast. There are forecasts for 0 weeks ahead up until 7 weeks ahead, named 'Forecast0wk.csv' to 'Forecast7wk.csv'. In each of these forecast files there is a header row to describe what is in the file, and a row that categorizes the first column and then counts the weeks, starting from 'Week 1'. The first column below the two header rows contains the item names, after that each column contains the forecast for each item according to the week number. The size of the forecast is given as a percentage, where 100 means 100% of actual demand is the forecast demand. A forecast file looks like the table below in Table 10. In the table it can be seen that the first item 'MEK' has a forecast percentage of 111 in Week 1. 111% of 1590, the actual demand from Table 9 for that item in Week 1, is 1765. The forecast demand for 'MEK' in Week 1 is thus 1765.

Table 10 forecast table

These are the forecast demands of the system.									
Item:	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9
MEK	111	89	84	91	124	123	123	97	99
MFK	80	97	89	76	111	84	60	68	57
MGK	146	106	83	82	158	135	103	86	95
MIK	101	101	94	83	111	61	80	58	98
MKK	120	132	90	122	102	96	96	85	129
MQK	116	112	99	116	94	133	74	100	137
MRK	91	99	86	79	98	79	88	100	116
MSC	97	119	110	85	115	65	146	96	84
MTK	98	115	111	101	95	93	136	103	50
MUK	107	96	112	84	109	69	106	69	102

6.2.2 Working of the model

The model works by loading the files as described before into the memory. It does so in the form of arrays of integers. For two-dimensional data like the MFI table, the change-over table and the demand table a two-dimensional array is made. For the forecast, a three-dimensional table is made.

The following processes then further handle the information that is loaded into the simulation.

Calcdays

A procedure that calculates the days of stock each item has by doing the following:

1. Make a metric called 'projected stock' and set it equal to the current stock of that item.
2. Keep subtracting the forecast demand of this stock until the projected stock would become negative.
3. At that moment, divide the remaining projected stock by the forecast demand and multiply that fraction by 5 (days).
4. For each week of full projected demand that can be covered, 5 days of stock are calculated and added to the part of the week that can be covered.
   Two arrays are then filled:
5. The first array is the PrioPlace array. In this array for every item the place in the priority order is noted. If item 0 has the third highest priority, the PrioPlace array will start with '2' (indexing starts at 0).
6. The second array is the PrioOrder. In this array the item numbers are given for items from highest priority to lowest priority.
7. The procedure ends with updating the days-of-stock overview in the control screen.

FindOrder

A function to organize the items by priority based on the days of stock. It needs a list of values and the index for which the new position will be returned. To so it does the following:

1. Set the first value as the first of an array of 'SortVals' and set the number 0 as the first of an array of 'Neworder'.
   For as long as the array of input values is, keep doing the following:
2. Compare the next value with the SortVals and, when the first time a SortVals value is larger, the new value is placed between that value and all values that are lower.
3. The same is done for the indexnumbers in the 'Neworder' array.
4. When all values are sorted this way, the result of the function is the new position in the priority list for the item number given to the function.

Findsize

A function that returns the production size of any specified item. The size depends on the planning method used.

If the planning method is the same method that is currently used at Mars OBL it begins by:

1. Determine where in the 8-week cycle the current week is.
   From the MFIArray the number of weeks ahead should be produced is retrieved. For that number of times the following is done:
2. The current stock is made negative and for the number of weeks ahead necessary forecast demand is added to it.
3. The amount to be produced is rounded and the minimum is 0.

If the planning method is other than the method used at Mars the following is done:

1. From the MFIArray, the forecast horizon is retrieved.
2. For the length of the horizon, the forecast is added to the negative current stock
3. If the resulting quantity is still negative, more weeks of forecast are added until a nonnegative number arises.
4. The result is rounded into an integer and returned.

Line (create/process)

The line is the process that simulates the operation of the production line in OBL. When there is an order it needs to know what to produce and how much of it. When the production of an order is finished it sends that message to the planner and when it receives a new order it starts to execute that order, but only when the machine is changed to the new item. Changing to a new item is only done if there is enough time in the week to do so. If the time runs out during a changeover, or the production of an item takes longer than there are work hours in a week the action is cut short to make sure the machine is always finished at the end of the week. When a new week is started this is done so by first changing over from shutdown to the first item by a startup changeover.

Repeat:

1. The process is held until activated by the ‘planner’ process. When activated:
2. Register the time the process is activated.
3. Retrieve a running efficiency from a sample.
4. Determine the stopping size for the assigned item.
5. Find the standard production rate for the assigned item.
6. The duration of the production run is determined by the size, divided by production rate and the running efficiency.
7. The change over time from the former item to the current item is retrieved from the change-over-array.
8. If the time remaining in the week is more than the change-over time and the time required to shutdown, the following happens:
    a. The change over is registered.
    b. The process holds for the change over time.
    c. The run duration is made sure to fit in the remaining time for the week.
    d. The number of items that is produced in the run duration is determined.
    e. That number of items is registered as production
    f. The process is held for the time required for production
    g. The number of items that is produced is added to the stock of that item.
    h. The number of items that is produced is added to the weekly production overview
    i. The new amount of days of stock is determined and updated.
9. Otherwise, if the time remaining in the week is less than the change-over time and the time required to shutdown, the following happens:
    a. The item to produce is the shutdown state.
    b. The change-over time to the shutdown state is determined.
    c. The change-over to shutdown is registered.
    d. The process is held for the change over time.
10. Now that the change-over and production of the assigned item are finished the planner is notified and activated.
11. The assigned item becomes the last produced item.

Planner (create/process)

The planner determines what the line should be producing. Three methods are defined and described in this section. In all methods the planner gives a job to the production line and then waits until the production line is finished and asks for a next job.

If the original planning method is used, for 8 weeks there is a list of what items should be produced. Depending on the week the length of these lists varies. To see what should be produced the following steps are taken:

Repeat:

1. While CurWeek is WeekNr:
2. The items-produced counter begins at 0
    a. Repeat:
        i. If the items-produced counter is as long as the number of items that should be produced, the planner holds until the end of week
        ii. In other cases, the production line is ordered to produce the next item of that week
    b. The items-produced counter is incremented by 1.
    c. The 'Line' is activated to continue.
    d. The planner process is held until activated by the 'Line' process

Since when all items are produced the planner is held until the end of the week, it is only activated to continue in a new week. At that moment the counter is reset to 0 and items from the next week are produced.

If the planner method is to only plan the most urgent, and to only start work in a week if the urgency is high, the following steps are repeated:

Repeat:

1. Determine how many days of stock there are for every item.
2. The highest priority item is selected as the 'assignment'.
3. At the beginning of a week, and as long as the number of days of stock for the 'assignment' item is more than 1 week, repeat the following:
    a. Wait one week.
    b. Recalculate the priorities and days of stock.
    c. Reassign the 'assignment' as the highest priority item.
4. Assign the 'assignment' item to the production line.
5. Activate the production line
6. The planner process is held until activated

If the planner method is to only plan the most urgent, and to stop working if there is no more urgency for the current week, the following steps are repeated:

Repeat:

1. Determine how many days of stock there is for every item.
2. The highest priority item is selected as the 'assignment'.
3. If the days of stock for the assignment item is less than 1 week do the following:
    a. Production line is assigned to produce the 'assignment' item.
    b. The production line is activated to continue.
    c. The planner is held until activated.

   Else if the days of stock for the assignment item is not less than 1 week do the following:
    a. Wait until the end of the week.

b. Recalculate the priorities and days of stock.
c. Assign the highest priority item to the production line.
d. The production line is activated to continue.
e. The planner is held until activated.

Outbound

The outbound process detracts the orders of all items at the end of each week. It does so by looking up the actual demand for that week, and subtract that from the stock, as described below:

Repeat:

1. For each item:
   a. Retrieve the name of the item.
   b. Retrieve the demand for that item in the current week from the actual demand array.
   c. Subtract from the stocks array the demand for the specific item.
2. After all demands have been subtracted the remaining days of stock are recalculated and updated.
3. A snapshot of the status is made.
4. The total week production for all item is reset to 0.
5. The process is held 1 week.
6. The week number is increased by 1.

Snapshot

A Snapshot of the current state is a simple periodic registration of available information. For each week, for each item, the following is registered: The stocks, the demand, the production and the estimate of days of stock.

6.2.3 Output files:

When running the simulation, two output files are created. A Results file and a Snapshots file. Both files are comma separated files but the information they contain is organized differently.

Results

The results.csv file registers operations of the production line. It does so by registering each production run, and by registering each change over. Each registration is on a new line and there are 5 columns. The first column describes the start item of the action, the second the end item of the action, the third the begin time of the action, the fourth the duration of the action and if there was production, the fifth column describes the number of items produced.

In general, a change over, with different start items and end items, and no production is followed by a production row. The production row consists of equal begin and end items and has a number of items produced. Table 11 gives an example of a results.csv file’s contents.

Table 11 example of results.csv contents

SU	MEK	0	3,25	
MEK	MEK	3,25	20,28125	6490
MEK	MRK	23,53125	0,5	
MRK	MRK	24,03125	11,55859	2959

MRK	MTK	35,58984	1,5	
MTK	MTK	37,08984	21,46816	5732
MTK	MKK	58,55801	3	
MKK	MKK	61,55801	39,94558	11744
MKK	MUK	101,5036	1	
MUK	MUK	102,5036	9,496413	2488
MUK	ShutDown	112	8	
SU	MFK	120	2	
MFK	MFK	122	9,307958	2690

Snapshots

Not only the results of the production are monitored. In the SnapShots.csv file a snapshot of the state of the system is made on the end of every week. In the snap shot the stocks, demands, production and estimated days of stock are presented for each item. It should be noted that the stock coverage can be negative, as the calculation for stock is stock divided by forecast demand.

Table 12 example of snapshot.csv with reduced number of items

Week	Stocks:			Demands:			Production:			Stock Coverage:		
Nr:	MEK	MFK	SU	MEK	MFK	SU	MEK	MFK	SU	MEK	MFK	SU
0	-390	135		1590	365		0	0		-0,044	0,092	
1	4921	-471		1179	606		6490	0		30,048	-0,160	
2	3691	2237		1230	-18		0	2690		25,051	50,123	

6.3 KPI's

6.3.1 Quantifying production schedule stability

Rejecting the theory that the downside of schedule changes can be expressed in a time-dependent cost, (de Kok & Inderfurth, 1996) state: *"Nervousness or, in other words, lack of planning stability can turn out to be a significant problem because it often generates a considerable amount of short-run and medium-term adjustment efforts as well as a general loss of confidence in planning."* And emphasize the non-quantifiable costs of nervousness, including "*the loss of good-will towards the planning system or planning department generating a negative contribution to the behavior of people engaged in developing and executing production plans can never be expressed in money."* Instead of quantifying the costs, they propose to make an independent metric measuring the nervousness. They do so by measuring the difference between expected production and real production in two measures. π_s Is the first measure, called *setup stability* and it measures if there is a change in the binary value 'production', or 'no production' of a specific item. The second measure, π_q measures the difference in quantity, or size, of production.

To do so the following parameters are used:

$$Q_t = \text{production in period '}t\text{'}$$

$$\hat{Q}_t = \text{predicted production in period } 't'$$
$$E[\cdot] = \text{expected amount}$$
$$max_{\mathcal{R},F_D} E[\cdot] = \text{maximum expected amount for all rules } \mathcal{R} \text{ and all demand profiles } F_D$$
$$\delta(Q) = \begin{cases} 1 \text{ if } Q > 0, \\ 0 \text{ if } Q \leq 0. \end{cases}$$

Equation 6 setup stability according to (de Kok & Inderfurth, 1996)

$$\pi_s = 1 - \frac{E\left[\left|\delta(Q_1) - \delta(\hat{Q}_1)\right|\right]}{max_{\mathcal{R},F_D} E\left[\left|\delta(Q_1) - \delta(\hat{Q}_1)\right|\right]}$$

Equation 7 quantity stability according to (de Kok & Inderfurth, 1996)

$$\pi_q = 1 - \frac{E\left[\left|Q_1 - \hat{Q}_1\right|\right]}{max_{\mathcal{R},F_D} E\left[\left|Q_1 - \hat{Q}_1\right|\right]}$$

This idea is not new, as (Sridharan, Berry, & Udayabhanu, 1988) already proposed to improve an existing method of measuring instability, or nervousness, that was formed by (Carlson, Jucker, & Kropp, 1979), who in turn based his method on research of (Steele, 1975). This method already quantified the appearance of production orders in the Main Production Schedule, where it would weigh the size of the order and the distance in the future as a penalty. It is worthwhile to notice that the earlier versions of this metric did not incorporate planned productions that got cancelled as a cost, but only new, unplanned, productions.

(Carlson, Jucker, & Kropp, 1979) formed the following method of quantifying the planned costs, including cost for instability of the planning over time, as C:

For period k:

d_k = amount demanded,
h_k = holding cost per unit of inventory carried into period $k+1$,
s_k = setup cost,
v_k = schedule change cost for a new setup,
$\hat{x}_k$ = production lot size in existing schedule,
x_k = production lot size in new schedule (to be determined),
I_k = beginning inventory,
N = number of periods in the planning horizon,

Equation 8: Cost model including cost of instability by (Carlson, Jucker, & Kropp, 1979)

$$C = \sum_{i=1}^{N} h_k I_{k+1} + \sum_{k=1}^{N} s_k \delta(x_k) + \sum_{k=1}^{N} v_k \delta[\delta(x_k) - \delta(\hat{x}_k)]$$

With:

$$v_k = \text{Schedule Change Cost} = \begin{cases} \infty, & k = 1, 2, \ldots, p, \\ f(k), & k = p+1, p+2, \ldots, r, \\ 0, & k = r+1, r+2, \ldots, N \end{cases}$$

For $f(k)$ a nonincreasing function of k was proposed. For the periods where $k < p$, no schedule changes are allowed and thus $v_k = \infty$, whilst after $k > r$ changes in the schedule are without cost. Between p and r the cost of adding productions to the schedule decreases or stays equal due to the nonincreasing property of $f(k)$.

Continuing this train of thought, (Sridharan, Berry, & Udayabhanu, 1988) adjusted the method. The cost of instability, which was the last term of the formula of Carlson et al., was altered to measure the quantity of the difference of production between two schedules. In this measurement an increase in planned production is considered equally costly as a decrease in production. Furthermore, for the nonincreasing term $f(k)$ a specific formula was formed. This has led to the formula for the schedule instability I:[1]

Q_t^k = scheduled order quantity for period t during planning cycle k
M_k = beinning period of planning cycle k
α = weight parameter (0<α<1)
S = total number of orders over all planning cycles

Equation 9: Cost of instability by (Sridharan, Berry, & Udayabhanu, 1988)

$$I = \left[\sum_{\forall k>1} \sum_{t=M_k}^{M_{k-1}+N-1} \left| Q_t^k - Q_t^{k-1} \right| (1-\alpha)\alpha^{t-M_k} \right] \Big/ S$$

Later research of Sridharan and LaForge (Sridharan & Lawrence LaForge, 1989) used this same formula as a benchmark for analyzing the impact of safety stock on instability, cost and service, but expanded the benchmark with eight more statistics.

Table 13: Measures of instability by (Sridharan & Lawrence LaForge, 1989)

Statistic	Explanation
F-NEW	Frequency count of new orders
F-CANCEL	Frequency count of cancelled orders
F-ENLARGE	Frequency count of orders that were increased in quantity
F-REDUCE	Frequency count of orders that were decreased in quantity
Q-NEW	Order quantity (in units) of new orders
Q-CANCEL	Order quantity (in units) of cancelled orders
Q-ENLARGE	Quantity increase (in units) of orders that were increased
Q-REDUCE	Quantity decrease (in units) of orders that were decreased

More recent research on MPS has also been performed and yielded a different method of measuring instability on a production schedule. Jeunet et al. (Jeunet & Jonard, 2000) presented a review of five methods to quantify the stability of a production schedule. The five methods presented were used to compare different lot-sizing techniques with varying levels of demand variability. The production schedule was represented in binary form for a fixed period. An Item is either produced, or it is not. With a limited number of items this means that production in each period can always be expressed as a string of '1's and '0's. These strings can then be compared with one another. Different sources of forming a production schedule can be used to make comparisons. The final production schedules generated by different lot sizing algorithm are used to measure the variability of these lot sizing algorithms. This means that the forecast production schedules are discarded and the variance between weeks is

[1] Note: numbers used previously are not redeclared

measured, and not the variance of a forecast production schedule that changes over time as the horizon approaches. The following methods have been identified:

$\#\mathcal{V}$:Measuring the total number of binary strings that occur

A next step is to weigh the strings based on how often they occur, similar to the Herfindahl index. To do so the occurrence frequency λ_i is determined for every unique string V_i. When normalized this gives the following formula for $0 \leq H \leq 1$:

Equation 10: measure of instability by weighed frequency analyses (Jeunet & Jonard, 2000)

$$H = \frac{\#\mathcal{V} \sum_{i=1}^{\#\mathcal{V}} \lambda_i^2 - 1}{\#\mathcal{V} - 1}$$

Alternatively, the highest frequency can also be noted as ϕ:

Equation 11: measure of instability by max frequency analyses (Jeunet & Jonard, 2000)

$$\phi = \max\{\lambda_1, \dots, \lambda_{\#\mathcal{V}}\}$$

In addition to these measurements of frequency it can also be analyzed how different the occurring production strings are. The first three measures do not make the distinction between one product, a single '1' or '0' different or all digits different is not distinguishable in the first three resulting indicators. The fourth and fifth however do take this into account.

This is done by measuring the 'distance' between two ordering vectors. For every digit the absolute distance is determined. The sum of these distances is the distance $\delta(\mathcal{V}_1, \mathcal{V}_2)$ between vectors. The product of occurrence frequencies λ_1 and λ_2 is the occurrence of this distance. The sum of all occurrences of all distances is the average distance between ordering vectors Δ:

Equation 12: measure of instability by frequency distance (Jeunet & Jonard, 2000)

$$\Delta = \sum_{i=1}^{\#\mathcal{V}} \sum_{j=1}^{\#\mathcal{V}} \lambda_i \lambda_j \delta(V_i, V_j)$$

With: $\delta(V_1, V_2) = \sum_{t=1}^{T} \left| V_{1,t} - V_{2,t} \right|$ for ordering vectors $V_{i,t}$ of length T .

