Effective adjustments on the production plan as a response to short term demand fluctuations

Mensen, A.

Award date:
2014
Effective adjustments on the production plan as a response to short term demand fluctuations

By
Annemarie Mensen

BSc Industrial Engineering & Management Science — TU/e 2011
Student identity number 0649662

in partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

Supervisors
dr. Z. Atan, TU/e, OPAC
dr. ir. N.P. Dellaert, TU/e, OPAC
Subject headings: forecast-based inventory policy, demand fluctuations, plan adjustments
Abstract
This master thesis is about effective adjustments on the production plan as a response to short term demand fluctuations. Adjustments to the production plan on the short term are performed in order to protect the fill rate. In this research the frequency, causes and effects of short term changes on the production plan are investigated. Besides a forecast-based inventory policy is investigated to determine the effectiveness of short term adjustments on the production plan. More specifically, a dynamic order-up-to policy is studied to analyze when it is preferable to adjust the production plan or to continue the original production plan with respect to the service level and costs. Furthermore, it is studied whether it is preferable to use inventory instead of short term adjustments on the production plan as a response to demand variability.
Management summary

The Production Planning team is responsible for the planning of the production lines. The job as production planner interacts between supply and demand, where in the perspective of production planning the factory is seen as supply and the demand planner is seen as customer. This is shown in Figure 1.

![Diagram showing the position of the production planner in the supply chain](image)

Figure 1: The position of the production planner in the supply chain

The production planning process consists of a number of recurrent steps. Each week the production planners create a production plan per production line for the upcoming week. There are two types of variability that have a significant influence on the planning process: demand and supply variability. Both demand and supply variability can result in short term adjustments on the production plan as shown in Figure 2. Short term adjustments refer to daily changes that take place during the week.

![Diagram showing the causes and effects of short term adjustments on the production plan](image)

Figure 2: The causes and effects of short term adjustments on the production plan

The production planner has to take the decision whether to adjust the production plan or to continue the original production plan; i.e. whether to allow a short term change. In the scope of this project short term adjustments on the production plan that are caused by demand variability are investigated. Here the production planner estimates the importance of the request when taking a decision. The customer oriented approach influences the decision making process, because short term adjustments on the production plan are made to protect the CSL. However, there is no uniform decision making process; i.e. each production planner makes his or her own consideration when taking the decision. Therefore, the management of the department Production Planning would like to structure the
decision making process by providing guidelines to their team how to deal with demand variability on the short term.

To support these guidelines, the first research question focuses on the current situation. The aim is to identify the causes and effects of short term adjustments on the production plan.

I. What are the main causes and effects of short term changes on the production plan and how are these currently handled by production planners?

In order to answer this research question, data is collected via surveys that have provided insights in the causes, effects and frequencies of short term changes on the production plan and interviews that have provided insights in the decision making process of the production planners.

The total number of short term changes during the data collection is equal to 174 changes. In perspective of the number of items that is produced on the production line, at most 10% of the items changes. It is found that the opening stock and the number of items that is planned per production both significant influence the frequency of short term changes. A lower opening stock than target stock and/or more items planned than average on a production line results in significant more short term changes on the production plan.

Most short term changes on the production plan are caused by CRP markets that experiences higher sales than expected as shown in Figure 3. Besides, the line performance causes 27% of the short term changes. It is interesting to note that half of the short term changes are caused by items that are categorized as small: small refers to an annual sales volume less than 100 ton.

Most short term changes result in a changed production quantity, even 71% results in an increased production quantity. When determining the effect of short term changes in terms of workload, it is found that the production planner spends on average 6.8 minutes on a short term change. Next to the production planner, the scheduler is involved in all short term changes to adapt the production schedule and communicate the changes to the associates of the factory. Furthermore, the packaging material needs to be checked. In 27% of all short term changes the Inbound department is contacted to perform this check, but mainly this check is performed by the production planner itself via the pick list. It is noted that the market is contacted only in 22% of all short term changes; this contact is mainly initiated by a request of the market. The total time that is spend by associates of different departments to perform a short term change is approximately one hour.
The main arguments in the current decision making process of the production planners whether to adjust the production plan or not are similar. First the available stock at the hub is considered. In 55% of all requests that are related to demand changes, the available stock at the hub was sent to the market warehouse via the LMSL. In case that there is not stock available at the hub, the capacity of the production line and the availability of the packaging material are considered in the decision whether to adjust the production plan or not. However, three factors can influence this decision: the urgency of the request, the size of the request and the current production schedule.

Different levels of urgency can be defined with respect to demand requests. This urgency is determined by the production planners based on their experience. Besides, some production planners challenge the urgency with the demand planner before taking the decision to adjust the production plan and/or some production planners look in detail at the stock level of the requested item in the planning system. Furthermore, it is expected that the willingness to take risks influence the urgency classification of a request.

However, a strategy that provides guidelines how to react on short term demand changes is desirable. These guidelines should offer rules of thumbs when to adapt the production plan and when to continue with the original plan and are investigated in the second research question:

II. What would be a preferred way to handle short term demand changes on the production plan?

In order to answer this research question, a forecast-based inventory policy is investigated. More specifically, the dynamic order-up-to policy as proposed by Babai and Dallery (2005) is studied and taken as a starting position to mimic the inventory model as used by the company. Numerical experiments are performed in order to provide insights in the effect of short term demand changes on the production plan with regard to costs and the service level.

In order to determine the optimal decision point to allow a short term change the customer service level is leading: the optimal decision point is chosen in such a way that the customer service level is met. Numerical experiments are performed to determine the decision variable when a short term change is profitable or not and come up with a guideline in the trend of: “An adjustment on the production plan is effective when the expected net inventory over x days drops below y percent of the safety stock level”. Firstly, the decision variable x is studied to determine when the expected net inventory should be considered to decide whether to adjust the production plan or not. The minimum value of decision variable x is equal to five days, because it takes five days to enable a short term change. The numerical experiments show that five days is also the optimal decision variable, because here the CSL is increased the most when performing a short term change. Secondly, the optimal value of decision variable y is determined in terms of a certain percentage of the safety stock level. The results strongly depend on the input parameters, that are set as close to the parameters at the company. It is found that under the specific input parameters and the condition that the CSL needs to be met, a short term change is profitable when the expected net inventory level drops below 70% of the desired safety stock level.

Furthermore, the safety stock level is incorporated in the numerical experiments, because a higher safety stock level leads to less short term changes. In terms of costs it is interesting to evaluate whether it is preferable to set a higher safety stock level to respond to demand variability or to set a lower safety stock level and adjust the production plan to respond to demand variability. For this reason the numerical experiments are performed for different levels of the safety stock. It is found that an increased safety stock level results in less costs and less short term changes under the specific input parameters. It is profitable to set the safety stock level in such a way that most demand variability can be covered by the safety stock and that less short term changes are required. Under the set input
parameters, it is most effective to set the safety stock level equal to ten days and perform a short term change when the expected net inventory over five working days drops below 20% of the desired safety stock level.

However, it is important to emphasize that these results strongly depends on the input parameters. In order to make the results of the numerical experiments more applicable in practice, numerical experiments are performed for eight items that are produced in the factory for the Dutch market. For these items the forecast values per week for the year 2014 are taken input values, where it is assumed that the forecast accuracy remains the same as in 2013. The numerical experiments show that the effectiveness of short term changes on the production plan depends on the demand variability of an item. When forecast values of an item show small differences over the year, it is profitable to use safety stock as a response to demand variability. However, when these forecast values differ strongly over the year, due to promotions, it is beneficial to use short term changes instead of safety stock as a response to demand variability. This is an important finding, because extreme sales values compared to the forecast values are mainly caused by promotions.

An important limitation of the research model is that the decision whether to make an adjustment on the production plan or not differs per item. For this reason the guidelines, as provided by the research model, cannot be generalized for all items. This means that it is not possible to provide one guideline that can be applied for all items due to two main reasons. Firstly, each market has a different forecast accuracy and in this project the forecast accuracy of the Dutch market is considered. Secondly, each item has a different demand variability (e.g. the forecast values of an item could differ weakly or strongly over the year). Therefore, the found guidelines in this project are only applicable for the items that are sold on the Dutch market and differs for items that show a high or low demand variability. Still three recommendations can be provided:

- The numerical experiments of the research model has shown that when the forecast values of an item show small differences over the year, it is profitable to use safety stock as a response to demand variability. For these items it is desired to increase the safety stock level till at most one short term change is required. It is recommended to make a note of specific items that require several short term changes. This indicates that the safety stock level should be increased for these items.

- Besides, for these items at most one short term change should be sufficient to deal with extreme sales values compared to forecast values. Therefore it is suggested to challenge the urgency of a market request in order to minimize the number of short term changes. It is recommended to determine and challenge this urgency of a market request before taking a decision how to respond to the market request.

- Provides insights about the safety stock level to the markets in order to provide guidelines with regard to the maximum acceptable percentage of forecast change. These guidelines are most beneficial with regard to promotions, because most extreme sales values compared to the forecast values are caused by promotions. It is recommended to determine borders with regard to promotions in which customers of the markets are allowed to change their forecast. These borders should limit the demand variability of promotions and therefore increase the reliability of the deliveries to the customers.
Preface

This report is the result of my master thesis project in order to fulfill my master degree in Operations, Management & Logistics at the Eindhoven University of Technology.

This master thesis represents the end of my study period in Industrial Engineering, during which I learned a lot. I have enjoyed the numerous group projects that have guided me through the different aspects of Industrial Engineering and showed me the value of cooperation with people from different backgrounds. I am grateful that I have got the opportunity to experience the student life at Boğaziçi University in Istanbul and the working life at the company where I have performed my master thesis. I would like to thank several people who gave me the opportunity to perform this project and who supported me during the project.

First, I would like to thank my primary university supervisor Zümbül Atan, for her overall support and feedback during this research project and its preliminary activities. In particular, I appreciated her confidence in succeeding the project while taking care of my workload. Moreover, I would like to thank her for the advices in order to determine the direction of the project, the concrete feedback in order to improve the structure of my report and the questions in order to challenge the quality of my research project. Besides, I would like to thank my second university supervisor Nico Dellaert for sharing his ideas in order to determine the project scope.

Furthermore, I would like to thank my company supervisors for their guidance and reflection during my project. I have enjoyed the weekly meetings to take care of my progress and discuss the direction of my project. Moreover, I have enjoyed the monthly meetings to define the scope of my project and discuss the sub results of my project. I would like to thank both my supervisors for the time and energy they spend on guiding me during this project, which makes this a great company to perform a research project. Besides, I would like to thank the team of Production Planning who were always willing to help me and made me feel part of the team.

Last, but not least, I would like to thank my family, friends and boyfriend for their continuous support during my study. I am grateful for their interest and confidence in my graduation project and stimulating me to enjoy my time at the TU/e and Boğaziçi University.

Annemarie Mensen

March 2014
# Contents

Abstract .......................................................................................................................... 3  
Management summary ................................................................................................... 4  
Preface ............................................................................................................................ 8  
1. Project context ........................................................................................................... 11  
   1.1 Production Planning .............................................................................................. 11  
   1.1.1 Production Planners ......................................................................................... 11  
   1.1.2 Planning process ............................................................................................... 12  
   1.1.3 Performance measurements ............................................................................ 13  
   1.1.4 Markets ........................................................................................................... 14  
2. Project description ..................................................................................................... 15  
   2.1 Motivation ............................................................................................................. 15  
   2.2 Problem description ............................................................................................. 15  
   2.3 Project scope ......................................................................................................... 18  
   2.4 Research questions ............................................................................................... 19  
3. Literature review ....................................................................................................... 20  
   3.1 Schedule instability .............................................................................................. 20  
   3.2 Inventory models .................................................................................................. 22  
4. Research method ....................................................................................................... 23  
   4.1 Data collection ...................................................................................................... 23  
   4.2 Research model ..................................................................................................... 24  
5. Description current situation ..................................................................................... 26  
   5.1 Response rate ....................................................................................................... 26  
   5.2 Frequency of short term changes ....................................................................... 26  
   5.3 Causes of short term changes ............................................................................. 30  
   5.4 Effects of short term changes ............................................................................. 31  
   5.5 Current decision tree ........................................................................................... 34  
6. Forecast-based inventory policy ................................................................................. 38  
   6.1 The (T, S) policy .................................................................................................. 38  
   6.1.1 Forecast values ................................................................................................. 38  
   6.1.2 Replenishment level ......................................................................................... 40  
   6.1.3 Safety Stock ...................................................................................................... 40  
   6.1.4 Order quantity ................................................................................................. 42  
   6.1.5 Short term changes ........................................................................................... 42
6.2 Numerical experiments ........................................................................................................ 44
7. Conclusion and recommendations ....................................................................................... 50
  7.1 Conclusion .......................................................................................................................... 50
    7.1.1 Research question I ..................................................................................................... 50
    7.1.2 Research question II ................................................................................................... 51
  7.2 Limitations and recommendations .................................................................................... 52
References ..................................................................................................................................... 55
List of abbreviations and definitions ......................................................................................... 58
Appendix I – Standard form data collection ........................................................................... 59
Appendix II – Semi structured interview ............................................................................... 62
Appendix III – Statistical analysis of frequency of short term changes .................................. 63
Appendix IV – LSML .................................................................................................................. 72
1. Project context

1.1 Production Planning

1.1.1 Production Planners

The department Supply Logistics is responsible for the planning of raw materials and packaging material, the production planning and the transportation of the chocolates by truck or ship. The distribution from the warehouse to the end consumer belongs to Market logistics and is out of scope of Supply Logistics. Both Supply Logistics and Market logistics aim to satisfy the end consumers: “Satisfy our customers is our common goal”.

The Production Planning team is responsible for planning the production lines of the factory and external factory. Each production planner has the responsibility of one or more production lines. The job as production planner interacts between supply and demand, where in the perspective of production planning the factory is seen as supply and the demand planner is seen as customer. On daily basis, the planners interact with different departments to compose the production planning: factory, quality, finance, markets, co-processors, inbound, transport and engineers.

The production planner defines a production plan in terms of requested quantities per item per week, whereas the week starts at Sunday and ends at Saturday. The production plan is based on the demand forecast and the available production hours, excluding lost time for e.g. planned stops, maintenance or change-over hours. The planner communicates the production plan to the scheduler and has the possibility to provide additional information, e.g. certain items that have priority to be scheduled in the beginning of the week to meet the customer demand. Subsequently, the scheduler translates the production plan to a production schedule that represents in detail what items have to be produced when (in terms of days, shifts and times) and on which machine for the upcoming week. The scheduler decides when to switch between different items to minimize the number of set-ups. Figure 4 represents the job of the production planner and the job of the scheduler.