The distance of a specific ordering vector can also be in referenced to the average ordering vector. Here, instead of using Boolean '1's and '0's, the average ordering frequency $\overline{V_t}$ per item is used to calculate R:

Equation 13: measure of instability by average deviation (Jeunet & Jonard, 2000)

$$R = \sqrt{\frac{1}{T} \sum_{t=1}^{T} \left(\sum_{i=1}^{\#\mathcal{V}} \lambda_i \left(V_{i,t} - \overline{V}_t \right)^2 \right)}$$

Table 14: overview of different measures of instability (Jeunet & Jonard, 2000)

Statistic	**Explanation**	**Interval (from most robust to completely nervous)**
$\#\mathcal{V}$	Count of order vectors	$[1, \infty]$
H	Frequency measure of ordering vectors	$[1, 0]$
ϕ	Maximum frequency of ordering vectors	$[1, 0]$
Δ	Weighted average distance between ordering vectors	$[0, \infty]$

R	Average deviation of the mean ordering vector	$[0, 1/2]$

6.3.2 Other important performance indicators

Besides the measures for instability, planning and scheduling methods are evaluated on different grounds as well. Historically, the computational requirements for forming a MPS and consequently a MRP was an important factor in deciding what method to use. (Blackburn & Millen, A Methodology for Predicting Single-Stage Lot-Sizing Performance: Analysis and Experiments, 1985) (Axsäter, 1983) Nowadays algorithms are judged on their performance in other ways. The results of the algorithm are what drives selection of them. Not only in terms of nervousness but also the resultant costs, or optimality, of the MPS that is formed. And lastly, the effectiveness of the MPS is important. This is measured as a Customer Service Level.

Cost

A general model for determining the cost planning and scheduling was formed by Wagner and Whitin (Wagner & Whitin, 1958) for a single item, and this was expanded into a model for multiple items by Manne. (Manne, 1958) In this model cost is attributed to the set-up of a production run and to the holding cost of inventory. Trigeiro et al., (Trigeiro, Thomas, & McClain, 1989) added the cost of production per item unit forming the equation:

Equation 14: Calculation of cost of production and keeping stock as presented by (Trigeiro, Thomas, & McClain, 1989)

$$C = \sum_t \sum_i H_{i,t} I_{i,t} + \sum_t \sum_i c_{i,t} X_{i,t} + \sum_t \sum_i S_{i,t} Y_{i,t}$$

With:

$H_{i,t} =$ holding costs per unit per time period for unit i in time period t
$I_{i,t} =$ inventory of item i at period t that is being carried over to period $t+1$
$c_{i,t} =$ cost of production per item i at period t
$X_{i,t} =$ productionsize of item i at period t
$S_{i,t} =$ set up cost to start production of item i at period t
$Y_{i,t} =$ production Boolean for item i at period t

Since the costs of inventory, for production and set-up of production for any item i are often assumed time-independent, the simplification can be made to exclude the time dimension from the equation. Furthermore, when the cost of production per item is time-independent, it is no longer of influence in the production planning. It occurs for every item made and can be used to determine the price of the item but does not influence the moment it is made.

Customer Service Level

The customer service level is the percentage of orders from clients that is delivered on time. Li et al., describe it as *"[...] meeting due dates has always been one of the most important objectives in scheduling and supply chain management"* (Li, Sun, Xu, & Li, 2010) , based on several sources. It was found that tardiness, or missing of due dates results in penalties like loss of customer goodwill and damaged reputation. Sawik states that cost optimization is equally important to Customer Service Level. (Sawik, 2014) and that together they are the most important criteria for supply chain performance. The measurement of CSL is as follows:

With:

$Z_i^t =$ On-time delivered items i on period t

Equation 15 Calculation for Customer Service Level percentage

$$CSL = \frac{\sum_i \sum_t Z_i^t}{\sum_i \sum_t D_i^t} \times 100\%$$

Capacity

In real world systems the availability of production capacity is limited. This leads to a constraint in what can be made per period of time. An equation to formalize this constrain was formed by (Trigeiro, Thomas, & McClain, 1989):

Equation 16: capacity limit of production as by (Trigeiro, Thomas, & McClain, 1989)

$$\sum_i b_i X_{i,t} + \sum_i s_i Y_{i,t} \leq CAP_t$$

With:

$$b_i = \text{capacity requirement per unit } i \text{ of production}$$
$$s_i = \text{capacity requirement per production setup of } i$$
$$CAP_t = \text{capacity limit at period } t$$

Taux de Rendement Synthétique

TRS is the measure that presents the ratio of useful time over required time in order to produce the useable production. Useful time, t_U, is the time required under optimal production circumstances to produce. t_R is the time required in reality to produce. This includes production of items that are below the quality threshold and thus are discarded, it includes the fact that production is not always at the optimal speed and it includes time where the machine is stopped for unforeseen events. Foreseen events that cause a stop, or no production for a certain amount of time are the installation of new equipment and replacements of larger components or public holidays. Change-overs fall in between these categories because they are planned, but they are also considered small enough and directly linked to production to allow them to be grouped with unforeseen events like small stops to fix errors, adjust settings or replace wearable items. It is therefore that both at Mars as in the definition by (Leveugle, n.d.) Change-overs are considered unplanned time loss and therefore affect the TRS.

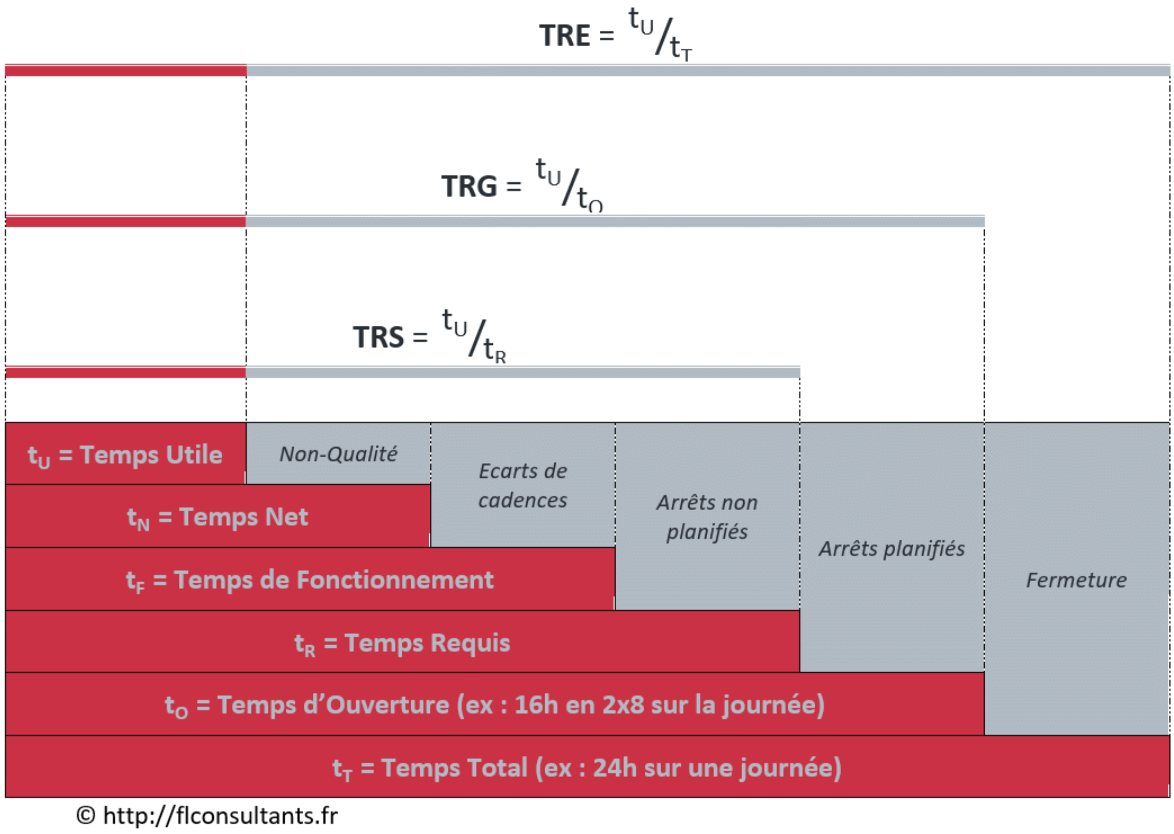

Figure 33 TRS calculation method by (Leveugle, n.d.)

6.3.3 Selected KPI's for designing a planning system at Mars Oud-Beijerland

In order to remain focused on delivering an improved planning and scheduling method, the number of KPI's that are used to measure and compare performances is limited. The objective is to reduce nervousness and improve customer service level. To do so Nervousness must be measured and quantified, as well as customer service level.

Nervousness

To quantify nervousness there are broadly three approaches. The first is to measure changes in the planning and to quantify these changes as a meaningful number in order to score the result. Equation 6 and Equation 7 and the measures presented in Table 13 follow from this approach. (de Kok & Inderfurth, 1996) (Sridharan & Lawrence LaForge, 1989)

The second method is to attribute costs to changes in the planning. It is a method to intrinsically benefit a stable planning to make sure forming a stable planning is valued. Equation 8 and Equation 9 are formed to use this method. The difficulty with this method is that it no longer allows to make a decision on how much added cost is acceptable to decrease nervousness, as not every system values the cost of nervousness equally. (Sridharan, Berry, & Udayabhanu, 1988) (Carlson, Jucker, & Kropp, 1979) (Steele, 1975)

The third approach is to make a statistical analysis on the occurrence of unique planning periods. In Table 14 an overview of Equation 10, Equation 11, Equation 12 and Equation 13. As this is primarily a measure of predictability of the planning this is not a suitable measure to quantify planning stability. (Jeunet & Jonard, 2000)

To quantify nervousness it was decided to use the method for setup stability of (de Kok & Inderfurth, 1996) as described in Equation 6.

Customer service level. The customer service level is the complement of the percentage of missed sales.

The performance indicator of CSL is straightforward and equal to Equation 15.

Table 15 Overview of KPI definitions

Performance indicator:	Equation:
Nervousness, Equation 6	$\pi_s = 1 - \frac{E[\lvert\delta(Q_1) - \delta(\hat{Q}_1)\rvert]}{max_{\mathcal{R},F_D} E[\lvert\delta(Q_1) - \delta(\hat{Q}_1)\rvert]}$
Customer Service Level, complement of Equation 15	$\gamma = 1 - \frac{\text{Sum of all negative stocks}}{\text{Sum of all demands}}$
Cost, simplified version of Equation 14	$C = \sum_t \sum_i H_{i,t} I_{i,t} + \sum_t \sum_i S_{i,t} Y_{i,t}$

6.4 Validation and Verification

This chapter provides a critical outlook on the research performed. It tests the research on the results and the link to the real world. It does so in two sections. In the first section the model is validated. The question on whether the model is the right thing for the real-world situation is asked. In the second section the model is verified. The question is asked if the model provides the correct answers, as one might expect.

6.4.1 Validation

To validate the model, the following question is proposed. *Are you building the right thing?* A positive answer leads to the conclusion that the model is a good way to approach answering the main research question. The research question is focused on selecting a good method to plan production of items on Line 4. Because disturbing operations to test if a proposed method works better can be costly if the proposed method does not work better, or if a large part of the supply chain needs to be redesigned in order to be able to test the proposed method, it makes sense to test the method in a less costly environment. Furthermore, analyzing multiple stochastic demands, stochastic forecasts and stochastic running efficiencies, becomes a very complex task. It also reduces the problem to a mathematical equation, or sum of equations, that require mathematical insight to understand. Creating a model and generating simulated results can provide insight in the working of the methods in a more visualized way.

One important aspect that needs to be validated is the nervousness indicator. In a truly fixed schedule setup, there is no nervousness. The production moments are fixed in time and the only thing that might happen is that the last the first items of a week take so much time to produce that there is no more time for the last item of the week, resulting in a missed production. This would be a direct consequence of a capacity constraint. The model that was made measures nervousness by comparing the estimated need to produce with the actual production. The idea is that when an item gets low on stock this causes stress, and that only when people know that the low on stock item is going to be produced, the stress is mitigated. In a fixed schedule system, the chances of the stress from the low stock being mitigated are not very high, since only when there is production in the next week this can be done. ‘missed production’, as defined as a low stock that needs replenishment is therefore still a good measure of nervousness, despite the fact production never was going to take place.

The current model allows for three methods to solve the same, selectable, problem. This gives the possibility to compare the methods on different aspects, providing key information to select the best suitable method. This answers the question: *'Are you building the right thing?'* Positively. Therefore, it validates the usage of the model as a research tool to come to an answer in the main research question.

6.4.2 Verification

To verify the model, the question *'Are you building it right?'* is asked. If this question is answered positively, it can be concluded that the model is verified to make a representation of reality. To test this, some simple example inputs are given to the model to see how they perform.

Comparison with historic demand data

When using the real demand that occurred in 2018 for the items of Line 4, the average demand per week is 2231 cases total. In the simulation, the average demand per week is 2290 cases. This indicates that the real-world average demand is 97.5% of the simulated average demand. When running the real world demands through the simulation model, the following data is found:

Table 16 Comparison of historic data results with simulated data results

Data + method:	Extra production	Missed production	Any alteration	Percentage negative stocks	Costs total [x1000]	Costs stocks [x1000]	Costs setup [x1000]
Historic + F&E	70%	3%	73%	0.1%	344	144	200
Simulated + F&E	64%	2%	66%	0.3%	334	137	197
Historic + Short	0%	3%	3%	0.8%	267	90	177
Simulated + Short	0%	2%	2%	1.1%	263	88	175
Historic + Fixed	15%	100%	100%	9.1%	203	46	157
Simulated + Fixed	19%	94%	95%	9.6%	205	47	158

Ideally speaking, the results from Table 16 would also be compared with the real-world data. For the costs however, this data is unavailable. For the extra, missed, or any altered production percentage of weeks the following data was found from the records of 48 weeks in 2018: 17% of the weeks had missed production, 8% had extra production and 23% had any change. In 2018, there were 42703 cases of Line 4 items not delivered, of which 23738 were due to a mismatch between production and demand. This leads to an Out of Stock percentage of 2,0 %. Significantly lower than the percentage of negative stocks the simulated Fixed method gets with the use of historic, or generated demand data. This is because in reality a safety stock is kept to prevent out of stocks. This part of the fulfillment stream is not simulated, but a general analysis has been made and is represented in section *8.1.2 Relation between Out of Stock situations and Costs*.

Analyses of basic performance

A general analysis of the model was also made. As input, demand for a single item is made with no variation in the demand, and a perfect forecast. The demand for all but one item is set to zero for 150 weeks, but kept average beyond that horizon. That way the days of stock measurement should be very large for these items, but not infinite. The analysis was made for 150 weeks. As can be seen, every four weeks the item is produced for the next four weeks. In Figure 35 a selection of weeks is made where it can be seen that the stocks for the item get replenished frequently and then deplete according to demand. In Figure 36 it can be seen that the estimate for ‘Days of Stock’ for the item MFK, an item that has zero demand for 150 weeks, is very high at the start of the simulation and diminishes over time until the demand is no longer zero. At that point production of the item starts again and thus the days of stock also get replenished. For the MEK item the Days of Stock graph is similar as the stock graph.

The verification of the other models is also included and present in Appendix B.