![Figure 4: The job of demand planner, production planner and scheduler](image)

When the production plan is implemented, the scheduler provides feedback to the production planner about the factory performance during the last 24 hours every morning. At the same time the production planner has the opportunity to give priority to specific items. Besides, it is the responsibility of the production planner to provide some guidelines that can be applied by the production associates. Firstly, guidelines need to be defined what to do in case of disruptions or unexpected events during the weekend. What to do when the packages of a specific item are not available? What to do when one of the raw materials gets out of stock? What to do when the production plan of the previous week is not finished in the last shift of the week on Saturday evening, do we start the new production plan on Sunday or continue the current production plan? The guidelines ensure that the production can take place during the weekend without contacting the
planners in case of unexpected events; every week new guidelines are communicated to the scheduler. Besides, every week a priority list is composed that indicates the lines that have priority in case of defects. For example, when two components are defect in different lines, the priority list indicates at which line the technical service needs to start the reparation first.

1.1.2 Planning process

Product characteristics
The products that are produced are classified as Fast Moving Consumer Goods (FMCG). These products can be sold quickly at a low cost price. An important characteristic is the freshness that restricts the time horizon that products can be hold in inventory.

Planning system
The production planners make use of a planning system that proposes a production plan that can be manually adapted by the production planners. The production plan is based on a demand forecast of each market. The demand forecast is officially updated once a week (Friday) in the system. The planning system intends to keep the stock level at the safety stock level. Based on historical data, the forecasted and realized sales are compared to calculate the safety stock level that incorporates:
- Correctness of the sales forecast; the more correct the forecast the less safety stock is required;
- Lead time; a longer lead time requires more safety stock to cover the transportation period.

Twice a year the safety stock levels of each item of each production line are reviewed and updated.

Standard planning process
The standard planning process of a production line consists of a number of recurrent steps each week as represented in Figure 5.

![Figure 5: Standard planning process](image)

The first step, creating a Sales and Operations Planning (S&OP) is performed periodically (a period consists of 4 weeks). The S&OP is “the way we ensure strategy is deployed and our business objectives are met. It balances demand planning with supply constraints and aligns demand and supply actions across the organisation”.

12
The second step, creating a long term planning is performed every week. The planner compares the sales forecast and the production capacity for the upcoming 18 months to check whether the required utilization is still healthy (i.e. utilization ≤ 95%). Besides, the planner takes a closer look to the proposed production plan of the system for the upcoming 8 to 10 weeks to create the production plan on recipe/family level. The recipe corresponds to the type of product and the family corresponds to the packaging type. This step is necessary to ensure the feasibility of the production plan, taken into account the maximal capacity of the different packaging machines, the production speed of the production line and the limited buffer capacity between the process and packaging part of the production line.

The third step, creating a production plan is performed every week. The production planner creates a production plan on item level (an item corresponds to a specific package, e.g. a box of 25 single packs) for the next week. The planner has to decide what items to produce in what quantities in the next week. Consequently, the packaging team checks the availability of the required packaging materials. After this check, the production plan for the upcoming week is sent to the scheduler, who translates the production plan into the production schedule and if necessary provides feedback to the planner to adapt the production plan (e.g. in case of current machine issues).

The fourth step, adjust daily plan, is important in the scope of this project. Each day the planners have a closer look at the produced items and inventory levels to be aware of unforeseen events that require adjustments on the production plan. The production plan of the current week can be adjusted in case of:

- **Demand variability**, including forecast changes and higher sales. These adjustments will be communicated by the different markets.
- **Supply variability**, including line performance, packaging problems, raw material problems and/or quality issues. These adjustments will be communicated by the corresponding departments (e.g. quality issues will be communicated by the quality department).

The production planner deals with both demand and supply variability on a daily basis and has to decide whether and/or when to adapt the production plan. Figure 6 represents the time horizon.

![Figure 6: Representation of the time horizon of the planning process](image)

1.1.3 Performance measurements

The goal of Production Planning is formulated as:

"Ensure excellent product availability in our market depots against lowest possible pipeline costs (inventory)"

To ensure the product availability the performance measure case fill (CSL) is introduced. This is the number of products (demand) that can be fulfilled from stock and is target at ≥ 98.5%. In general this service level is known as the fill rate (β) (Hopp & Spearman, 2008). Next to the CSL, the stock cover is
a performance measure of the production planners. The stock cover represents the number of days that demand can be fulfilled from stock. The number of products is variable, since it is based on the current sales forecast.

1.1.4 Markets
In the perspective of the production planners, the different markets are seen as customers. Each market corresponds to a country or group of countries (e.g. Belgium or South-Africa), whereas two types of markets are distinguished: Continuous Replenishment Product (CRP) and Periodic/Weekly Order Process (POP/WOP).

The CRP markets are mainly situated in Europe and the main part of the production volume in the factory is intended for these markets. The products of these markets are produced to stock, in literature known as Made To Stock (MTS). This type of production can be characterized as push production, where the production quantities are based on forecast demand. The POP/WOP markets are mainly situated outside of Europe. These products are produced to order, in literature known as Make To Order (MTO). For these products zero safety stock is required. This type of production can be characterized as pull production, where the production quantities are based on actual demand.

The CRP markets and POP/WOP markets offer different items to customers. The total demand of an item consists of the summed demand of CRP markets or the summed demand of POP/WOP market, depending on the legal text on a product. As noted, currently the CRP markets are the main customers of the factory. However, the demand of POP/WOP markets is expected to increase in the upcoming years. In Table 1 the percentages of demand that is requested from POP/WOP markets is shown over the year 2012. On average 17% of the production volume of the factory is produced for POP/WOP markets.

<table>
<thead>
<tr>
<th>Production line</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of demand requested from POP/WOP markets</td>
<td>21%</td>
<td>23%</td>
<td>8%</td>
<td>25%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Table 1: The percentage of demand that is requested from POP/WOP markets per production line

It is important to note that when the demand of a POP/WOP market is increasing rapidly and the company has decided to build a new factory close to the specific POP/WOP market, the factory will produce the requested demand in the mean time till the factory is finished.
2. Project description

2.1 Motivation
In June 2013, another business segment has presented some insights in demand control and has triggered the management of the department production planning by their results. This project was driven by three main factors (Wrigley, 2013: 4):

- Efficiency: Waste of resources to manage demand and supply variability in the short term
- Effectiveness: We are not able to shape demand to match our short term supply constraints
- Management focus: “Noise” in the short term distracts the organization from focusing on the S&OP+ time horizon

The questions raise why so many short term changes are necessary and whether the safety stock is used appropriately, since the demand variation is relatively small and a lot of inventory is hold. Besides, a simple calculation shows the impact of short term demand updates on operations in terms of time. Assumed is that a simple demand update takes 5 minutes time on the market side and 5 minutes on the factory side. In their example, 276 demand updates are received for the next week, resulting in $276 \times 10 \text{ minutes} = 46 \text{ hours}$ extra operation time. However, the impact on volume is negligible. Therefore, the need for guidelines with regard to allowing short term changes and the use of safety stock are emphasized. This leads to the improvement of the mentioned factors:

- Efficiency: Deploying a standard, lean process to achieve our cash, cost and service targets
- Effectiveness: We collaborate with our customers to shape demand to match our short term supply constraints
- Management focus: Short term variability is tackled at the right level and a formal link to S&OP+ is established

In this perspective “planners are responsible for protecting the orders, not the safety stock”. It is the responsibility of the production planner to enable the fulfillment of orders and not to protect the safety stock, this safety stock is introduced to buffer demand and supply variability and to ensure the fulfillment of orders in periods of uncertainty. The simple calculation regarding the impact of short term changes has raised questions at the production planning department of this business segment: What is the impact of short term changes on the production planning of our team and how should we react on these short term changes? These questions have initiated this project.