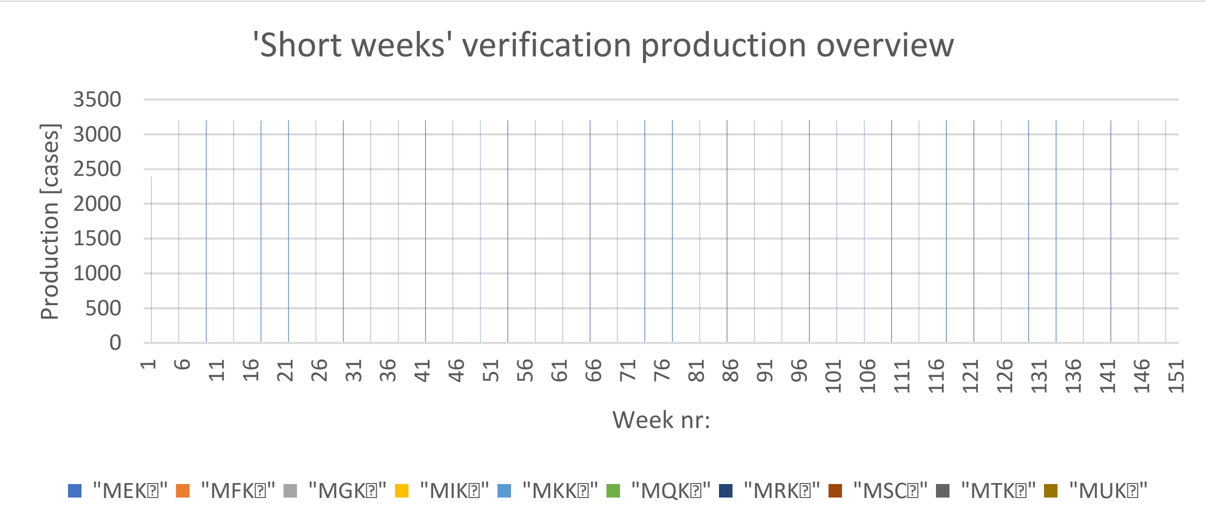

Figure 34 Verification of behavior of the 'Short weeks' method - production

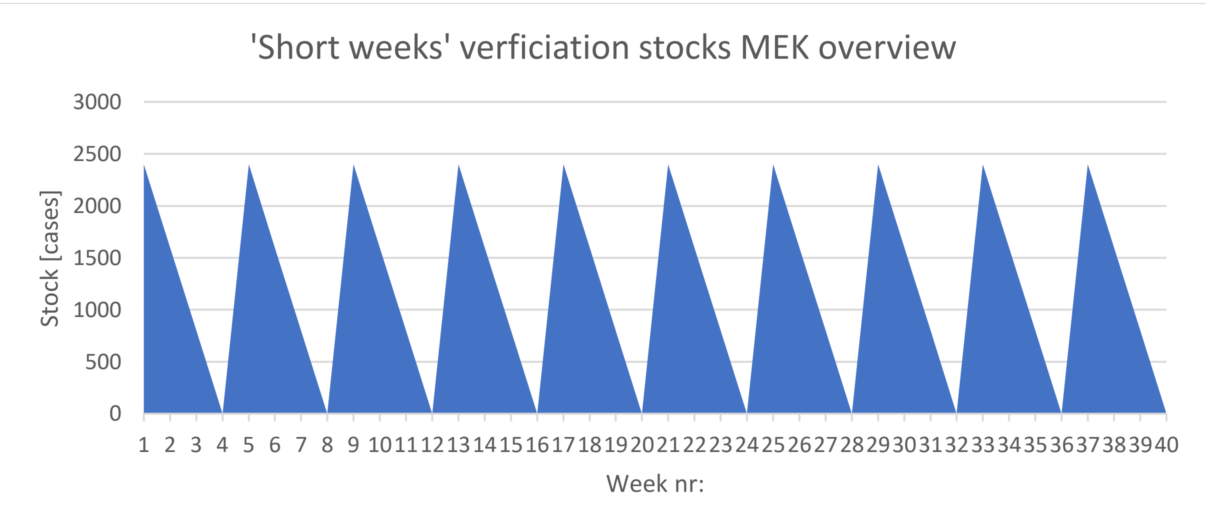

Figure 35 Verification of behavior of the 'Short weeks' method - stocks

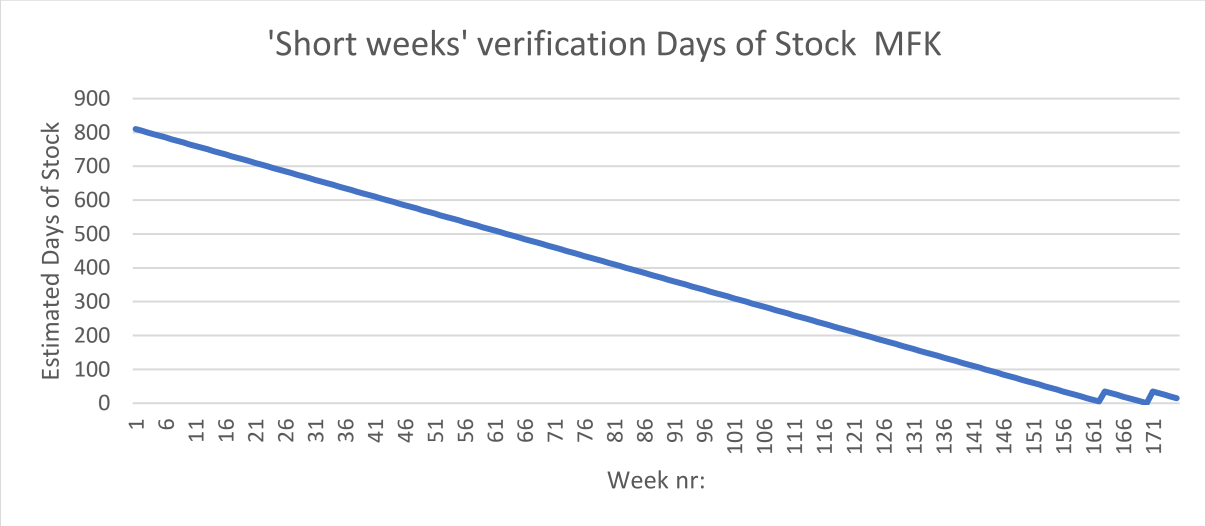

Figure 36 Verification of behavior of the 'Short weeks' method - Days of Stock

Analyses of standard performance

A second analyses on performance is done to see how the systems reacts on stable conditions. The demand standard deviation, forecast standard deviation and running efficiency standard deviation are all set to zero. This should result in a system that operates continuously over time. When the start up effect is left out of the results, the following graphs can be formed:

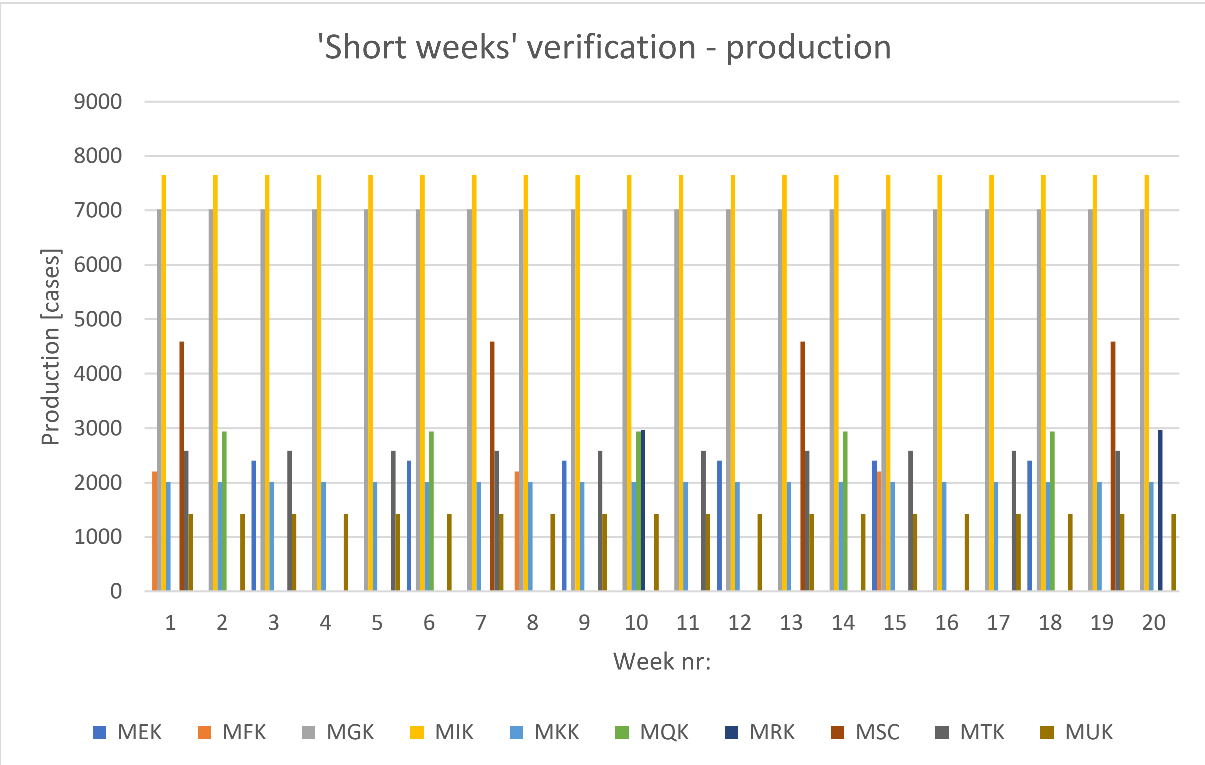

Figure 37 Verification of behavior of the 'Short weeks' method - Production

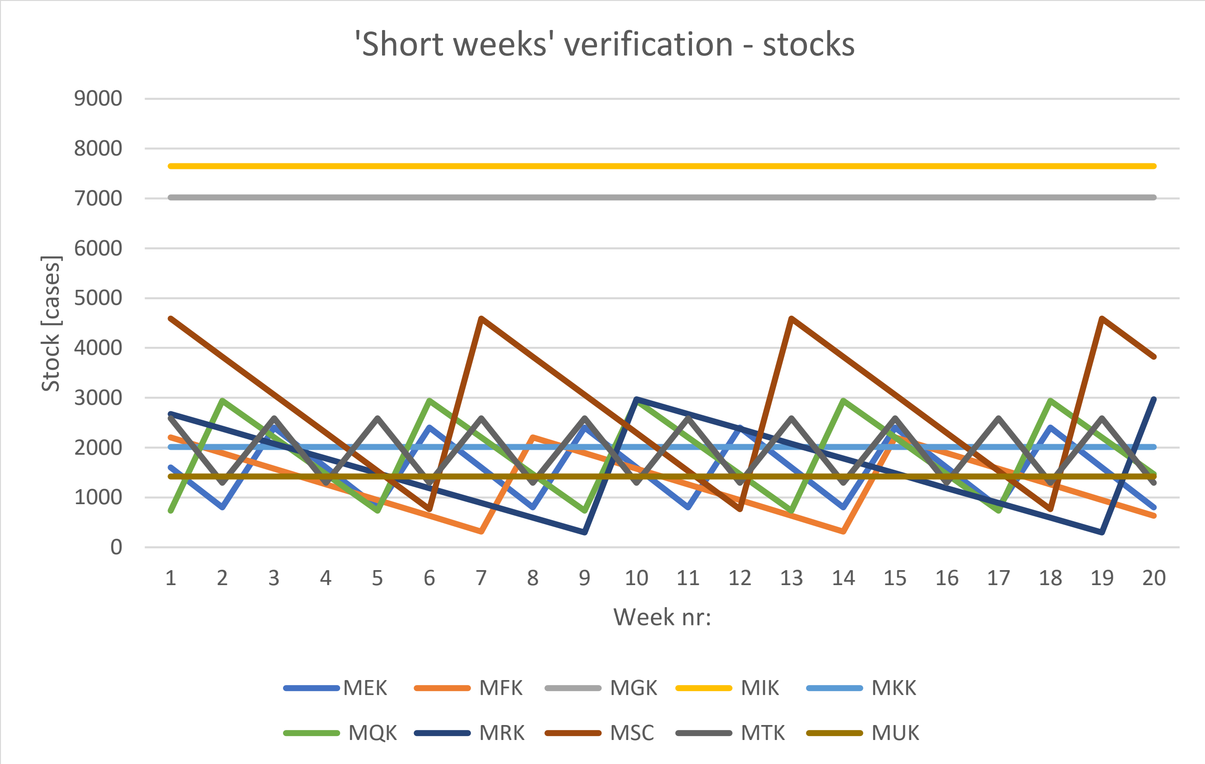

Figure 38 Verification of behavior of the 'Short weeks' method – Stocks

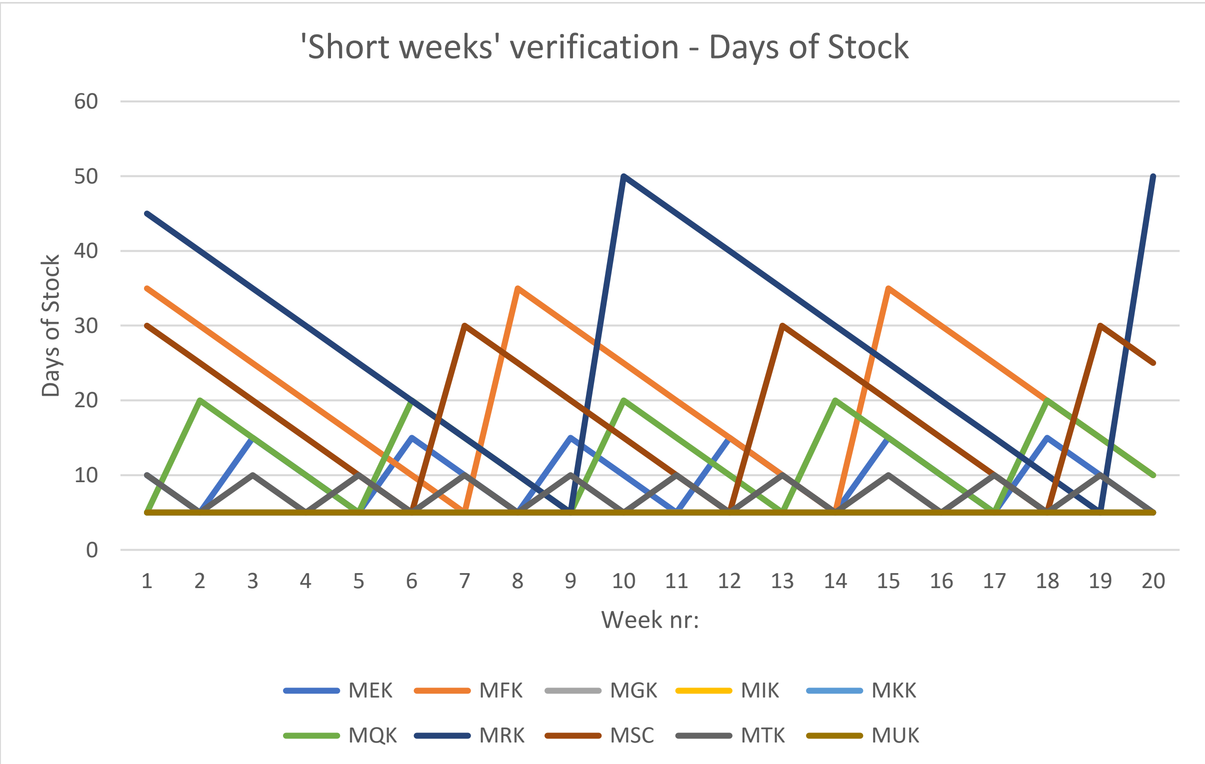

Figure 39 Verification of behavior of the 'Short weeks' method - Days of Stock

It was found that the patterns that are visible in these graphs repeat over time. A 20 week cut-out was used for visibility. It can be seen in Figure 37 that items MIK and MGK are produced weekly and in large quantities. An item like MSC is produced in weeks 1, 7 and 13 and is 6-weekly, whilst the MKK item is produced every three weeks, starting in week 3. In Figure 38 it can be seen that items that are produced every week have a constant stock level, whilst items that are produced intermitted form a saw-tooth pattern. The height is determined by the size of the productions and the angle of the downward slope is determined by how many weeks are between productions. In Figure 39 it can be seen how the stock horizon decreases for all items. It is worthwhile to notice the rate with which the stock decreases is equal for all items when there is no production. Every week, the stock level decreases with 5 days, which makes sense as workweeks are 5 working days.

Finally, a mathematical analysis of the verification run for 'Short weeks' is done. The sum of 258 weeks demand is compared with the sum of production for those weeks. In Table 17 the results hereof are presented. As can be seen, production is always more than demand, but not excessively.

Table 17 Verification of 258 weeks

Item:	MEK	MFK	MGK	MIK	MKK	MQK	MRK	MSC	MTK	MUK
∑Production	207459	81900	1811418	1973442	519354	191835	79299	198900	333852	366618
∑Demand	206658	81270	1811418	1973442	519354	189630	76626	197370	333852	366618
Difference	801	630	0	0	0	2205	2673	1530	0	0

From these analyses it is concluded that the model works correctly.

6.5 Scenarios for experiments

Several possible scenarios are tested to provide insight in the performance of the different methods. These scenarios are based on trends distinguished within the company.

6.5.1 Base level

To analyze the different scenarios under different circumstances a base demand scenario is made. This scenario is the starting point for all other scenarios. In other scenarios different parameters are analyzed in order to see what does what.

In the base scenario the demands are equal to what was found in section *5.2 Formalizing the historic demand*, both in terms of mean demand and standard deviation of demand. The forecast for this situation is made according to the section *5.4 Demand forecast.* When making the demand and forecast files, it is ensured all values are non-negative. This is done by changing negative values into zeros.

6.5.2 Adjusting average demand

Currently, Line 4 is not capacity constrained. However, if demand were to increase this could become the case. To see how the different methods cope the demand is fluctuated from 80% of the measured, current demand, to 150%.

6.5.3 Adjusting standard deviation

In the current situation there is significant fluctuation in the demand. This is represented by the standard deviation in the generated demand. It is uncertain if in the future the variability of the demand stays equal, increases or decreases. To see how different methods react to this a series of experiments must be performed. To do so demand files have been generated with different standard deviation. The standard deviation is varied from 0 to 8 times the measured normal standard deviation.

6.5.4 Accuracy of the forecast

The forecast that is used at Mars OBL has a limited accuracy. Predicting what the demand in the future will be appears to be difficult, and increasingly difficult for further horizons. The forecasts that are generated increase in accuracy toward the current date from 1.5 times the standard deviation to 0.7 times the standard deviation, and so does the average percentage of the occurring demand. These values are multiplied with a factor to see how resilient the different methods are to changes in forecast accuracy. The accuracy is varied from perfect, where the actual demand is always predicted, to half as accurate as the current forecast is.

6.5.5 Seasonality in the demand

The notion exists that for certain items there is a seasonality effect present. This means that the demand fluctuates within a year, depending on the seasons, or date related events such as Christmas, or (Chinese) new year. To see if the various planning methods are resilient to this effect all demands are multiplied with a sine curve that varies from 67% to 133% and has a frequency of 1 year, to allow a maximum seasonality effect of two times as much demand during peak as in low demand period. Smaller seasonality effects are added to see if a trend can be found.

7 Results

The different scenarios are all run in the simulation for the different methods of planning. The first 8 weeks are considered start-up time where start-up effects are present. To overcome this, the first 8 weeks are not considered in this simulation. The simulation is stopped when at least 275 weeks have passed. This way there are always 5 times 50 weeks available to analyze. The simulation is run on an Intel Core i5 processor at 2.6 GHz with 8GB RAM, and a simulation of 275 weeks takes approximately 33, 26 or 24 seconds depending on the planning method used. Respectively, Full and Empty weeks, Short weeks or Fixed method.

7.1 Average demand

Altering the average demand from 25% up to 150% allows to see how the different methods of planning cope with different demands.

7.1.1 Nervousness under varying demand

The week plans that were altered one week in advance of production are measured for the different planning methods under varying demand levels.