2.2 Problem description
The production planning process consists of a number of recurrent steps each week as explained in the planning process. There are two types of variability that have a significant influence on the planning process: demand and supply variability. Both demand and supply variability can result in short term changes on the production plan; short term changes refer to daily changes that take place during the week. The production planner has to take the decision whether to adjust the production plan or to continue the original production plan; i.e. whether to allow a short term change. According to Silver, Pyke and Peterson (1998) these decisions can be classified as operational decisions, since these activities are very detailed and have a short time horizon.

In case of supply variability, the scheduler provides information that can make the production planner decide to adjust the production plan; an example is a lower line performance than planned. Sometimes supply variability can force the decision when a short term change is unavoidable; e.g. the production plan has to be adjusted when packaging material is not available. In case of demand variability, the demand planner and stock controller provide information that can make the production planner decide to adjust the production plan. In Figure 7 the position of the production planner is represented in the supply chain.
Two examples of requests are the following of respectively a demand planner and a stock controller:

- “Dear all. Please find below the low stock coverage list. Could you pls. schedule these items asap and give us an update regarding next production/qty”.
- “Dear all. Please see here below the list of items with low stock cover. According to the planning system, everything should be ok within the next few days, but still there should be a problem for item A and item B. Can you please have a closer look and come back to me with updated feedback on both items?”

The causes of demand variability are twofold as represented in Figure 8: forecasts are updated once a week in the system and the sales can be higher or lower than forecasted. The forecast that is used by the production planners consists of a summation of the demand forecast by the different markets.

In case of demand variability, the production planner estimates the importance of the request when taking a decision. The customer oriented approach influences the decision making process, because short term adjustments on the production plan are made to protect the CSL. However, there is no uniform decision making process; i.a. each production planner makes his or her own consideration when taking the decision. Therefore, the management of the department Production Planning would like to structure the decision making process by providing guidelines to their team how to deal with demand variability on the short term.

Currently the flexibility of the production lines and the factory in combination with safety stock is used to deal with the demand variability. The flexibility of the factory refers to the opening times of the factory, since the factory is open 24 hours a day 7 days a week (except for Christmas). This flexibility enables last-minute changes; e.g. recipe changes can be postponed. The flexibility of the production lines refers to the possibility to shift items. The scheduler minimizes the number of set ups as much as
possible, but the production planner has still the possibility to extend or shorten the production run of an item or to add a production run of an extra item.

However, the flexibility of the production lines and the factory is limited and the safety stock needs to be balanced with the corresponding inventory costs and the desired service level. The forecast accuracy interacts with the safety stock and service level as shown in Figure 9.

As can be seen in Figure 9, improved forecast accuracy results in less safety stock and less shortage (i.e. a higher service level). Since holding inventory and shortages are directly related to costs, a higher forecast accuracy results in fewer costs. This exponential relation between inventory and forecast accuracy is shown in Figure 10: a higher forecast error (i.e. lower forecast accuracy) requires a higher inventory level to realize the same service level. Besides, Figure 9 shows that less shortage (i.e. a higher service level) requires a higher safety stock and vice versa the allowance of more shortage enables a lower safety stock. This relationship is exponential as represented in Figure 11. The higher the target of the service level (i.e. fill rate), the more safety stock is needed to satisfy the demand uncertainty and the more costs are involved to keep this inventory. Therefore in cost perspective a consideration needs to be made between the safety stock level and the required workload to deal with demand variability. A higher level of safety stock results in less workload for the production planners, since the safety stock will cover the variability in supply and demand. Vice versa, a lower level of safety stock results in more workload, since the production plan needs to be adapted more frequently to satisfy the demand (and meet the service level).

The interaction between service level, forecast error and safety stock is important for the planning process of perishable products. Currently, the CSL is set to 98.5%, the forecast accuracy is approximately 58.2% and the target safety stock is about 3 weeks. These set CSL and safety stock targets are challenging with the current forecast accuracy.

Concluding, a strategy that provides guidelines how to react on short term demand changes is desirable. These guidelines should offer rules of thumbs when to adapt the production plan and when to continue with the original plan. To support these guidelines, first an analysis of the causes and effects of short term adjustments on the production plan is required.
2.3 Project scope
The project scope is defined to indicate the main focus of the project and the project boundaries.

Production planning
The adjustments on the production plan performed by the department Production Planning, require adjustments of other departments as well as represented in Figure 8. However, the main focus of the project will be on the department Production Planning.

Demand variability
There are two types of variability that influences the production plan: demand and supply variability. In the scope of this project, the supply variability is assumed as a given. In this case the production plan has to be adapted. However, when demand variability appears the planners have to take a decision whether to adapt the production plan or not. Therefore, the main focus of this project will be on the impact of demand variability.

CRP markets
There are two types of markets: CRP markets and POP/WOP markets. The main difference between these markets is that CRP markets are MTS and POP/WOP markets are MTO. In this project, the possibility to buffer against demand uncertainty by increased safety stock will be investigated. Therefore, the focus will be on CRP markets, because these markets make use of safety stock. The safety stock is measured in number of days that demand can be fulfilled from stock. However, the capacity of a production line is shared by both markets. Therefore it is important to realize that POP/WOP markets influence the production possibilities of CRP markets as well, since the production capacity is shared.

Production lines
The department Production Planning is responsible for the production planning of the production and packaging lines. The project scope will be on a number of production lines; the packaging lines are out of scope of this project. To investigate the impact of short term adjustments on the production plan, a thought-out selection of production lines is necessary. Firstly, two types of production lines will be investigated: a production line that produces one recipe and a production line that produces more than one recipe. Besides, the production lines with more production capacity will be analyzed to enable a more generalized conclusion (by collecting more data).

Short term adjustments
When referring to short term adjustments on the production planning, the time horizon is set to one week. During one week, short term adjustments can result in an adjustment in the current production plan or in the production plan of next week. Referring to the standard production planning process, the third and the fourth step (respectively create weekly plan and adjust daily plan) are involved.

Forecast methodology
Currently the forecast is based on the expected sales supplemented with the planned promotions. Another way to create a forecast is to look at the historical sales data. It would be interesting to incorporate the different ways of forecasting and to evaluate the different methods with respect to the costs.
2.4 Research questions

The project description and problem result in two research questions. The first research question focuses on the current situation and the aim is to identify the causes and effects of short term adjustments on the production plan.

I. What are the main causes and effects of short term changes on the production plan and how are these currently handled by production planners?

I.1 What are the effects of short term changes on the production plan on the workload of the production planners and the final production plan?

I.2 Are there different levels of urgency with respect to demand requests?

The output of the first research question provides support for the goal and deliverables of the project and will be the input for the second research question. The second research question focuses on the future and the aim is to provide guidelines how to deal with demand variability.

II. What would be a preferred way to handle short term demand changes on the production plan?

II.1 When is it preferable to adapt the production plan and when is it preferable to continue with the original production plan with respect to the service level and costs?

II.2 Would it be preferable to use inventory to respond to demand variability instead of changing the production plan?

The output of the second research question directly results in the main deliverable of this project: providing guidelines how to react on short term demand changes.
3. Literature review

3.1 Schedule instability

In many companies schedule instability is a major issue, as confirmed by Pujawan and Smart (2012). Schedule instability and schedule nervousness refer both to frequent changes to the production schedule (Pujawan & Smart, 2012). These adjustments could be in terms of a different item, an increased/decreased production quantity or an earlier/later due-date compared to the original production schedule (Pujawan, 2008; Pujawan, 2004).

According to Pujawan (2004) and Blackburn, Kropp and Millen (1985) uncertainty in demand and supply causes the most schedule changes. Another cause of schedule instability is due to the effect of a rolling planning horizon (Pujawan, 2004; Carlson, Jucker and Kropp, 1979). Each period a production plan is developed and implemented for the current period. The production plan for later periods is revised periodically and adjusted to the current information of demand and supply. These revisions can cause schedule instability. Moreover, the variation in lot-sizing decisions is studied as a cause of schedule instability (Blackburn, et al., 1985).

There are different methods to measure schedule instability (e.g. Blackburn, Kropp & Millen, 1986; Sridharan, Berry & Udayabhanu, 1988; Sridharan & LaForge, 1989). A recent measurement of schedule instability is defined by Kadipasaoglu and Sridharan (2010) that incorporates positive lead times in multi-level MRP environments: “the weighted change in order quantities for all items at all levels over the horizon through subsequent planning cycles” (Kadipasaoglu & Sridharan, 2010: 726).

Frequent changes to the production schedule results in a higher responsiveness to the customer (Hozak & Hill, 2009). However, frequent changes to the production schedule results in increased schedule instability that subsequently results in disruptions in the production and delivery schedule (Pujawan, 2008). These disruptions cause changes with respect to e.g. personnel scheduling and machine loading (Carlson et al., 1979), rescheduling costs, variable capacity utilization and confusion in delivery schedules (Ho, 1992). In the trade-off between schedule instability and customer responsiveness, Carlson et al. (1979) suggest that many managers prefer a stable schedule above an optimal schedule based on costs. Besides a stable Master Production Schedule (MPS) results in less schedule instability in the Material Requirements Planning (MRP) what is beneficial in planning and controlling the production operations (Sridharan, Berry & Udayabhanu, 1987; Zhao & Lee, 1993).

Different approaches to reduce schedule instability are studied. A much studied remedy to reduce schedule instability is to freeze the production schedule (e.g Sridharan, et al., 1987; Sridharan & Berry, 1990; Zhao & Lee; 1993; Zhao, Xie & Jiang, 2001). Freezing the MPS can reduce the number of schedule changes. However, the freezing parameters (e.g. the length of the frozen interval) have a significant influence on the performance of the system, because a long-term frozen MPS can result in increased costs, a decreased service level and a more schedule instability (Zhao & Lee, 1993; Tang & Grubbström, 2002; Zhao, Xie & Jiang, 2001).

Another much investigated remedy to reduce schedule instability is the introduction of safety stock. Safety stock “can buffer against uncertainty from the production processes as well as uncertainty due to forecast errors” (Graves, 2008). Kampen, Donk and Zee (2010) found that safety lead time results in an increased delivery performance in case of supply uncertainty and safety stock results in an increased delivery performance in case of demand uncertainty. According to Sridharan and LaForge (1989) and Zhao, Lai and Lee (2001) the introduction of safety stock can reduce the costs and schedule instability while improving the customer service, but “too much safety stock can result in increased nervousness” (Sridharan & LaForge, 1989: 345). Furthermore, an improved forecasting accuracy and reduced setup costs stabilize the production schedule (Sridharan & LaForge, 1989).
Another remedy to stabilize the production schedule is the selected lot-sizing model. Carlson, et al. (1979) and Kazan, Nagi and Rump (2000) argue that the ‘schedule change costs’ should be added in the lot-sizing model in order to minimize the total costs. However, Ho (2008) suggest that schedule change costs does not have to be explicitly included in the model, since a change of the production schedule will affect the total costs as well. According to Zhao et al. (2001) the selected lot-sizing rule does not have a significant impact on the selection of the freezing parameters. However, the reducing effect of freezing the production schedule on schedule instability depends on the selected lot-sizing rule (Zhao, Goodale & Lee, 2005).

Tang and Grubbström (2002) incorporate the relation between the above described remedies to stabilize the production schedule by a planning and replanning model. The replanning decision is based on the tradeoff as described in the paper of Grubbström and Tang (2000) by Figure 12. This model provides a procedure to find the optimal replanning interval and to estimate the frozen period. Both, the replanning interval and frozen period show to be little influenced by the forecast error, since the forecast error is buffered by the safety stock.

Recently, Pujawan and Smart (2012) have found that stronger relationships with buyers and suppliers can reduce schedule instability. The results indicate that “buyers have better information and communication infrastructures than suppliers, but suppliers are more willing to share information than buyers” (Pujawan & Smart, 2012: 2259). With regard to the relationship with buyers, “schedule instability is significantly affected by the volatility of the buyers’ orders, the willingness of buyers to provide supply-chain related information and the extent to which the company plans collaboratively with their key buyers” (Pujawan & Smart, 2012: 2261). Besides, it is noted that the accuracy of the information is important, not the amount of shared information by the buyers. With regard to the relationship with suppliers, schedule instability is significantly affected by the flexibility and reliability of the deliveries.

Inman and Gonsalvez (1997) performed a case study in the automotive industry and identified the causes of schedule instability at a first-tier automotive supplier. The factor that causes the most schedule changes is gains and losses in material consumption. Other causes that result in schedule changes at the first-tier supplier are scrap and engineering changes. Pujawan (2004) performed a case study in a manufacturing company of shoes to quantify the causes and effects of schedule instability in practice. The case study indicates that on average 31.5% of the orders changes, mainly caused by the change of a customer order (35%) or a problem in the delivery/availability of the main raw material leather (24%). With regard to this case study, Pujawan (2004) refers to training and changes of the reward system of employees. In general, the implementation of a frozen period and safety stock are recommended.
3.2 Inventory models

The classical inventory models assume a probabilistic and stationary demand and can be classified based on the review interval (continuous or periodic) and the order quantity (variable or fixed). Well known classical inventory models are (s,Q), (s,S), (R,S), (R,s,S) and (R,s,Q) policy (Silver, Pyke & Peterson, 1998). These classical inventory models are a simplification of the actuality and extended in the literature to represent the actuality as accurate as possible.

The classical inventory models assume a stationary demand pattern (Axsäter, 2006). However, the cost efficiency of basic inventory models and the service level decreases when demand variability increases (Kok, 2013; Tunc & Eksioglu, 2011). To incorporate the demand variability (caused by forecast uncertainty) in an inventory model, demand forecast updates are introduced in the literature. The Martingale Model of Forecast Evolution (MMFE) assumes that each period new demand information becomes available that results in a new demand forecast (Heath & Jackson, 1994; Graves, Meal, Dasu & Qing, 1986). Several authors have applied the MMFE model to study production-inventory planning systems (Graves, Kletter & Hetzel, 1998; Güllü, 1996; Toktay & Wein, 2001; Iida & Zipkin, 2006; Lu, Song & Regan, 2006; Altug & Muharremoglu, 2011). It is found that improved forecasts results in less safety stock while maintaining the service performance.

Recently, updates of information are incorporated in the inventory system via imperfect Advanced Demand Information (ADI) “which means that early uncertain indication of prospective future orders is utilized” (Tan, Güllü & Erkip, 2007: 898). “The main motivation of employing imperfect advance demand information in an inventory/production system in general is that it can improve the performance of the system through decreasing uncertainty on future demand” (Tan, Güllü & Erifik, 2009: 676). According to Benjaafar, Cooper & Mardan (2010), ADI is always beneficial for the supplier, while it does not have to be beneficial for the customers that provide ADI. More updates are always beneficial. Besides, rationing can be used to improve the system performance when non-stationarity, uncertainty and long lead times characterize the inventory system (Tan, Güllü & Erkip, 2009). Rationing refers to policies that reserve some stock for the use of high priority customers only.