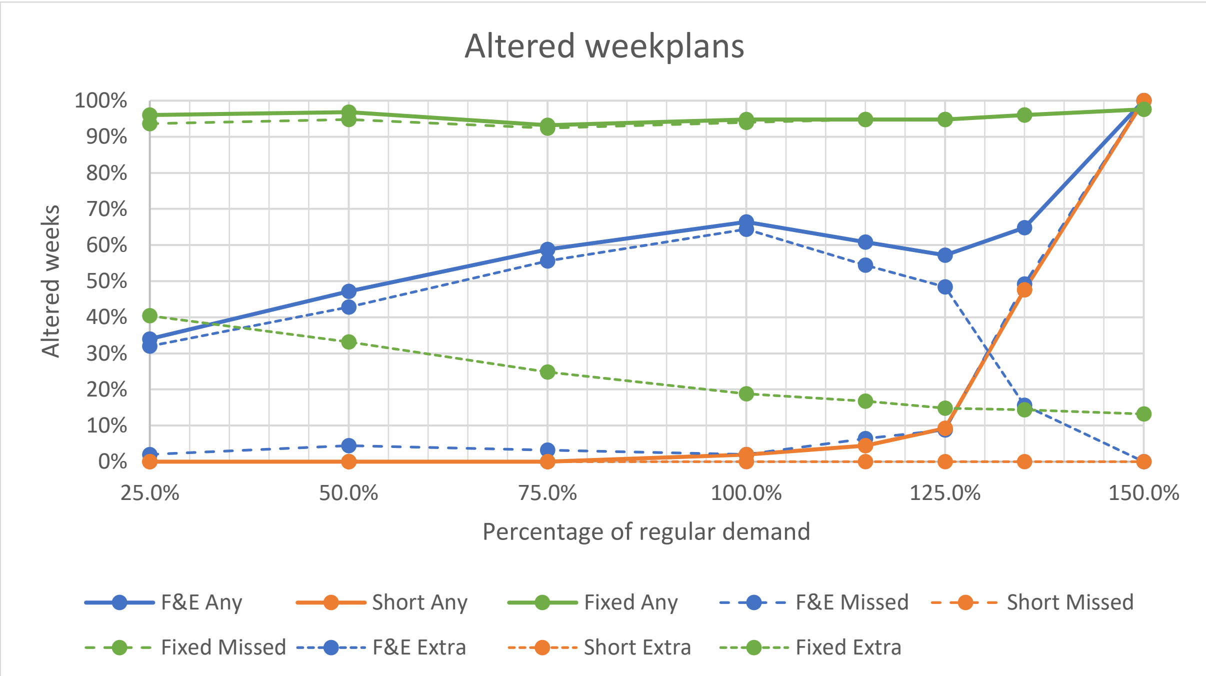

Figure 40 Changes in weekplans under varying demand

As can be seen in the figure, at 100% of regular demand the Full & Empty weeks method has any alteration in 66% of the weeks. These alterations consist for the majority out of extra weeks. It happens often that there is production added to the week schedule that are not planned. This is done so because when the production of all planned items is finished, the algorithm will look for an item that might be planned for the next week to work ahead. The percentage of weeks where a planned production is missed is very low. That means there are few weeks where one or more items that were planned to produce, were not actually produced.

The 'Short weeks' method never has production that was unplanned. That is because the method simply stops working when all items are produced that were planned to produce. The percentage of missed productions, and the percentage of any changes in production are therefore always equal. At 100% of the average demand, the percentage of missed productions is very low at 2%.

The current, ‘Fixed schedule’ method does not take into account the level of stock for determining when to produce. This means that when an item goes out of stock, it is not prioritized for production. This leads to 94% of the weeks occurring with the need for production of an item, but without the actual production of said item. In 20% of the weeks production of an item is present even though the item has more than a week of stock left.

When looking at varying levels of average demand, it can be seen that between a 100% and 125% of average demand, the behavior changes significantly. Before this change, at lower demands, the Full & Empty method produces a stable percentage of missed productions and an increasing percentage of extra productions, leading to an increasing percentage of weeks with any change in schedule. After the change at around a 100% of average demand, the percentage of weeks with extra production decreases, while the percentage of weeks with missed production increases. This leads to a small decrease of weeks with any alteration up until 125% of average demand, but also to a strong increase after 125% of average demand.

For the short weeks algorithm, the same tipping point can be distinguished. The percentage of missed productions, and therefore any altered schedules, increases exponentially when the demand percentage increases beyond 100%.

The current method of planning, with fixed production dates, has a continuously high level of missed productions and therefore high percentage of weeks with any alteration. As the average demand increases, the percentage of weeks with production that is not based on low stock level decreases. This is because the chance an item has a low stock increases and when there are more items with low stocks, there are less weeks with production despite a sufficient stock level.

7.1.2 Service Level under varying demand

The percentage of sales that are fulfilled is measured and expressed as a percentage of total demand for the same period. At regular demand this means that for the Full & Empty weeks method, 99.7% of the demand is available in the stocks and can be delivered. This method is flexible enough to always be able to deliver the ordered items. The other Most Urgent First method, Short weeks, has a small percentage of 1.1% of the ordered items not in stock, and thus 98.9% of the items in stock. The current method, with fixed production moments, has a significantly higher percentage of items not in stock of 10%, as there is only 90.4% in stock. This makes sense as when the demand has an equal chance of being higher than the forecast demand as being lower than the forecast demand, and the production size is only as big as the forecast estimates it needs to be, in half of the production cycles the estimated production size is smaller than the actual demand for that period.

When the demand is equal or less than the normal average demand, the out of stocks are generally quite stable. Only when the demand is increased all methods have trouble fulfilling the demand and end up with low service levels. For the Full & Empty week method, and the Short week method there is a clear decrease in service level for more the 125% of normal demand. For the Fixed schedule method, it is more gradually but it starts earlier at more than 100% of average demand. All methods have significantly higher out of stocks at >125% average demand, as the Service Level drops to 0%.

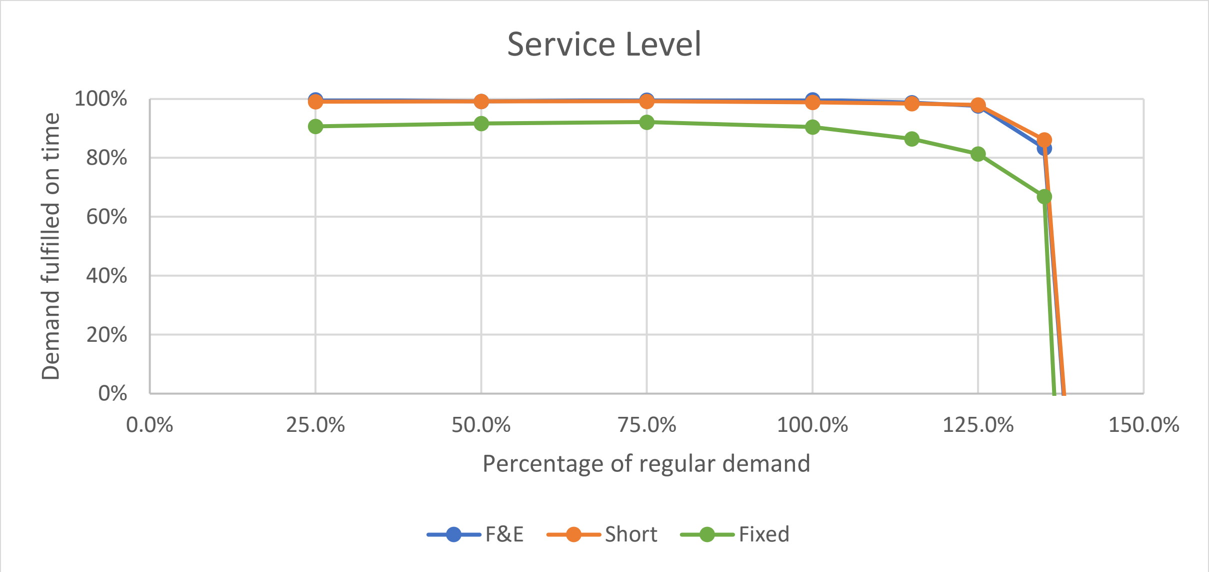

Figure 41 Service Level as a percentage of total demand for varying demand levels

7.1.3 Costs under varying demand

Cost of fulfillment is split into two parts. The cost for keeping stock and the cost for setting up productions. Combined they are the total cost for fulfillment. At normal, average demand, the costs for both stock and setup costs are highest for the Full & Empty method. The leads inevitably to the total costs being the highest as well. Next to that comes the cost for the short weeks method and finally the cost for the fixed production schedule method are the lowest.

When the demand is altered this split in costs remain present, although the Full & Empty weeks methods set up costs decrease faster at lower average demand, then the Short weeks set up costs, leading to a crossover at around 60% of average demand. The setup costs for the fixed schedule remain almost entirely equal for all demand scenarios. This is not surprising as regardless of the demand, production is scheduled at fixed intervals and thus the setup costs also occur. Interestingly, all stock costs decrease between 100% and 125% of average demand, and dramatically decrease after 135%. This is because significant stock shortage presents itself at higher average demand levels, and when the stock is negative, the holding costs are also negative.

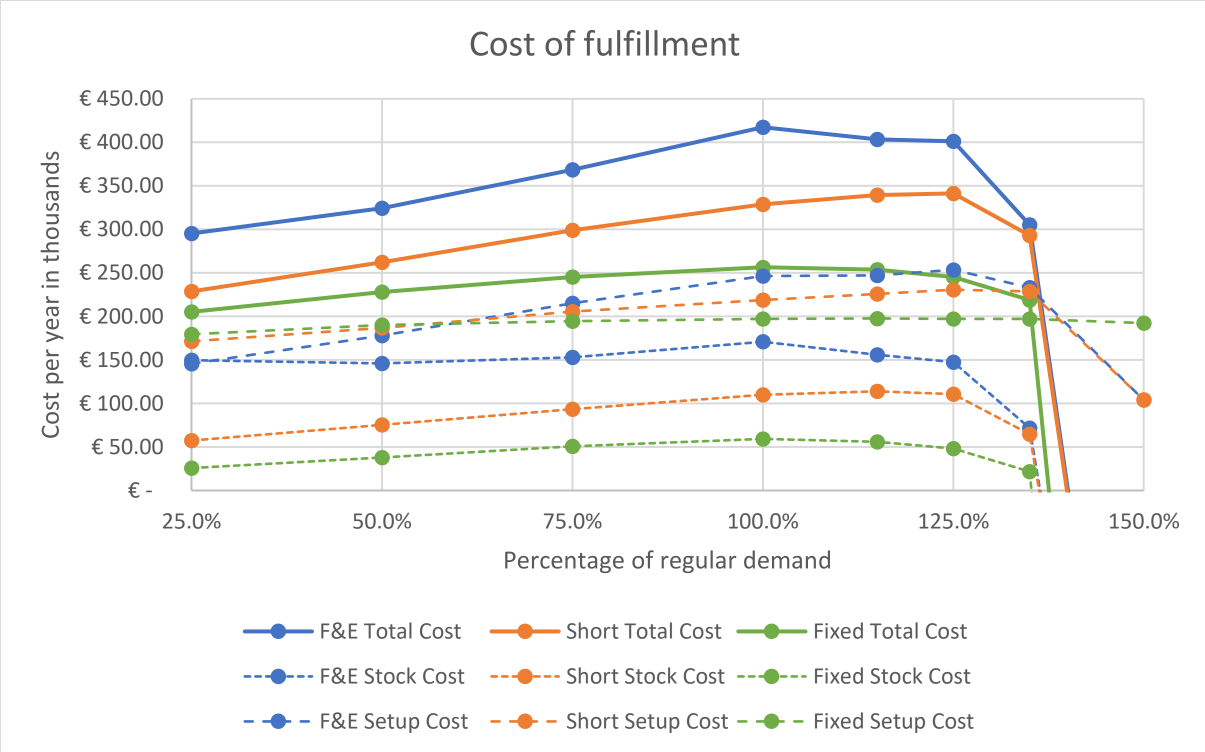

Figure 42 Cost for varying percentages of regular demand

Table 18 Overview of results for varying Average Demand

	Nervousness			Service Level			Cost		
Average Demand	F&E	Short	Fixed	F&E	Short	Fixed	F&E	Short	Fixed
25%	34.0%	0.0%	96.0%	99.7%	99.1%	90.7%	€ 295.36	€ 228.84	€ 205.37
50%	47.2%	0.0%	96.8%	99.2%	99.2%	91.7%	€ 324.25	€ 262.17	€ 227.93
75%	58.8%	0.0%	93.2%	99.6%	99.2%	92.2%	€ 368.48	€ 299.16	€ 245.52
100%	66.4%	2.0%	94.8%	99.7%	98.9%	90.4%	€ 417.41	€ 328.95	€ 256.55
115%	60.8%	4.4%	94.8%	98.8%	98.5%	86.5%	€ 403.40	€ 339.62	€ 253.63
125%	57.2%	9.2%	94.8%	97.6%	97.9%	81.3%	€ 401.14	€ 341.38	€ 245.25
135%	64.8%	47.6%	96.0%	83.3%	86.1%	66.9%	€ 305.11	€ 293.23	€ 218.97
150%	100.0%	100.0%	97.6%	-347.0%	-347.0%	-602.4%	€ -602.00	€ -602.00	€ -1,069.36

7.2 Standard deviation of demand

It is estimated that the demand might become significantly more volatile because of a changing market. That brings a challenge to the planning and scheduling method and to see the resilience of the various methods the standard deviation of normal demand is varied. Under a varying standard deviation of demand, the nervousness, missed sales percentage and costs also vary. In this section it is described how so.

7.2.1 Nervousness under varying demand standard deviation

Without demand variability, all demand is equal to the mean of regular demand. The forecast still has regular inaccuracy so it still happens in 90% of the weeks that in the Fixed schedule method, production of a specific item is required based on the stock level, but is missed because the schedule is fixed. Furthermore, in 7% of the weeks a production is scheduled that is not necessary based on the stock level. The Full & Empty weeks method adds production to a week without a necessity in 64% of the weeks, although it rarely misses a production that is required based on the stock level. Only the Short weeks method has completely no alteration to the week plan made n short notice.

When variability of the demand is increased, certain trends become apparent until a variability of 250% of the normal variability. For the Fixed schedule method both missed production and extra production percentages increase, while for the Full & Empty weeks method the percentage of extra weeks slightly decreases and the percentage of missed production slightly increases. For the Short weeks method there are never extra productions, but the percentage of missed productions increases and surpasses that of Full & Empty weeks.

For demand with a variability of more than 250% of the current variability, it becomes apparent that all methods fail to keep nervousness low. The Full & Empty method starts to increase the percentage with weeks with missed production and rapidly decreases the weeks with extra production, leading to a sharp increase for weeks with any alteration for a variability of >300% of the standard variability. The Short weeks method also increases the percentage of missed production weeks sharply. The Fixed schedule method already had a percentage of almost 100% for weeks with missed production, but with a demand variability of >250% the steadily increasing percentage of extra weeks starts to decrease.

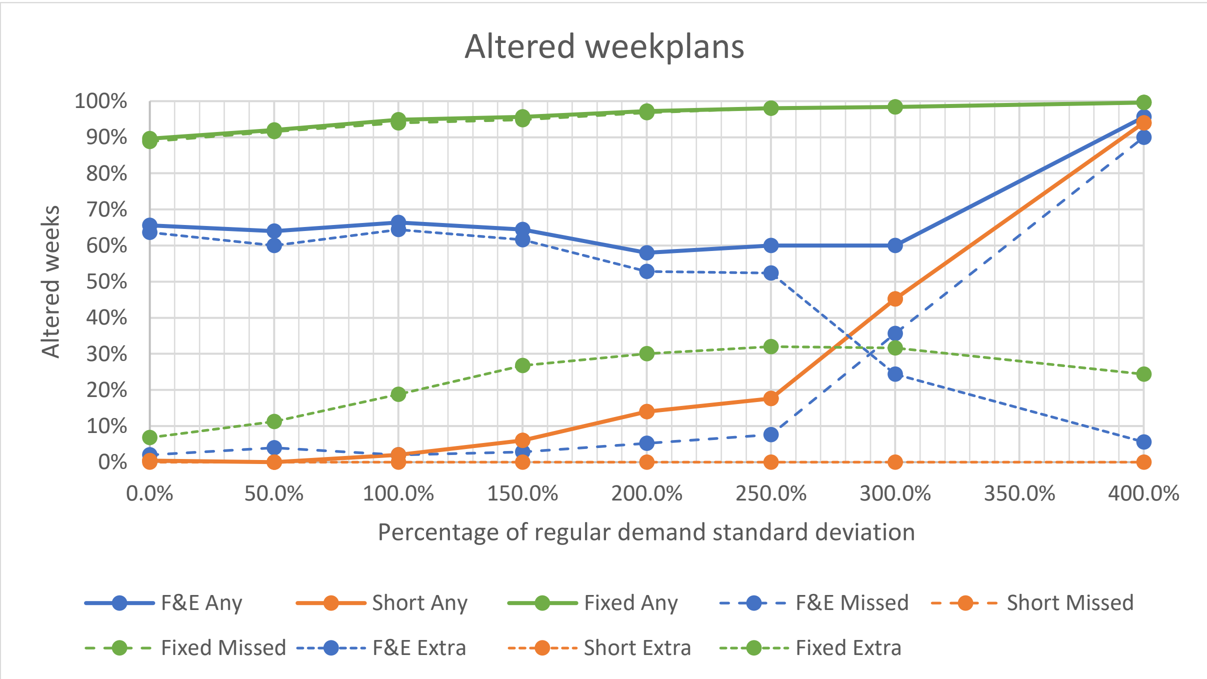

Figure 43 Percentage of schedule alterations depending on demand variability

7.2.2 Service Level under varying demand standard deviation

When the Service Level is plotted as a function of the demand variability, the graph of Figure 44 appears. Here it can be seen that all planning methods have increasing out of stock situations as the demand variability increases. It also becomes apparent that the Full & Empty weeks method has the highest Service Level, the Short weeks method has slightly less Service Level and the Fixed schedule method has a significantly lower Service Level.