Another method to incorporate demand variability (caused by forecast uncertainty) in an inventory model is introduced by a forecast-based inventory policy that assumes non-stationary demand and a time dependent forecast. Babai and Dallery (2005) propose two forecast-based inventory policies: the dynamic reorder point policy and the dynamic order-up-to policy. The policy parameters are calculated periodically and based on the forecast. Besides, the authors provide a method to calculate a dynamic safety stock level that “adjusts better to the variability of the demand” (Babai & Dallery, 2005: 10). Recently, Vega Guzman (2012) developed two forecast-based inventory policies: one that account for the exact demand uncertainty and one that approximates the demand uncertainty when the variability is increased because of a biased prediction. Both forecast-based inventory policies assume stochastic, non-stationary demand, a positive constant lead time, a periodic review period and backorders. The policies apply an adaptive base stock level and the objective of the model is minimize the holding and backorder costs. It is found that forecast-based inventory policies achieve lower total costs and therefore outperform standard inventory policies. Besides, the results show:

- “When demand is stochastic and non-stationary, forecast-based inventory policies that cope with the exact demand uncertainty outperform forecast-based inventory policies making use of forecasting techniques assuming stationary demand patterns;
- The presence of demand variance is more important than the level of demand variance;
- Recent demand observations provide a better prediction for future demand;
- The value of information increases with the level of demand variability” (Vega Guzman, 2012: 9).

Currently, the literature that investigates forecast-based inventory policies is limited. To my knowledge, Babai and Dallery (2005) and Vega Guzman (2012) are the only authors that have presented a forecast-based inventory policy.
4. Research method
The research method consists of two parts: data collection and a research model. The data collection provide insights in the current situation and the research model provide insights in a preferred way to handle short term demand changes on the production plan.

4.1 Data collection
The analysis of the current situation will include the five core production lines A, B, C, D and E and should provide insights about the causes, effects, urgency and frequency of short term changes on the production plan. To identify the cause and urgency of a short term change, it is important that the production planner takes a note of each short term change. This also provides information about the number of times that short term changes occur. An important requirement to make these notes successful is that the notes are structured in order to collect the same information of each short term change. Therefore it is chosen to develop a standard form that include different categories to identify the cause, urgency and effect of a short term change. The effect of short term changes on the production plan can be seen in terms of the different adjustments on the production plan or in terms of workload. Therefore the categories as shown in Table 2 are included at the standard form.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling</td>
<td>How many times the same item has caused a short term change on the same day</td>
</tr>
<tr>
<td>Initiative</td>
<td>The initiator of the plan adjustment</td>
</tr>
<tr>
<td>Reason</td>
<td>Whether the short term change is done because of an cause or resulting from another short term change</td>
</tr>
<tr>
<td>Type change</td>
<td>The cause of the plan adjustment</td>
</tr>
<tr>
<td>Urgency</td>
<td>The urgency of the plan adjustment</td>
</tr>
<tr>
<td>Time</td>
<td>The time spend by the production planner to succeed the plan adjustment</td>
</tr>
<tr>
<td>Action</td>
<td>The production plan that is affected by the short term change</td>
</tr>
<tr>
<td>Change</td>
<td>The adjustment on the production plan in terms of extra, less or moved cases</td>
</tr>
<tr>
<td>Contact</td>
<td>Other departments that are contacted to succeed the plan adjustment</td>
</tr>
</tbody>
</table>

Table 2: The categories at the standard form

The standard form should be user friendly and quick to fill to stimulate that all short term changes are noted. For this reason the standard form includes multiple choices; these multiple choices are discussed with two of the production planners to ensure that all options are available at the standard form and clear to fill in. These multiple choice options can be found at the standard form in Appendix I. Moreover the item number and the weight per case are included in the standard form. Additional to the standard forms, there is a questionnaire that has to be filled on a weekly basis. This questionnaire includes questions about the production plan of that week, including the opening stock, the number of items, tonnage and number of recipes that are planned and whether the line is a controlled line. This information is collected to analyze which variables have a significant influence on the frequency of short term changes. Summarized, the production planners are asked to fill in the questionnaire on a weekly basis and the standard form each time a short term change take place. The data will be collected for a time horizon of 12 weeks (i.e. 3 periods); every week the production planners will receive a new set of forms including one questionnaire and several standard forms. During the first weeks of data collection some evaluation moments are planned with the production planners to evaluate whether the standard forms are user friendly and whether multiple choice options are missing. Besides, these moments are used to share the first results of the data collection to show the value of their participation and stimulate the continuation of the data collection.

The standard forms provide insights about the short term changes that have taken place during the period that data is collected. Besides, it is interesting to investigate the decision making process of the production planners; what are the criteria used by the production planners to decide whether to adjust
the production plan or not? In the ideal situation the production planners would like to know in advance whether a plan adjustment would prevent an out of stock. However, since the current forecast accuracy is less than 100%, differences between the forecast and actual sales are common. This makes that the ideal situation is not applicable in practice. It would be valuable to investigate what criteria production planners apply to decide whether to adjust the production plan or not. These criteria will be investigated via individual semi-structured interviews with the production planners of these production lines. It would be interesting to combine these semi-structure interviews with a numerical analysis regarding the percentage of requests that results in an adjustment of the production plan. However, the number of requests is hard to determine, because the production planner receives information and requests from different channels such as the market, the scheduler and the planning system. Subsequently, the production planner decides whether to adjust the production plan. Therefore it is decided to analyze the decision making process with regard to demand variability via semi-structured interviews; the total number of requests are not in the scope of this project. Besides these interviews provide an opportunity to evaluate the data collection via the standard forms. The semi-structured interview can be found in Appendix II.

Summarized, the surveys should provide insights in the causes, effects and frequencies of short term changes on the production plan and the interviews should provide insights in the decision making process of the production planners.

4.2 Research model

The research model should provide insights in the effect of short term demand changes on the production plan with regard to costs. According to the literature, there are two options to investigate the effect of short term changes on the production plan. One option is to measure the schedule instability of a production schedule, i.e. the frequency of changes on the production schedule. The optimal costs can be found when calculating the schedule instability and CSL at different levels of safety stock. The disadvantage of this method is that the concept schedule instability is an abstract concept and therefore difficult to translate to guidelines that can be applied in practice. For example when the optimal value of schedule instability is determined, this value can be translated in a number of changes on the production schedule that is allowed. However the translation of an optimal schedule instability value to a guideline how to react on a specific short term demand change is much more complicated. Another option is to develop an inventory model that mimics the planning system that is applied by the company to determine the production plan. The inventory model will have a rolling horizon and different scenarios will be simulated when a demand change appears. Two extreme scenarios that can be analyzed in case of a demand change are:

- Keeping a high safety stock and never adjust the production plan;
- Keeping a low safety stock and always adjust the production plan.

A comparison of these extreme scenarios can be made in terms of costs, where the scenario that results in the lowest costs is seen as a preferred way to handle short term demand changes. Subsequently, a scenario that is in between the two extreme scenarios can be found that should results in an optimum in terms of costs and a guideline in terms of “Do not change your plan if your forecast is affected by a percentage less than X, and make a change otherwise”.

One of the main deliverables of this project is a guideline how to react on short term changes. For this reason it is decided to develop an inventory model at the market warehouse on item level, because customer demand is satisfied from stock at the market warehouse. At this level the CSL is measured. The demand planner at the market warehouse creates the forecast and based on this forecast products are ordered at the factory. The time that expires between the placement and arrival of an order, i.e. the replenishment lead time, is shown in Figure 13 and consists of:

- The production time of the order at the factory;
- The transportation time from the factory to the hub;
The time that the order is hold on inventory in the hub;
- The transportation time from the hub to the market warehouse.