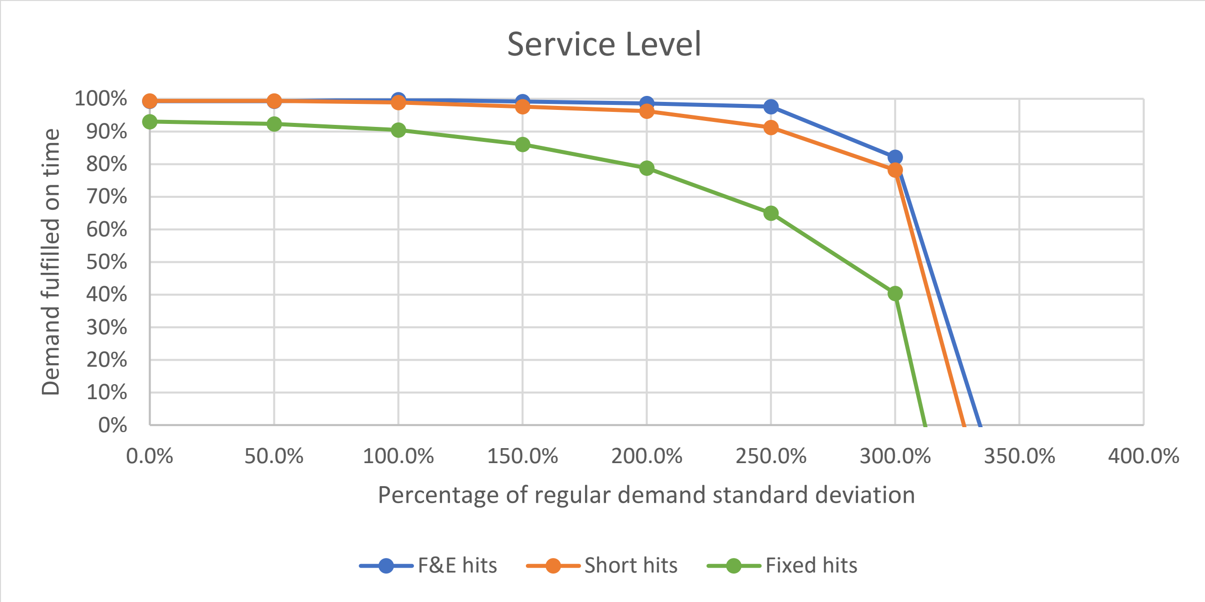

Figure 44 Service Level with varying demand variability

7.2.3 Costs under varying demand standard deviation

The cost to operate appear largely unaffected by the demand variability. Up until 250% of regular variability there is only very little difference in costs over variability. Only for the Fixed schedule method there is somewhat of a trend visible, where the costs decrease because of the reduced stock costs due to high negative stocks. This same effect is visible for the Most Urgent First methods but most predominantly after a demand variability of >250%.

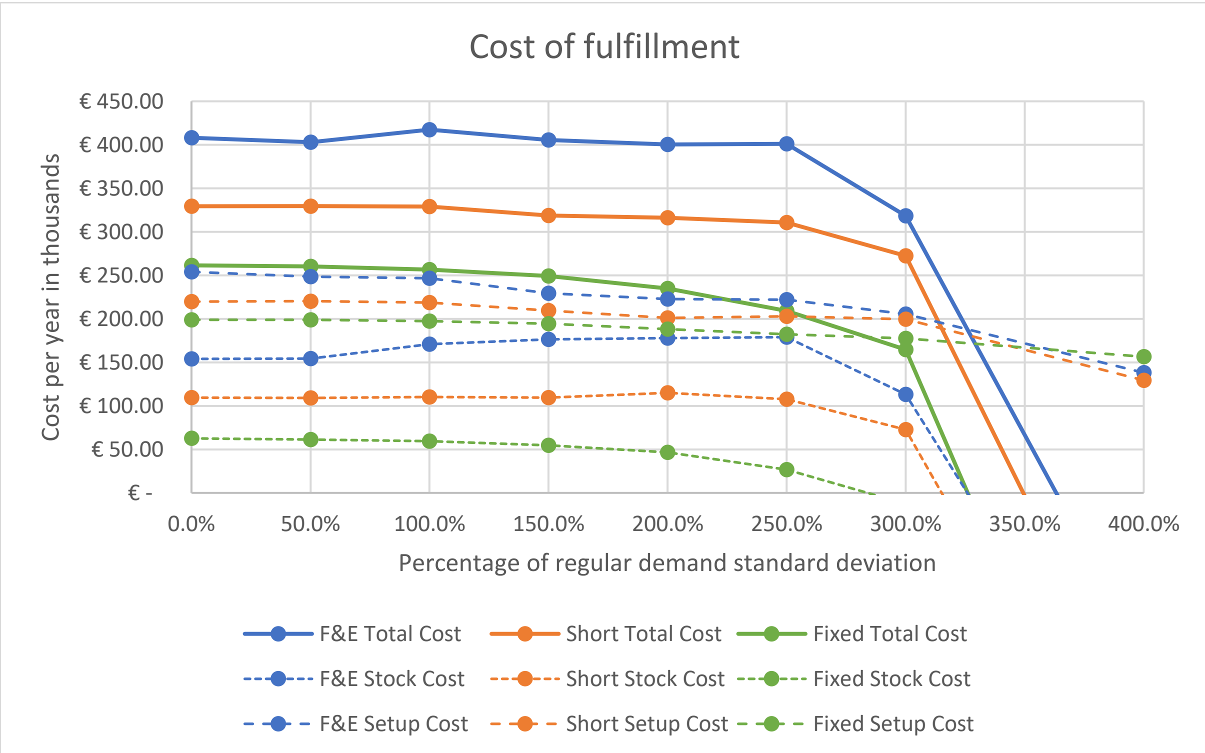

Figure 45 Cost for varying levels of demand variability

Table 19 Overview of results for varying demand standard deviation

	Nervousness			Service Level			Cost		
Standard Deviation Demand	F&E	Short	Fixed	F&E	Short	Fixed	F&E	Short	Fixed
0%	65.6%	0.4%	89.6%	99.3%	99.3%	93.0%	€ 408.11	€ 329.25	€ 261.50
50%	64.0%	0.0%	92.0%	99.3%	99.4%	92.3%	€ 402.82	€ 329.58	€ 260.21
100%	66.4%	2.0%	94.8%	99.7%	98.9%	90.4%	€ 417.41	€ 328.95	€ 256.55
150%	64.4%	6.0%	95.6%	99.2%	97.6%	86.1%	€ 405.60	€ 318.87	€ 249.06
200%	58.0%	14.0%	97.2%	98.6%	96.2%	78.8%	€ 400.53	€ 316.15	€ 234.99
250%	60.0%	17.6%	98.0%	97.6%	91.2%	64.9%	€ 401.16	€ 310.56	€ 209.30
300%	60.0%	45.2%	98.4%	82.1%	78.2%	40.4%	€ 318.50	€ 272.36	€ 164.73
400%	95.6%	94.0%	99.6%	-158.6%	-204.4%	-295.5%	€ -185.01	€ -279.17	€ -467.35

7.3 Accuracy of the forecast

Since the forecast is not completely reliable, it takes extra effort to handle the difference between predicted demand and actually occurring demand. This is presented as extra nervousness, Missed Sales or extra costs. To see this effect, the forecast variability is increased from 0% to 200%, where at 0% the forecast is completely accurate, at 100% the forecast is similarly inaccurate as it is in the current situation, and at 200% it is twice as inaccurate as the current situation.

7.3.1 Nervousness under varying forecast accuracy

In Figure 46 it can be seen that for the Full & Empty weeks method, the percentage of weeks with extra production slightly increases from around 55% to 68%, while the percentage of weeks with missed production remains a few percent. For the Short weeks algorithm, the percentage of weeks with missed production is also very low, and because there is no extra production the total weeks with alterations is very low. For the Fixed schedule method however, the percentage of weeks with missed production starts at 100%. This comes from a programming solution to avoid dividing by 0, as it would make sense that when the forecast is completely accurate, no extra, and no missed production is necessary as the stock runs out exactly in the week where a new production run is planned.

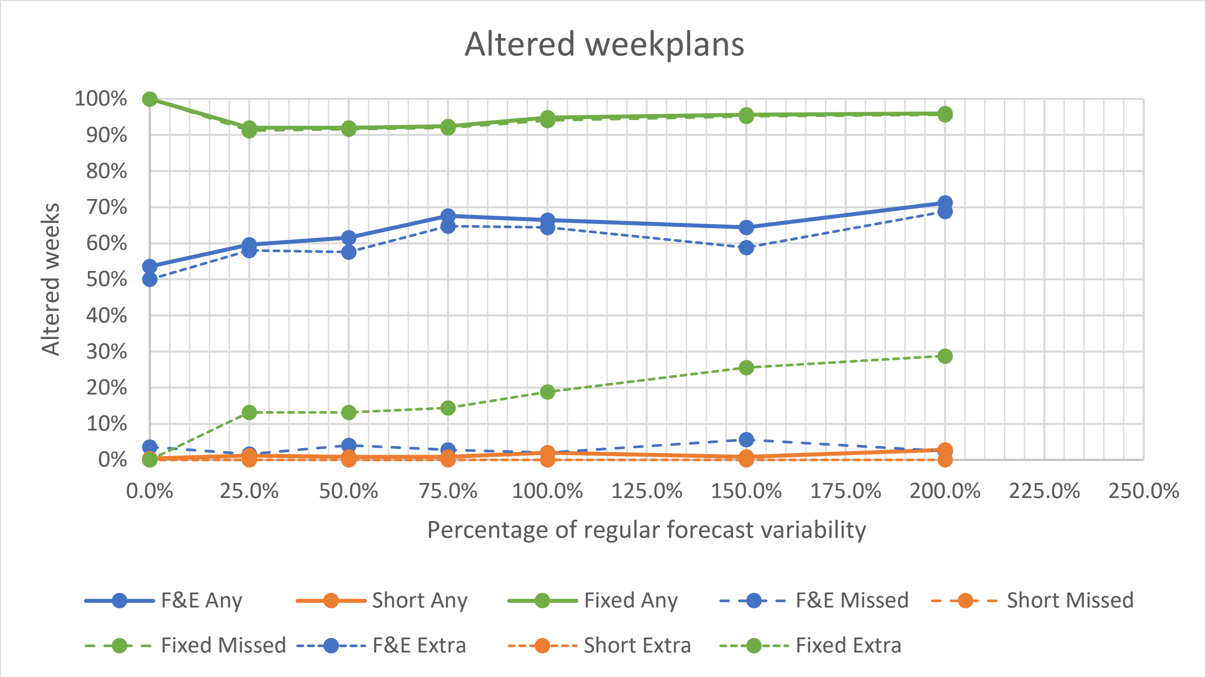

Figure 46 Percentage of schedule alterations depending on forecast accuracy

7.3.2 Service Level under varying forecast accuracy

Forecast accuracy, or lack thereof, causes too high, or too low productions, and when the production is too low an out of stock situation might occur. For the Most Urgent First methods increasing forecast inaccuracy leads to reduced service levels. For the Fixed schedule method, however, the increase in demand variability leads to clearly linear reduction in Service Level, which becomes significantly present. This is because this method lacks the ability to handle forecast inaccuracies.

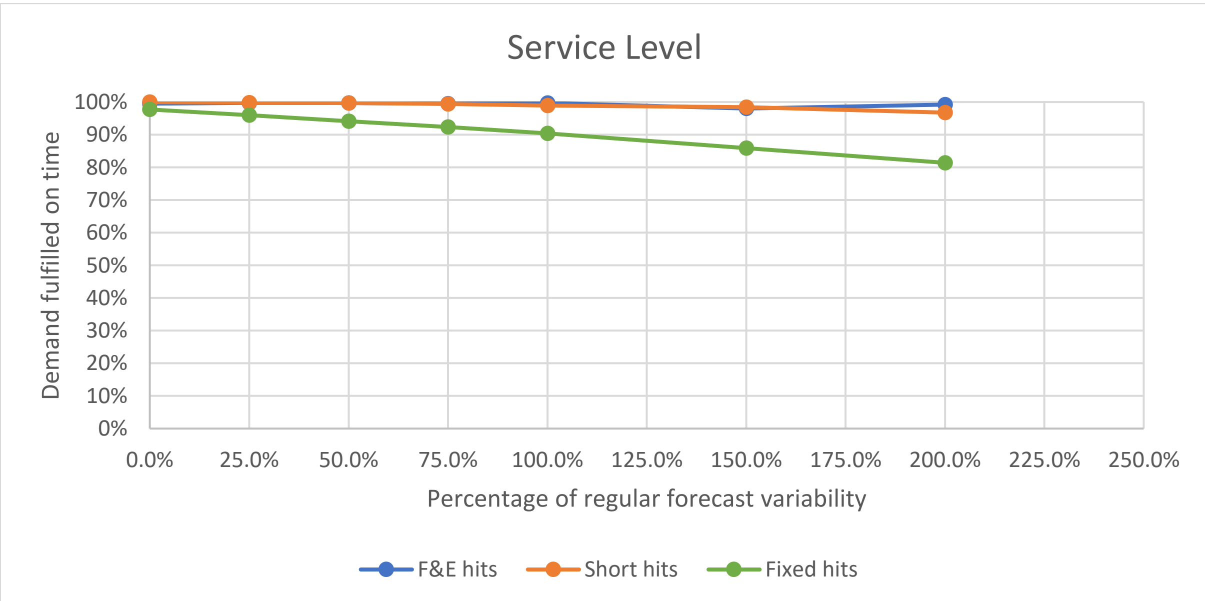

Figure 47 Service Level for varying levels of forecast accuracy

7.3.3 Costs under varying forecast accuracy

When the forecast variability is increased, the cost remains largely equal or almost equal. This is because the setup costs remain almost constant throughout the range of forecast variability as does the stock cost. However, two notable facts can be distinguished. Firstly, there is the fact that the stock cost for the Full & Empty method increase from 146 thousand euro to 213 thousand euro. An increase of 46%. Secondly, the setup costs for the Short weeks method is significantly higher (17%) at 0% variability than it is for the non-zero variability levels.

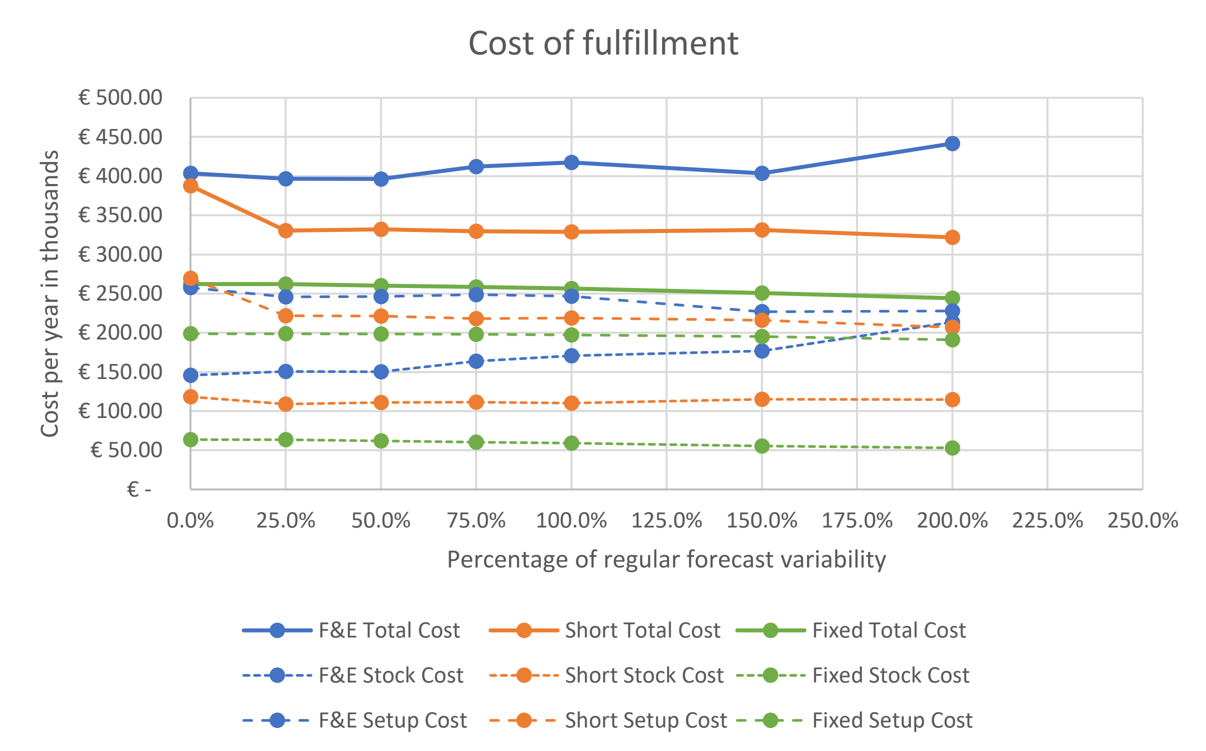

Figure 48 Cost of fulfillment for different levels of forecast variability

Table 20 Overview of results for varying forecast variability

Standard Deviation Forecast	Nervousness			Service Level			Cost		
	F&E	Short	Fixed	F&E	Short	Fixed	F&E	Short	Fixed
0%	53.6%	0.4%	100.0%	99.5%	100.0%	97.7%	€ 403.44	€ 387.75	€ 262.18
25%	59.6%	1.2%	92.0%	99.7%	99.8%	96.0%	€ 396.49	€ 330.62	€ 262.19
50%	61.6%	0.8%	92.0%	99.7%	99.7%	94.1%	€ 396.46	€ 332.22	€ 260.20
75%	67.6%	0.8%	92.4%	99.5%	99.4%	92.4%	€ 412.27	€ 329.62	€ 258.66
100%	66.4%	2.0%	94.8%	99.7%	98.9%	90.4%	€ 417.41	€ 328.95	€ 256.55
150%	64.4%	0.8%	95.6%	98.0%	98.4%	85.9%	€ 403.58	€ 331.11	€ 250.75
200%	71.2%	2.8%	96.0%	99.2%	96.8%	81.4%	€ 441.65	€ 321.85	€ 244.15

7.4 Seasonal demand

The demand seasonality is an effect that is simulated by multiplying demand with a sinusoidal function with an average of 1 and a period of 50 weeks. The range is varied from 0 to 33%. At 33% the peaks of the average demand (133%) are twice as high as the bottoms (67%).

7.4.1 Nervousness under seasonal demand

With a varying range of demand seasonality, the graph from Figure 49 is generated for the percentage of altered week plans. As can be seen the Full & Empty method becomes more stable as the demand seasonality increases, because the percentage of weeks with extra production becomes lower. The percentage of weeks with missed production increases, but not so much as to increase the percentage of weeks with any alteration in the week schedule.

For the Short weeks method the percentage of weeks with missed production also increases albeit less so than for the Full & Empty method.

The Fixed schedule method is practically unaffected by the demand seasonality, as both the percentage for extra production as the percentage for missed production remain constant.

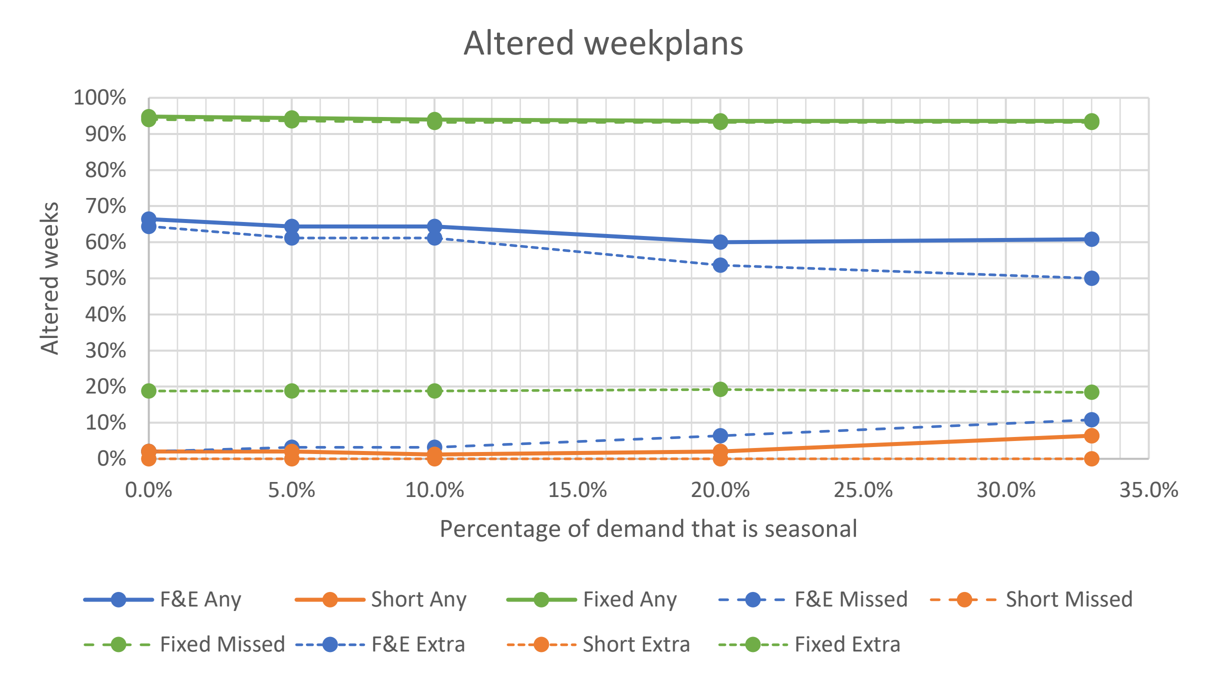

Figure 49 Percentage of altered weekplans under varying demand seasonality

7.4.2 Service Level under seasonal demand

Contrary to the nervousness under varying demand seasonality, the Service Level varies more. All methods seem to have slightly decreasing Service Levels as demand seasonality increases, with the Full & Empty weeks and Short weeks methods being very close to one another, and the Fixed schedule method starting and increasing more.

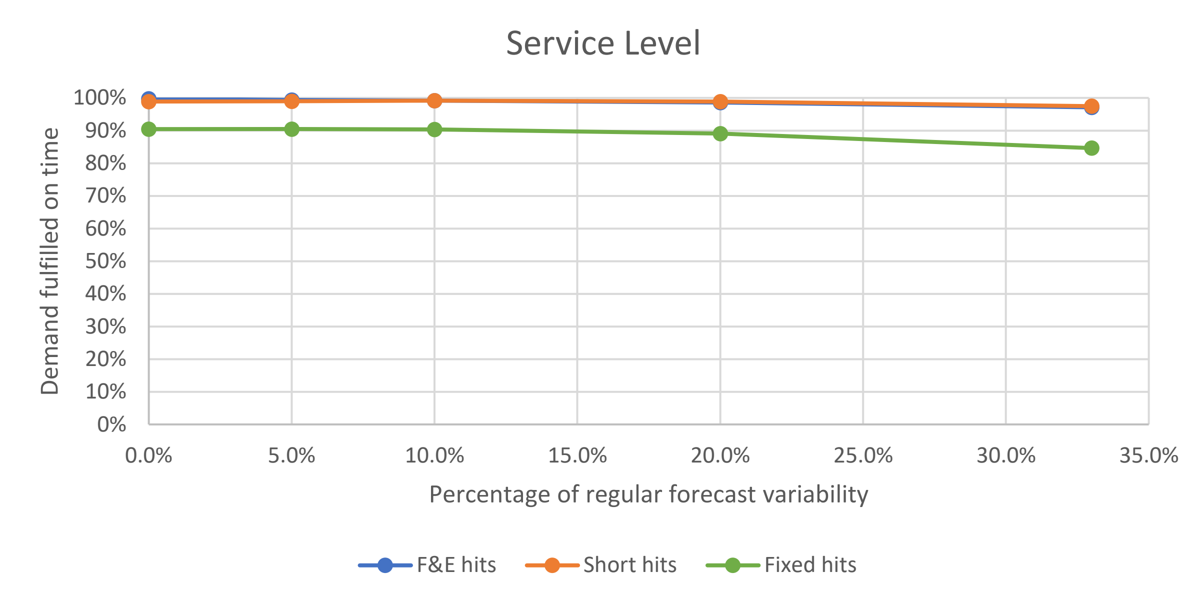

Figure 50 Service Level under varying levels of demand seasonality

7.4.3 Costs under seasonal demand

The cost for fulfillment under varying levels of demand seasonality decreases slightly for all methods. This is solely due to the decrease in stock costs for all three methods, as the setup costs remain virtually equal throughout the range of demand seasonality.

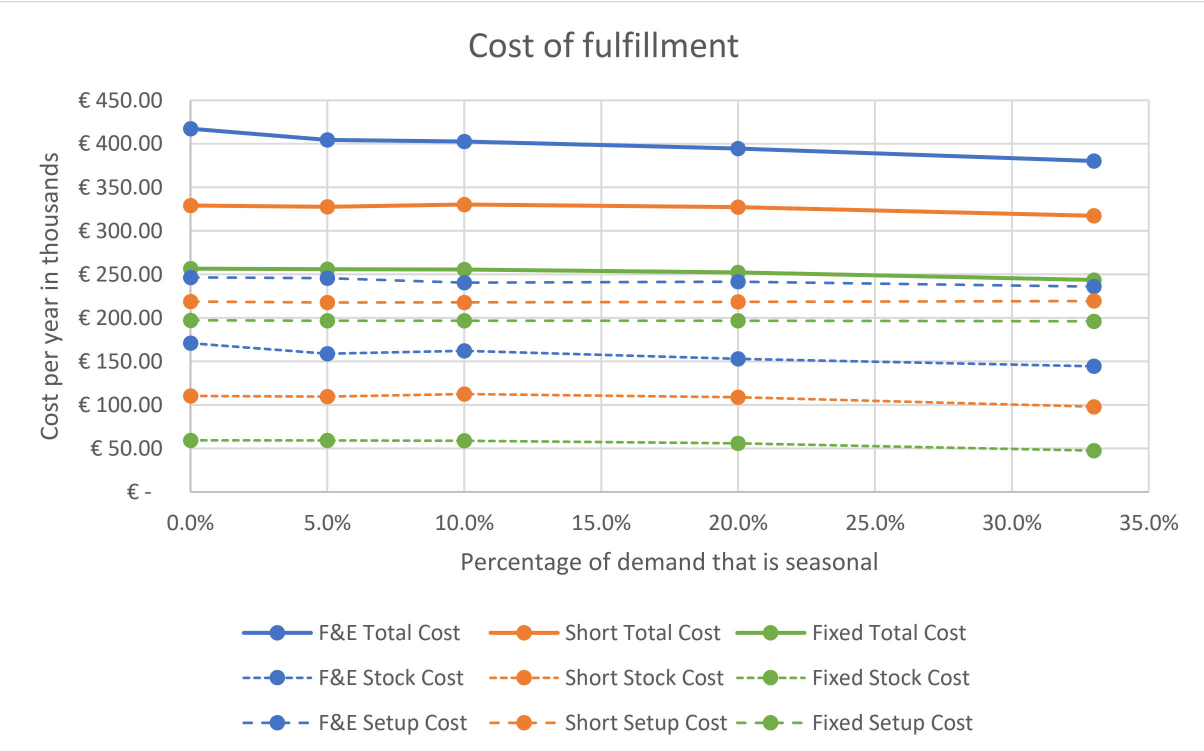

Figure 51 Costs for varying levels of demand seasonality

Table 21 Overview of results for varying demand seasonality

Seasonality Demand	Nervousness			Service Level			Cost		
	F&E	Short	Fixed	F&E	Short	Fixed	F&E	Short	Fixed

0%	66.4%	2.0%	94.8%	99.7%	98.9%	90.4%	€ 417.41	€ 328.95	€ 256.55
5%	64.4%	2.0%	94.4%	99.3%	99.0%	90.5%	€ 404.44	€ 327.47	€ 255.98
10%	64.4%	1.2%	94.0%	99.1%	99.2%	90.3%	€ 402.63	€ 330.27	€ 255.47
20%	60.0%	2.0%	93.6%	98.5%	98.9%	89.1%	€ 394.59	€ 327.35	€ 252.40
33%	60.8%	6.4%	93.6%	97.1%	97.5%	84.6%	€ 380.27	€ 317.32	€ 243.58

8 Conclusion

8.1 Discussion and recommendations for future research

8.1.1 Nervousness not only a quantifiable metric

Measuring the nervousness by measuring the difference between expected production and executed production provides insight in the predictability, and unpredictability of a system to a certain limited degree. As a measure of nervousness, it is adequate but it is debatable how effective nervousness is to represent the stress in an organization that arises from the uncertainty of operations. Ensuring the organization is capable of coping with changes, or is aimed towards being flexible, can reduce the stress more than only reducing the situations where stress occurs.

In the nervousness measure that is used two components determine the number of weeks with ‘any changes’ in the production plan. The number of weeks with extra production, or more items produced than estimated on the basis of stock at the beginning of the week. In reality this metric is not purely negative. It means a change has occurred, but a change that is not necessary to prevent an out of stock situation. It could be argued that this is rather a positive change than a negative, as the scheduler has the option of not implementing it without the risk of having a stock shortage. This is the main reason for the difference between the Full & Empty weeks method and the Short weeks method. In the former extra production that is not necessary to prevent out of stock situations is added at the end of the week, while in the latter this is not done. In the case of missed productions, where based on stock production is to be expected but there is no production the metric is a good indicator to represent stress in the organization. However, in the fixed weeks schedule, the inaccuracies of the demand are solved with the use of a significant safety stock. The actual stress within the organization occurs when the safety stock is depleted, or at risk of depletion, but that is not how this metric is measured.

8.1.2 Relation between Out of Stock situations and Costs

For the current method of planning, a significant amount of safety stock is kept. This safety stock is to be used to overcome any difference between production and actual demand between production periods. In the simulation, even for the current ‘Fixed schedule’ method, this safety stock is assumed to be zero. There is no limit added to any of the simulations that prevents stock becoming negative. This leads to situations where the stock is negative. The negative stocks are recorded and related to the total demand to determine what percentage of demand would not be delivered on time. The negative stock is carried over to the next period and results in an increased production size. This simulates that the entirety of the negative stock can be considered delayed delivery, or backlogging of demand. In reality this is not always the case. Furthermore, the stocks, and thus also the negative stocks, are multiplied with the holding cost for stocks and summed to form the cost of stock metric. When there are large quantities of negative stock, this skews the cost of inventory, and when the average inventory level becomes negative, the cost of inventory even becomes negative.

This shows that when looking at the cost of fulfillment, the cost of stock should be scrutinized thoroughly, and always be judged in combination with the level of out-of-stocks.

For the standard simulation situation, an analysis has been made on how much extra stock costs will reduce out of stock situations. This is done by finding the maximum stock shortage for each item. Then, in small increments of 10% of the maximum, the situation is represented as if that safety stock is available. This incurs cost of keeping safety stock, and reduces out of stock situations as only the negative stock that surpasses the safety stock is counted as out of stock. These two metrics are plotted against each other in the following graph:

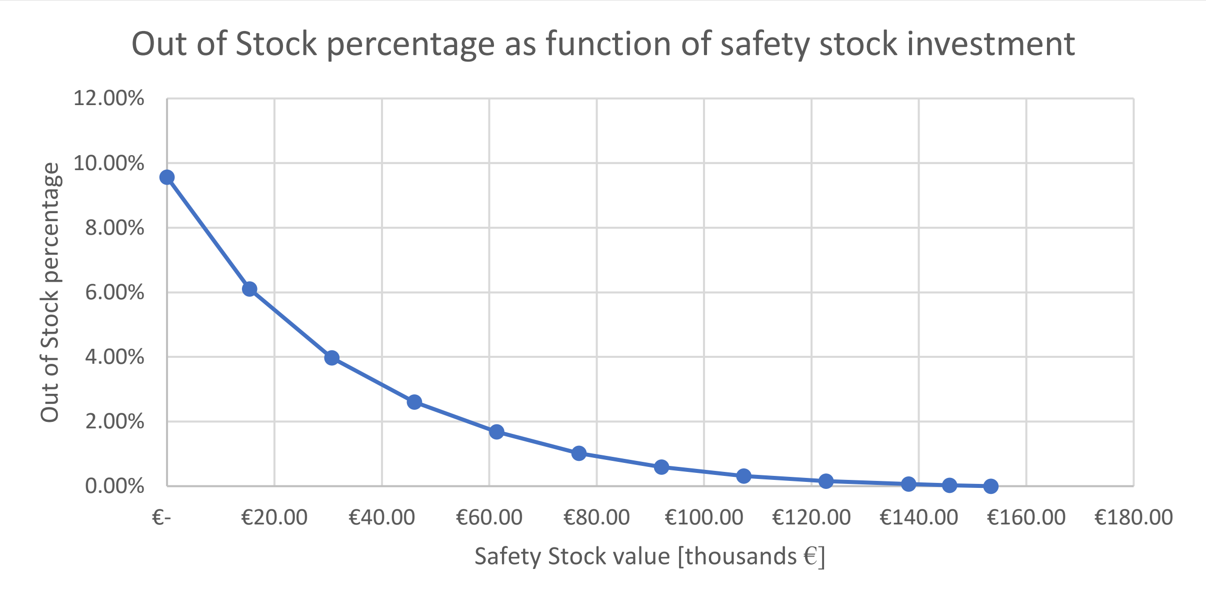

Figure 52 Diminishing Out of stock percentage over increasing safety stock investment

Since this is a rough estimate on the relation between cost of safety stock and reduction in out of stocks, based on a single year of out of stocks, it provides some insight but is not directly applicable to all out of stock percentages. Further research in the effectiveness of safety stock for different planning methods may provide more definite answers on the effects of using safety stock.

8.1.3 Other solution

This research has analyzed two possible implementations of the Most Urgent First algorithm. There are more solutions thinkable and in various states of development. From conceptual to industry-tested and proven. This research is limited to the two versions of Most Urgent First in comparison with the existing, implemented Fixed schedule. Furthermore, all methods tested us the Periodic Order Quantity lot-sizing technique, whilst combining the planning algorithms with different lot-sizing techniques might prove positive as well.

8.1.4 Other benefit of ‘Full & Empty weeks’ method

The ‘Full & Empty weeks’ method performs somewhat differently than the ‘Short weeks’ method in terms of Cost and Altered weekplans but very similar in terms of Out of Stock percentage. This is largely due to the fact that even when there is no out of stock risk, production continues until a full week can be stopped. This leads to higher stocks and therefore higher stock costs, and it leads to extra productions when they are not expected based on necessity. The benefit of this method is that the production can be halted for a week sometimes. The cost saved of halting a full week instead of making multiple weeks shorter could be quantified and subtracted from the total cost of fulfillment for the ‘Full & Empty weeks’ method, making it more competitive in terms of cost.

8.1.5 Extensive requirements for most urgent first

In order to implement any of the ‘Most Urgent First’ methods, a complete redesign of the supply chain might be necessary. Because of the strong reduction in planning horizon it is necessary to keep stocks of raw-, and packaging materials as Just In Time deliveries are not possible on such a short notice. Current lead times are up to 12 weeks and vary for all components.

A distinction can be made in perishable goods, such as tomatoes, and non-perishable goods such as packaging materials. For packaging materials, the downside for keeping stock is mainly the capital that is locked in as stock. For perishable goods the problem is bigger. Not only is the shelf life limited, to keep ingredients fresh the storage climate must be controlled constantly. The benefit of having raw-, and packaging materials as stock instead of finished goods is due to the lower value of the components than that of the finished goods, but it might be lost if the storage costs are higher.

To determine the size of the raw,- and packaging material stocks a model was formed at the company. (Diepenhorst, 2019) With the help of this model it is possible to determine the size of the stocks based on the variance of the demand for those stocks, and the quality of the supply.

Combined with the findings in this report, a thorough analyses of the required raw-, and packaging materials stock should be made before implementing a different planning method.

8.2 Conclusion

The main research question can be answered with the help of the sub questions and their answers. The main research question is:

How should planning and scheduling of the production of Miracoli Dinnerkits be organized in order to lower nervousness and increase the customer service level?

To come to an answer the sub questions are answered first.

8.2.1 Research question 1

The first sub question is answered in chapter

3 Analyses of the current system*.*

What is the current process for planning and scheduling of production?

Currently, a method that this report calls 'Fixed schedule' planning is used. It works in two steps and uses some standards that are adjusted incidentally. The predetermined standards are the optimum production frequency (MFI), the production rate and the changeover times. Furthermore, a forecast for all demand with a horizon of over 2 years that is continuously refined is available. To form the planning of production, the production frequency and the changeover times between production of different items are used to determine a fixed schedule. With items that are produced in three out of 4 weeks, bi-weekly, once every four weeks or once every eight weeks, 8-week schedules are made that repeat indefinitely. This fixed schedule is then filled with production quantities. The quantities are based on the forecast demand between production moments. This leads to variability in the foreseen production quantity as the forecast changes over time. The determination of the production order for all items of the week is done once, when the repeating schedule is made.

8.2.2 Research question 2

The second sub question is answered in chapter *4 Requirements and limitations for production.*

What are the requirements and limitations for production?

It was found that for the production of items on line 4, several requirements must be met. People must be present to operate the line, packaging materials must be present and raw materials must be present. Furthermore, basic resources as electricity, water and gas must be readily available. It was found that for the packaging materials a long lead time of up to 12 weeks can occur and for raw materials a shelf life of only 1 month can be the case, which limit the freedom of planning.