**Figure 13: The replenishment lead time of an order**

The inventory model at the market warehouse makes use of a target stock. The target stock level consists of the safety stock level and the average demand during the lead time.

\[
\text{Target Stock} = \text{Average demand during lead time} + \text{Safety Stock}
\]

At the end of the year the average stock level should be equal to the target stock level. The inventory level at the company is reviewed once a week: the review period is equal to one week. In case that the stock level is going to drop below the safety stock during the protection interval, a new order is placed. The protection interval equals the review period and lead time. The order quantity is determined by the order-up-to-level. The stock levels are shown in days as shown in Figure 14.

**Figure 14: The inventory model at the company**

As can be seen, the target stock and safety stock are fixed in terms of days under the assumption that demand is stationary (i.e. does not include seasonality). However, the demand per day varies over time and therefore the stock levels in terms of cases vary over time as well. The forecast for the upcoming days/months is used to translate the stock levels from number of days into number of cases. It is important to emphasize that the stock levels are calculated based on the forecast, instead of based on historical data. For this reason a forecast-based inventory policy is considered in this project. As investigated in the literature review (Mensen, 2013) the literature regarding forecast-based inventory policies is limited. Babaï and Dallery (2005) presented a dynamic reorder point policy and a dynamic order-up-to policy. In the scope of this project, the dynamic order-up-to policy is taken as a start position. The next step is to extend this inventory policy in order to enable short term changes and analyze the different scenarios based on the costs. Furthermore, the analysis of the current situation is used as input for the research model (e.g. the frequency of short term changes on the production plan). By analyzing the effect of short term changes on the dynamic order-up-to policy a new topic can be contributed to the literature.
5. Description current situation

5.1 Response rate
The response rate is hard to measure in quantitative numbers, because the number of short term changes that has occurred during the period of data collection is unknown. During the semi-structured interviews the production planners emphasized their willingness to fill in the standard forms. Besides they noticed that the standard form was user friendly, but that they had to become aware of the fact that a short term change occurred and had to get used to filling in the form each time a short term change has taken place. For this reason the production planners indicated that they are not able to ensure that all short term changes are filled in (a rough indication of the number of short term changed that is filled in is about 90%).

The representativeness of the period of the data collection differs per production line; the data collection has taken place over three periods (i.e. twelve weeks). The production planners of production line A, C and D indicate that the measured period is representative. The production planner of production line B indicates that during this period the production line has performed above average, what most probably resulted in less short term changes. The production planner of production line E indicates that during this period sales were significantly below plan in the markets, which has resulted in more capacity on the production line and therefore less short term changes.

5.2 Frequency of short term changes
There are two types of short term changes to distinguish:
A. Short term changes that are caused by a market or supply request;
B. Short term changes that are the effect of another short term change (e.g. an increased production quantity of item X could result in a decreased production quantity of another item).

The focus of this project is on type A short term changes, because the goal of the project is to provide insights in the initial cause of the short term changes. Besides type B short term changes are hard to measure, because not all short term changes of type B are actually noticed. The scheduler has already created some flexibility in the production schedule by scheduling items that have a small production quantity at the start of the week ('small items') and items that have a large production quantity at the end of the week ('large items'). An increased production quantity of a small item can therefore be buffered by a decreased production quantity of another item (type B short term change) or a decreased production item of a large item. This is shown in Figure 15.

Figure 15: Different types of short term changes to the production schedule
In total 202 short term changes have been analyzed of which 179 type A short term changes and 23 type B short term changes. Furthermore, 3% of these short term changes are handled for the second time. However, the cause of the short term change remains the same. Therefore in the continuation of this report short term changes will refer to type A short term changes that are handled for the first time; this equals to 174 short term changes. Figure 16 shows the occurrences of these changes over the 12 weeks that data has been collected. During this period two special events has occurred that has influenced the number of changes on the production line. First, in week P10W2 production line C has faced a system issue, i.e. the forecast was not updated correctly in the system and therefore several short term changes has been made for the production plan of P10W2 and P10W3. Second, in week P12W4 production line A has a planned shutdown, therefore several short term changes has been made in the week before.

![Figure 16: The occurrence of short term changes during the data collection](image)

These short term changes occur mainly within the time period of one day according to the scheduler of production line A, B and C (i.e. value stream 2): “Changes within 24 hours takes place circa 2 times a day and changes within 8 hours circa 1 times every two days”. A simple calculation results in 12 weeks * 5 days a week * 2,5 change every 24 hours = 150 changes for production lines A, B and C.

Besides it is interesting to translate the number of short term changes to the percentage of items that is changed on a production line. These percentages are shown in Table 3.

<table>
<thead>
<tr>
<th>2013</th>
<th>Line A</th>
<th>Line B</th>
<th>Line C</th>
<th>Line D</th>
<th>Line E</th>
</tr>
</thead>
<tbody>
<tr>
<td>% items</td>
<td>8%</td>
<td>6%</td>
<td>10%</td>
<td>7%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Table 3: The number of short term changes during this research

Different variables that can have a significant influence on the frequency of short term changes are investigated: the opening stock at the beginning of the week, the number of items that are planned, the tonnage that is planned, whether the production line is a controlled line, the utilization level of the production line, the factory performance of the production line and the number of recipes that is produced.

First, the different variables are transformed to exclude the influence of the characteristics of the production lines:
- Opening stock is transformed to the opening stock minus the target stock per production line;
- Number of items planned is transformed to the number of items planned minus the average items planned per production line;
• Tonnage planned is transformed to the tonnage planned minus the average tonnage planned per production line.

The relation between the different variables is analysed by a correlation matrix. Besides, this provides insights in the impact of these variables on the frequency of short term changes. In Table 4 the significant correlations are shown; here the Pearson’s correlation coefficient is applied, because of normality of the variables. The correlation theory and all correlations can be found in Appendix III.

<table>
<thead>
<tr>
<th>Correlation matrix</th>
<th>Stock</th>
<th>Utilization</th>
<th>Planned tonnage</th>
<th>Factory performance</th>
<th>Short term changes</th>
<th>Planned items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock</td>
<td></td>
<td>-0.323*</td>
<td>-0.277*</td>
<td>-0.369**</td>
<td>0.423**</td>
<td></td>
</tr>
<tr>
<td>Utilization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned tonnage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.502**</td>
</tr>
<tr>
<td>Factory performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short term changes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned items</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.298*</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Correlation matrix
* = Correlation is 0.05 significant
** = Correlation is 0.01 significant

As shown in Table 4, many variables are significantly correlated. Here it is important to investigate the effect of the sample size on the analysis. Data is collected of 5 production lines over a period of 12 weeks, what results in 60 data points. This small sample size can influence the results of the analysis (Snijders, 2009). When a significant result is found in a small sample size, this could be a coincidence. This result could be only significant under the specific circumstances during the data collection and generalization of the results could lead to incorrect conclusion. However, in the time frame of this project there was no possibility to collect more data. Therefore, the found significances are evaluated whether it is an expected result or an unexpected result due to the small sample size:

• The negative correlation between stock level and utilization level indicates that production lines that have a lower stock level than the target stock are highly utilized. In order to increase the stock level up to the target stock, the full capacity of the production line is used.

• Correspondingly more tonnage than average is planned (in order to increase the stock level up to the target level) as proved by the negative correlation between stock level and planned tonnage. It is logical that there is no significant negative correlation found between the stock level and the number of items that is planned, because the stock level cannot be increased by the production of more items, but by the production of more tonnage.

• In general the correlation between factory performance and stock is expected to be positive, because a lower factory performance is expected to result in a stock level that is less than the target stock. However, when the factory performance is fluctuating, a higher stock level is desired to cover the supply uncertainty and vice versa a stable high factory performance enables a lower stock level.