8.2.3 Research question 3

In chapter *5 Input to the system*, it is described what the characteristics the demands have. The chapter provides an answer to the question

What characteristics do the demands for the products have?

It was found that these characteristics can be described as having an average and a standard deviation. The ratio between standard deviation and average demand is different for all items. It was found that there is no or hardly any autocorrelation in demand. For each item a forecast is made and updated every week. The accuracy of the forecast varies for each item but for all items it holds that the further in the future a demand is forecast, the less accurate the forecast is.

8.2.4 Research question 4

Chapter *6.3 KPI's* gives an overview of several performance indicators that are used to measure various performance metrics. The question

How should the performance of the methods be measured?

Is answered by first dividing the measured metrics and then attributing KPI's. This way it was found that the schedule stability can be measured by the percentage of last week changes. Both unforeseen production and expected but missed productions are monitored, as are the weeks in which either one of the instabilities occurs. By measuring the sum of all stocks that are negative and relating that to the sum of all demand, a percentage of undelivered orders can be found, and this percentage can be used to compare the performance of different methods. Finally, the cost of the production and stock can be combined to come to a comparable cost metric.

8.2.5 Research question 5

In chapter *6.1 Description of Alternative methods* an answer is given to the sub question:

What alternative methods of planning and scheduling can be proposed?

An alternative strategy for planning was formed with inspiration from literature and other solutions. The method formed was named 'Most Urgent First' and consists of a very short planning horizon, which is adhered to either as best as possible, with the 'Short weeks' implementation of the method, or where extra production are allowed to work ahead in the 'Full & Empty weeks' implementation.

8.2.6 Research question 6

What other effects will alternative methods for planning and scheduling have in the fulfillment stream?

It was found that choosing an alternative solution consisting of the 'Most Urgent First' method requires significant stocks for raw-, and packaging materials. This is because it is difficult to estimate when what materials will be needed for production and lead times are long. However, because of the incredible flexibility, it is possible to significantly reduce the amount of finished goods safety stock. This would mean that implementing this method results in a shift of buffer stocks from finished goods stock to raw and packaging materials stock.

8.2.7 Main research question

With the help of the previous sub questions an answer can be formulated

How should planning and scheduling of the production of Miracoli Dinnerkits be organized in order to lower nervousness and increase the customer service level?

The goal of this research is to find a method that is both less nervous and provides a higher level of demand satisfaction. In the current situation the 'Short weeks' implementation of the 'Most Urgent First' method is the best solution. It has no 'extra' productions and very little missed production. The 'Full & Empty weeks' implementation has a comparable low number of missed productions, but a significantly higher percentage of extra productions and therefore nervousness. The current method 'Fixed schedule' has almost every week missed productions and therefore significant levels of stress. The percentage of extra production is lower than that of the 'Full & Empty weeks' but still more than the 'Short weeks' method.

The high percentage of missed productions for the current method is related to the performance of delivering what is ordered. The current method of 'Fixed Schedule' planning leads to a high percentage of items that are not available. In the current situation this is overcome with an expensive safety stock model. Both the 'Short weeks' and the 'Full & Empty weeks' methods provide a better coverage of demand. 'Full & Empty weeks' scores a little better than 'Short weeks' but both score significantly better than 'Fixed schedule'.

As described, the high percentage of out of stock situations for the 'Fixed schedule' need to be solved by a significant safety stock. It was not researched how costly the safety stock would be but it is estimated that this brings the total cost for fulfillment for this method up significantly and perhaps even so that the method becomes competitive in terms of costs with either 'Short weeks' or even with the more costly 'Full & Empty weeks' methods.

8.3 Recommendations for Mars

8.3.1 On implementation

It is concluded that a Most Urgent First method of planning helps reducing nervousness and improves the capability to deliver to demand on time. Contrary to the 'Fixed schedule' method this can be done without a safety stock. When there is a risk of depletion of the stock, an item is produced. Further research should be performed in the possible cost savings from reducing safety stock and potential extra costs from keeping raw-, and packaging materials in stock.

Within the organization, the role of the planner shifts towards an advisory role, where he or she needs to make sure the priority of items is up to date at all time. The scheduler on the other hand gets more responsibility because this person should make the judgement if it is better to make the most urgent item, or if there is a possibility to optimize changeovers by selecting an item with lower urgency first. Buyers for raw-, and packaging materials need to change their way of working into a stock management style. At the start of, or right before, production of a new item the scheduler needs to make the call that the right materials are present, but in order to be able to do so, the buyers need to make sure enough stock is kept nearby so this can happen.

8.3.2 General recommendations

Record produced week plans

During the research it was found that no record is kept of produced production plans. Keeping a record of what was planned to be produced allows to make a comparison with what is actually produced. If changes occur these changes must be registered and categorized along with a root cause analyses on why they occur. This can provide insight in the practice of planning and can show what is done successful and what needs improvement.

Reduce the lead time for suppliers

Engage in conversation with suppliers to reduce the lead time of raw-, and packaging materials. As a more flexible planning method also comes with a more volatile demand for raw-, and packaging materials, it is important to find ways of ensuring the availability of everything that is needed for production. Whether by use of extensive stocks or by shortening the lead time of suppliers, or a combination of both, the challenge of being ready for production becomes much harder under these flexible conditions. To reduce the lead time, it is vital to start the ordering process as soon as possible. It might therefore be valuable to pass the forecast information that exists through to

Improve forecast quality

For all methods of planning the question of how much to produce is relevant. This lot-sizing problem can be solved in a variety of ways and all methods benefit from an accurate view into the future. Of course, it is impossible to predict with certainty what is going to happen so improving the forecast accuracy will never be a finished but with Items that have a production cycle of eight weeks, a good idea of how much to make when it is produced is very valuable.

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Appendix A

An applied approach for reducing nervousness and increasing flexibility in planning of production of FMCGs

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Abstract

Purpose – Developing a new method for planning of production of FMCG and evaluating that against the existing method.

Design/Methodology/Approach – From literature design opportunities were selected and formed into a planning method. Two implementations of that method were compared to the existing planning method in a simulation under different scenarios and for different performance indicators.

Finding – The 'Most Urgent First' method has great potential when implemented in the 'Short weeks' variant. At increased costs the nervousness and the service level increase.

Research limitations/implications – For this method to work, availability of raw-, and packaging materials must be possible on short notice.

Keywords planning, lot sizing, nervousness, simulation, case study

Paper type: Research paper

Introduction

Within the FMCG industry supermarkets use promotional activities to compete with one another. These promotions lead to high volatility in demand towards suppliers and are kept silent for as long as possible, until the public is informed. This, combined with the already volatile weekly demand from regular sales, brings a challenge to suppliers of FMCGs to be resilient to an increasingly volatile and unpredictable demand.

The company this case study was performed at makes dinner kits. Boxes containing uncooked pasta, condensed tomato sauce and herbs and spices. With these boxes a simple yet complete meal can be cooked by just adding water. To make the dinner kits, the company makes sauce and other ingredients. The materials to make the sauce come from various suppliers and several types of dinner kits are produced on the same machine. Finished products are sent to a warehouse and from the warehouse to the clients, the retailers.

Production at the company is performed 24 hours per day, for 5 days a week. Starting up, changing production from one item to another, and shutting down take considerable time. Not every product is produced every week, thus a stock system is used. Yet, the operations at the production line are not capacity constraint.

Analysis

The current method of operations at the company is to work with a Fixed schedule of production. For each production moment, the size of production is determined with a lot-sizing technique. To come to a schedule, a manufacturing frequency is determined. The manufacturing frequency is based on the economic order quantity (Harris, 1913), Equation , and from that quantity and the yearly demand an ideal production frequency is determined. The ideal production frequency is rounded in such a way that it fits into an eight-week, repeating production schedule.

Equation 1: Economic Order Quantity as by (Harris, 1913)

$$Q^* = \sqrt{\frac{2DK}{h}}$$

$Q^* =$ Economic order quantity
$D =$ annual demand quantity
$K =$ cost per order set up
$h =$ annual holding cost per unit of inventory

With the production moments determined, the next step of production is to determine the amount that needs to be produced. At each production moment enough should be produced to cover the demand until the next production moment. A forecast of expected demand is used to determine how much needs to be made. This lot-sizing method is called the Periodic Order Quantity.

As the forecast is not completely accurate, it happens that the actual demand is higher than what was expected. To overcome that situation a safety stock is used. This is a specific amount of extra stock that is kept to handle the difference between forecast demand and actual demand. However, when the actual demand exceeds the forecast demand, a decision needs to be made on whether or not the safety stock is sufficient. If it is decided that the safety stock is not sufficient, an extra production moment needs to be planned. In order to be able to produce such an extra production, all resources need to be available and extra transport to the warehouse needs to be organized. This leads to stress in the organization as the logistics department has to divert from regular operations to handle this situation.

The disruption of normal operations is called *nervousness* and is frequently described as problematic. Attributing the problems of nervousness to specific causes if proven difficult. It has led to planners deliberately choosing less than optimal solutions for planning problems to avoid nervousness. (Carlson, Jucker, & Kropp, 1979) (Demirel, Özelkan, & Lim, 2018) (Sridharan & Lawrence LaForge, 1989)

Relevance and objective

In literature it was found that the ‘Periodic Order Quantity’ lot-sizing method that is currently used, in general performs the least nervous. (Jeunet & Jonard, 2000). Furthermore, it was found that increasing the proportion of the production schedule that is frozen increases schedule stability. (Blackburn & Millen, 1985) (Sridharan, Berry, & Udayabhanu, 1988) It was also found that decreasing the planning horizon length increases stability. (Sridharan, Berry, & Udayabhanu, 1988)

It was decided that a new method of planning and scheduling could be developed where these findings could be implemented. To do so, inspiration was drawn from research where the scheduler was allowed more freedom in deciding what to produce, in order to be able to handle the variance of performance in reality. (Veeke, 1983)

This has led to the objective of the research being: ‘*To determine how planning and scheduling of the production of Miracoli Dinnerkits must be organized to lower nervousness and increase the customer service level.’*

Method

To see if a newly formed method performs better or worse, a model simulation is made. In this simulation demand and forecast are input data streams. The periodic order quantity, starting stock, change-over times and production rate are given and deemed constant. To solve the question of what to produce when, different methods are programmed. The resulting production schedule is then analyzed in order to compare its performance. By changing the input data, the performance can be measured in different scenarios.

What is measured is defined by the KPI’s, the key performance indicators. Three performance metrics are sought. Nervousness, demand satisfaction and costs. For nervousness the occurrence of unplanned productions or the absence of planned production in a week’s production results are considered indicators of nervousness.

Equation 2 setup stability according to (de Kok & Inderfurth, 1996)

$$\pi_s = 1 - \frac{E\left[\left|\delta(Q_1) - \delta(\hat{Q}_1)\right|\right]}{max_{\mathcal{R},F_D} E\left[\left|\delta(Q_1) - \delta(\hat{Q}_1)\right|\right]}$$

$$Q_t = \text{production in period '}t\text{'}$$
$$\hat{Q}_t = \text{predicted production in period '}t\text{'}$$
$$E[\cdot] = \text{expected amount}$$
$$max_{\mathcal{R},F_D} E[\cdot] = \text{max for rules } \mathcal{R} \text{ and demand } F_D$$
$$\delta(Q) = \begin{cases} 1 \text{ if } Q > 0, \\ 0 \text{ if } Q \leq 0. \end{cases}$$

The demand satisfaction is the percentage of the total demand that can be delivered. The complement of this percentage is the part that is not delivered. By tracking the stock levels each week, and by letting the model subtract the week’s demand even if the stock is not sufficient, any negative stock is undelivered demand. This undelivered demand is expressed as a percentage of total demand.

Equation 3 Calculation for Customer Service Level percentage

$$CSL = \frac{\sum_i \sum_t Z_i^t}{\sum_i \sum_t D_i^t} \times 100\%$$

Z_i^t = On-time delivered items i on period t
D_i^t = Demand for items i in period t

Equation 4 Calculation for Costs of fulfilling demand (Trigeiro, Thomas, & McClain, 1989), simplified

$$C = \sum_t \sum_i H_{i,t} I_{i,t} + \sum_t \sum_i S_{i,t} Y_{i,t}$$

$$H_{i,t} = \text{holding costs per unit per period for unit } i$$
$$I_{i,t} = \text{inventory of item } i \text{ at period } t$$
$$S_{i,t} = \text{cost to start production of item } i \text{ at period } t$$
$$Y_{i,t} = \text{production Boolean for item } i \text{ at period } t$$

Future states

To overcome the discrepancy between actual demand, and the demand that was forecast when an item was last produced, it was decided to test a system with a shorter planning horizon, and possibly with a completely fixed planning horizon. This has led to two implementations of a ‘Most Urgent First’ planning method. The implementations are called ‘Full & Empty weeks’ and ‘Short weeks’, after the predicted form of planned production weeks.

Full & Empty weeks works by frequently determining the length in days a stock will cover. All items are then ranked and to determine the production priorities. These priorities are then passed through to the work scheduler. The work scheduler starts work with the highest priority item. To determine the size of the lot, the existing Periodic Order Quantity is used. This means a quantity to cover the predicted demand of a predetermined number of weeks is produced. After the production of this quantity, the remaining days of stock, and consequent priority of items are updated.

Under normal conditions there is a higher production capacity than there is demand. To overcome this difference, the planning method keeps producing, and adding weeks to the forecast demand that stock needs to cover, until at the beginning of the week there is no need to start up the production facility, because all items have more than one week of stock. This leads to full weeks of production wit sometimes a week without production.

Short weeks works by allowing the scheduler to stop working as soon as all items for the next week are produced. This allows for the length of production time to be shorter than the time capacity of the line. In other words, the workweek ends when all that is needed is produced. Contrary to the Full & Empty weeks method, it prevents the addition of unplanned production of items, unless the item has the risk of going out of stock.

Model

These two implementations of the Most Urgent First method are tested next to a simulation of the current method of planning in a model. The input data for the model is varied in four ways. To do so, a profile of the demand has been formed. For each item the average demand, the demand standard deviation and the forecast accuracy was determined. To determine the performance under varying circumstances the following parameters are varied: The average demand, the standard deviation of the demand and the accuracy of the forecast. Furthermore, a seasonality is added to the demand, where the demand average is cycled between lower and higher in the length of a year.

Results

The results that were found provide insight in the working of the alternative methods. It was found that the 'Short weeks' method has no extra production and few missed productions, and thus a very low percentage of weeks with any change at al. The 'Full & Empty weeks' method has similarly low missed weeks, but because of the workings of the method it has considerable amount of extra productions and therefore a considerable number of weeks with any change. The original method, with a 'Fixed schedule', has some extra productions but also a very high percentage of missed productions.

Looking at the amount of demand that cannot be delivered, or stock shortage, it can be seen that both methods of 'Most Urgent First' scheduling have very low amounts of stock shortage, whilst the 'Fixed weeks' method has a considerable amount of out-of-stock situations.

The large percentage of low and negative stocks in the 'Fixed schedule' method leads to a considerably lower cost of keeping stock. For the 'Short weeks' method, this holds to a certain degree, as there is no extra production and thus no extra stock. In contrast, the 'Full & Empty weeks' method has the highest stock costs. And with quite similar set-up costs, this leads to an equal order for total costs.

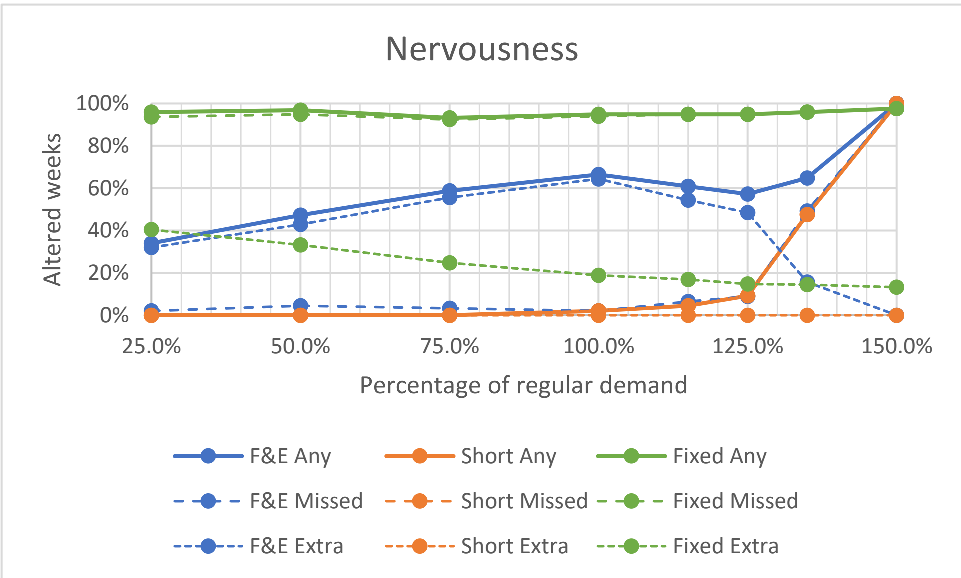

Figure 1 Percentage of weeks with specific forms of nervousness for increasing percentages of regular demand

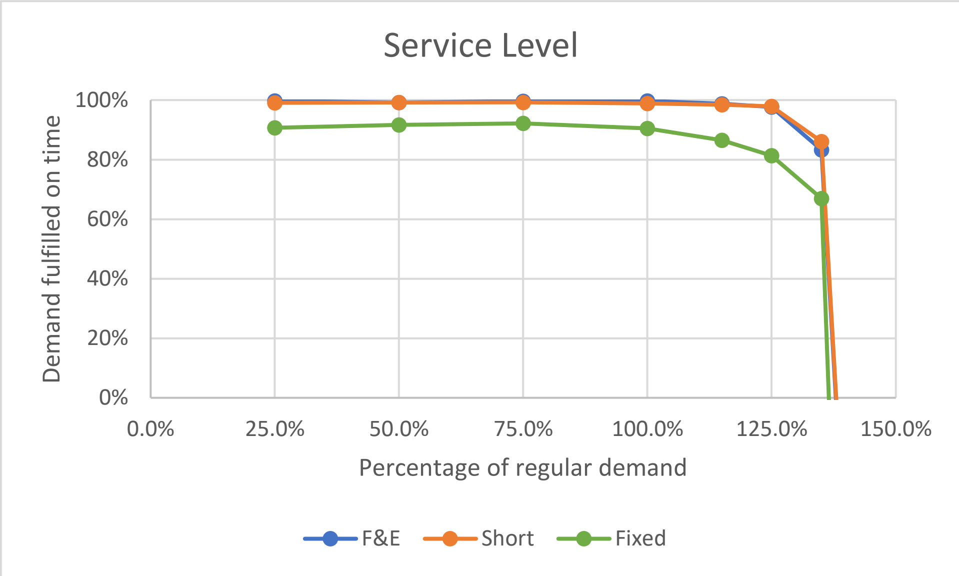

Figure 2 Service Level for increasing percentages of regular demand

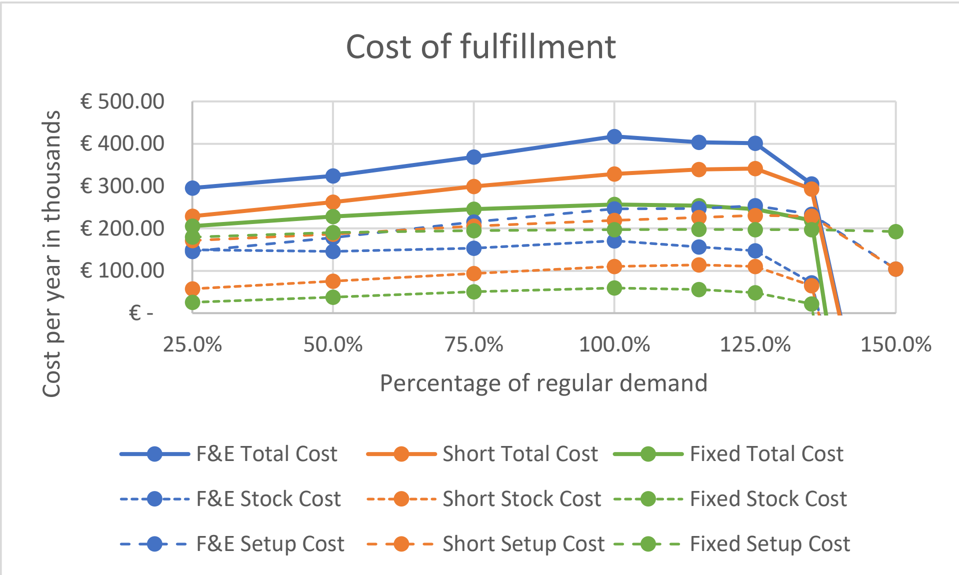

Figure 3 Cost of operating for increasing percentages of regular demand

It was found that under increasing demand, a clear crossover is present at around 125% of regular demand. Maximum capacity is reached and the lack of time to spare results in nervousness from missed productions, high percentages of unfulfilled demand and because of the high amount of negative stocks, a very strong decrease in stock holding costs.

For the simulation where the standard deviation of the demand was increased, it was found that a similar failure of reliable operation was present at 250% of regular standard deviation. Furthermore, it was noticed that the 'Full & Empty weeks' method's nervousness performed increasingly well under higher levels of standard deviation, whilst the other methods became more nervous.

When the forecast accuracy was examined, it was found that all three methods were hardly influenced. A small increase in nervousness was witnessed for the 'Fixed schedule' method as well as a quite linear increase in stock shortage for increasing forecast variability.

Verification

When running the real world demands through the simulation model, the data from Table 16 is found. This would ideally speaking also be compared with the real-world data. For the costs however, this data is unavailable. For the extra, missed, or any altered production percentage of weeks the following data was found from the records of 48 weeks in 2018: 17% of the weeks had missed production, 8% had extra production and 23% had any change. In 2018, there were 42703 cases of Line 4 items not delivered, of which 23738 were due to a mismatch between production and demand. This leads to an Out of Stock percentage of 2.0 %, and thus a complement of 98.0% Service Level. Significantly lower than the percentage of negative stocks the simulated Fixed method gets with the use of historic, or generated demand data. This is because in reality a safety stock is kept to prevent out of stocks. This part of the fulfillment stream is not simulated.

Table 1 Comparison of historic data results with simulated data results

Data + method:	Extra production	Missed production	Nervousness	Service Level	Costs total [x10³]	Costs stocks [x10³]	Costs setup [x10³]
Historic + F&E	70%	3%	73%	99.9%	344	144	200
Simulated + F&E	64%	2%	66%	99.7%	334	137	197
Historic + Short	0%	3%	3%	99.2%	267	90	177
Simulated + Short	0%	2%	2%	98.9%	263	88	175
Historic + Fixed	15%	100%	100%	90.9%	203	46	157
Simulated + Fixed	19%	94%	95%	90.4%	205	47	158

Discussion

This research explores the possibilities of one solution to the planning and scheduling problem. Countless more solutions can be formed and investigated. The applied approach limits the analyses to use in the system as it was present. The research was limited to the effects on service level, nervousness and costs, whilst other parts of the supply chain must adapt to this new method as well.

Conclusion

Using the 'Most Urgent First' method provides opportunities for decreasing nervousness and increasing demand fulfillment. The potential of the 'Short weeks' method is good. Future demand profiles in the FMCG industry might increase demand variability as well as decrease forecast accuracy, and in both cases the 'Short weeks' method scores better on nervousness as on Service Level, although at a higher cost.

Recommendations/future research

Exploring the possibilities of the 'Most Urgent First' methods can provide valuable insight and help shape the future of the FMCG industry. A complementary research in the design of the supply chain for raw and packaging materials or an extension on the existing research is necessary to ensure the availability of raw materials and packaging materials. (Diepenhorst, 2019)

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Appendix B

B.1 Verification of the Full & Empty weeks method

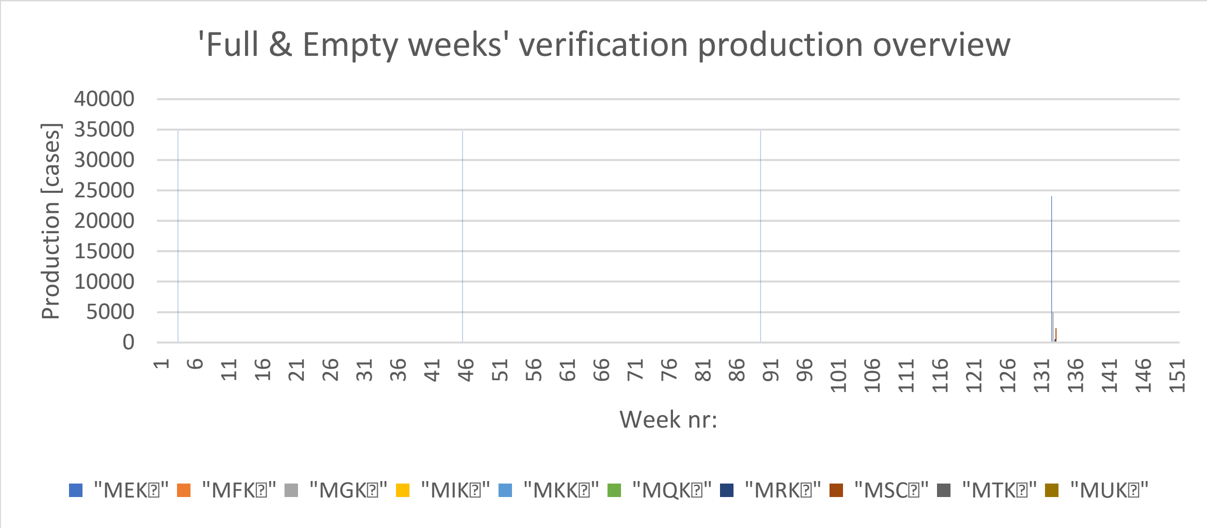

Figure 1 Verification of behavior of the 'Full & Empty weeks' method - production

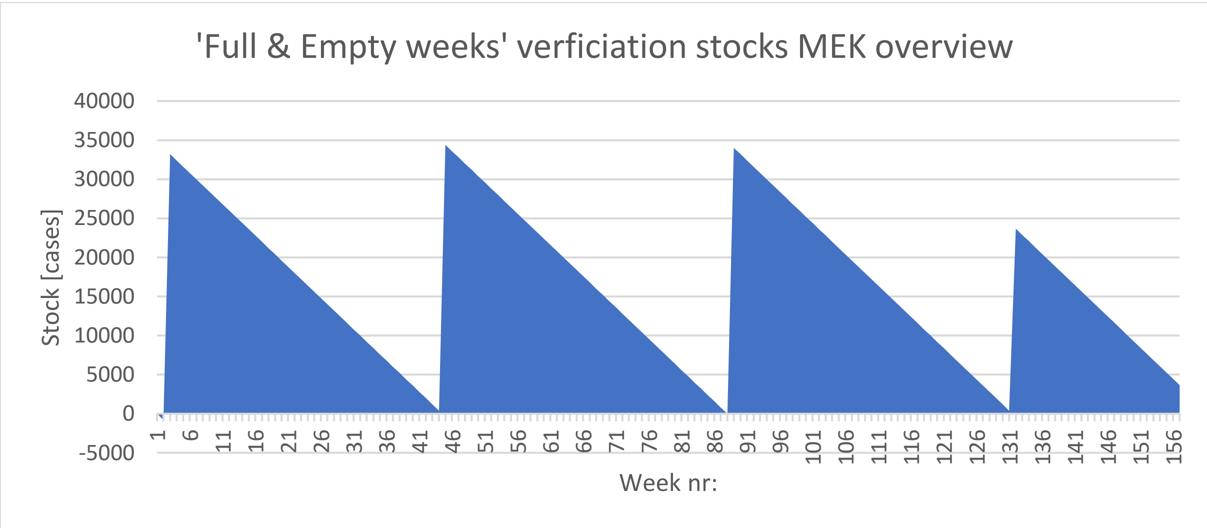

Figure 2 Verification of behavior of the 'Full & Empty weeks' method - Stocks

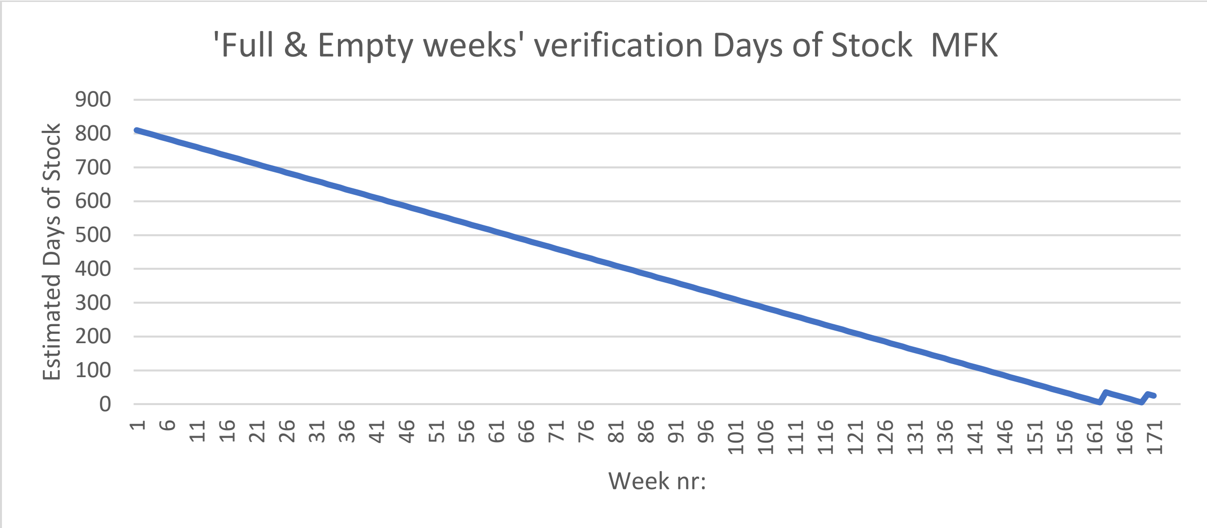

Figure 3 Verification of behavior of the 'Full & Empty weeks' method - Days of Stock

B.2 Verification of the Fixed Schedule weeks method

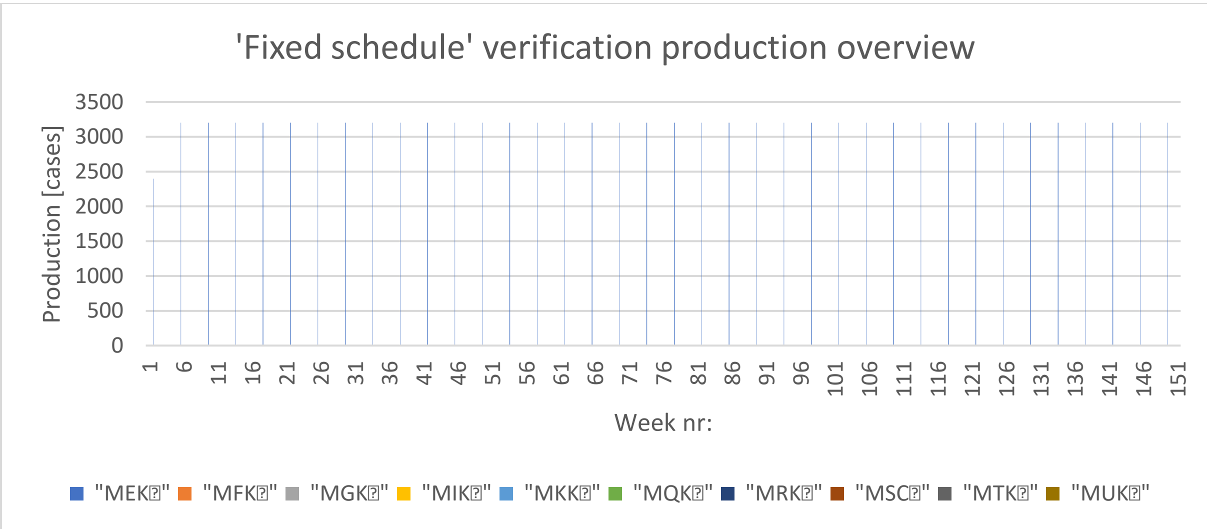

Figure 4 Verification of behavior of the 'Fixed schedule' method - production

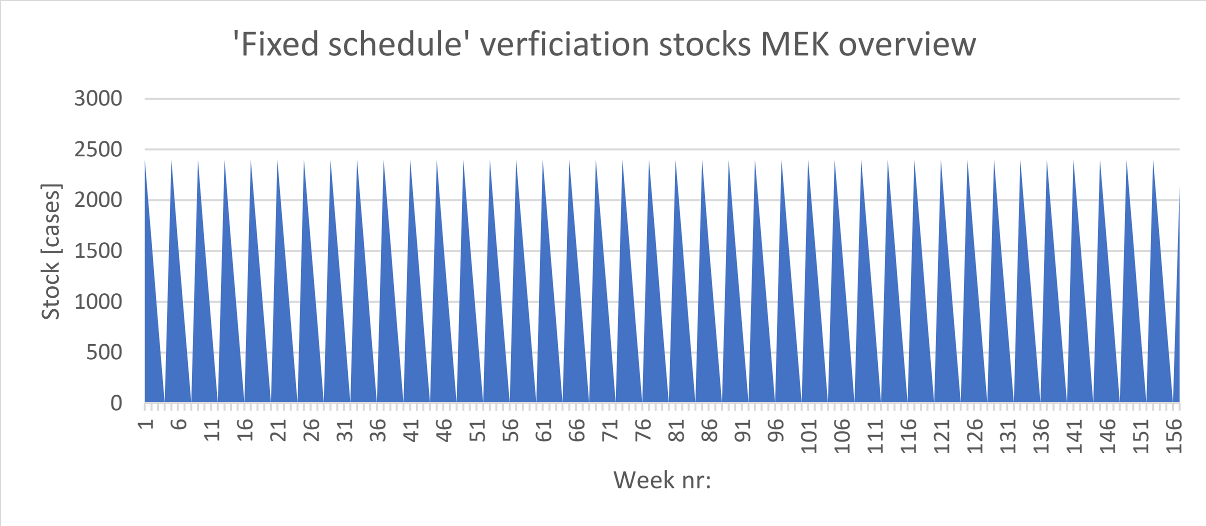

Figure 5 Verification of behavior of the 'Fixed schedule' method - stocks

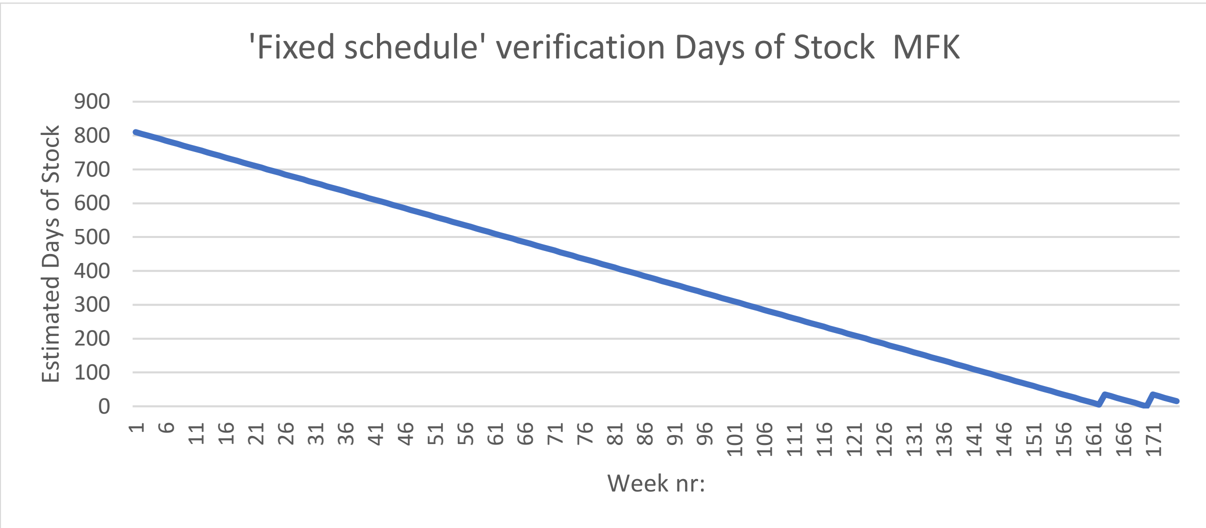

Figure 6 Verification of behavior of the 'Fixed schedule' method - Days of Stock