• An interesting (negative) correlation is found between the frequency of short term changes and the stock level: significant more short term changes occur when the stock level is less than the target stock. This relation is indicated by the production planners as well during the semi-structured interviews, because a lower stock level can buffer less variability in the demand and therefore short term changes are applied to satisfy the demand.

• The positive correlation between frequency of short term changes and number of items that is planned indicates that more short term changes occur when there are more items planned than average. A simple explanation can be found by the fact that when more items are planned, there is more chance that one of the items does not have enough stock to fulfill the demand and a short term changes is required.

• The positive correlation between the number of items and the tonnage that is planned indicates that when more items are planned than average on a production line, there is also more tonnage planned than average on a production line and vice versa. Most probably this correlation is found by coincidence because of the small sample size, because the average tonnage that is produced per item differs.
Next to the correlation matrix, the influence of the different factors on the frequency of short term changes is analyzed via a t-test. The t-test is applied to test whether the means of two groups are significantly different (Montgomery & Runger, 2007). In order to perform the T-test the variables are transformed into binary variables to create two groups as defined in Appendix III. The results are consistent with the found correlations. First, when the opening stock is less than the target stock, significantly more short term changes are applied. Also in case that there are more items planned than on average on the production line, significantly more short term changes are applied. Besides, it is found that the number of recipes influences the frequency of short term changes on the production plan. In case that more than one recipe is planned, significantly more short term changes occur than in case that one recipe is planned. However, it is important to note that this relationship could be influenced by another variable, because the data points that include more than one recipe shows a lower openings stock than target and more items planned than average as well. Therefore it is tested whether this relationship can be explained by a mediator as represented in Figure 17.

![Figure 17: The mediation between the number of recipes and the number of short term changes](image)

The analysis shows that the relationship between the number of recipes and the frequency of short term changes can be explained by full mediation of the number of items that is planned (in Appendix III the calculations are shown). Therefore it is concluded that the number of recipes does not have a significant direct influence on the number of items that is planned.

Based on the correlation matrix and the T-test, there are two variables that have a significant influence on the frequency of short term changes:
- The opening stock (compared to the target stock)
- The number of items planned (compared to the average items that is planned per production line during the period of data collection)

Both variables are included in a regression analysis (in Appendix III the regression theory and detailed analysis can be found). The found regression model is, with a significance level of 0.06 is:

\[
Y = 2.783 - 0.186x_1 + 0.060x_2
\]

with \(Y = \# \text{ short term changes}\)

\[x_1 = \text{Openings stock} - \text{Target stock (of the production line)}\]

\[x_2 = \# \text{ items planned} - \text{average items planned (on the production line)}\]

The regression model meets the assumptions of a regression analysis (the detailed analysis can be found in Appendix III). However, the model explains only 20% of the variability of the frequency of short term changes. The low percentage indicates that the frequency of short term changes is hard to predict, because the production planners has to deal with both demand and supply uncertainty.

Concluded, the correlation matrix, T-test and regression analysis prove that both the openings stock versus the target stock and the number of items planned versus the average items planned have a significant influence on the frequency of short term changes on the production plan.
5.3 Causes of short term changes

The causes of short term changes are classified in two main categories: demand and supply.

A short term change that is caused by demand refers to:
- Higher sales than expected by the forecast for CRP markets;
- Lower sales than expected by the forecast for CRP markets;
- Higher sales than expected by the forecast for POP/WOP markets;
- Lower sales than expected by the forecast for POP/WOP markets;
- A system issue (e.g. the forecast as shown by the system is incorrect).

A short term change that is caused by supply refers to:
- A quality issue (e.g. produced products are rejected or put on hold when the quality of a product is disputable and more tests needs to be performed);
- Line performance (e.g. the production line produces more or less than the expected output);
- A packaging problem (e.g. there is not enough packaging material available);
- A raw material problem (e.g. there are not enough raw materials available);
- An engineering issue (e.g. the engineering department has to fulfill unexpected maintenance).

Figure 18 represents the frequency of these causes during the period that data was collected. In total 58% of the short term changes was due to demand causes and 42% was due to supply causes.

![Type of change](image)

**Figure 18: The causes of short term changes**

The main cause of short term changes on the production plan is caused by CRP markets that experience higher sales than expected. In total 44% of all changes are caused by higher or lower sales than expected by CRP markets. Secondly, the line performance causes several short term changes on the production plan. In both cases, when the production line performs more or less cases than expected, the production plan has to be adjusted.

Remarkable is that more than half of the short term changes are initiated by the production planner. However, it is expected that there is some noise in these results because of an ambiguous definition of the word initiative with regard to short term changes that are caused by supply. The production planner receives information about e.g. the line performance or available packages and decides whether to adjust the production plan or not. Here the plan adjustment can be seen as an initiative of the production planner (who has taken the decision) or as an initiative of supply (who has provided the information). For this reason it is decided not to draw any conclusion regarding the initiative of short term changes that are caused by supply. The definition of the word initiative with regard to short
term changes that are caused by demand is more clear: the production planner can decide to make a plan adjustment based on the insights provided by the out of stock list of the planning system (classified as ‘Initiative of the production planner’) or based on a request from the market (classified as ‘Initiative of the market/supply’). Figure 19 represents these results.

![Initiative of short term changes caused by demand](image)

**Figure 19: The initiative of a short term change that is caused by demand**

In total 62% of the short term changes that are caused by demand are initiated by the production planner and 38% is initiated by a request of the market. This indicates that the production planners are aware of items that are having less stock than desirable. They feel responsible to prevent an out of stock and do not wait till the market makes them aware of possible risks by sending a request.

Furthermore the production quantity of the items that cause the short term changes is investigated, as shown in Figure 20. It is found that 50% of all short term changes is caused by items that have a production quantity equal to less than 100 ton per year. These items, that have a smaller volume per year, experience more difficulties to deal with demand fluctuations.

![Type of item](image)

**Figure 20: Type of item in terms of size that cause a short term change**

Summarized, the two main causes of short term changes on the production plan are higher sales of CRP markets and the performance of the production line.

### 5.4 Effects of short term changes

The effect of short term changes on the production plan can be determined in terms of different actions and in terms of workload. Here the system issue that has occurred in the first week of the data collection on production line C is excluded, because it is assumed that this is exceptional. First, the different types of actions are distinguished. As shown in Figure 21, 89% of the short term changes results in a changed production quantity of which 71% results in an increased production quantity. Besides it is found that most changes are performed in the production plan of the current week; 87%
of all short term changes are made in the production plan of the current week and 13% is made in the production plan of next week.

![Action Chart]

Figure 21: The action that is taken to perform a short term change

Looking at the number of cases that has been added, removed or changed in the production plan, it become visible that most short term changes involves less than or equal to 5000 cases as shown in Figure 22. In total 93% of all short term changes involves less than or equal to 5000 cases. More than half of all short term changes (56%) involve less than or equal to 1000 cases.

![Number of cases chart]

Figure 22: The number of cases that is involved by a short term change

The same result is found when comparing the percentage of items that is changed to the percentage of volume that is changed on a production line as shown in Table 5. Most short term changes involve a small volume.

<table>
<thead>
<tr>
<th></th>
<th>Line A</th>
<th>Line B</th>
<th>Line C</th>
<th>Line D</th>
<th>Line E</th>
</tr>
</thead>
<tbody>
<tr>
<td>% items</td>
<td>8%</td>
<td>6%</td>
<td>9%</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>% volume</td>
<td>4%</td>
<td>5%</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Table 5: The percentage of items and volume that is changed on the production line by short term changes

Second, the fulfillment of a short term change on the production plan requires different actions from different departments. The production planner spends on average 6,8 minutes to adjust the production plan. The collected data shows that there is a small difference in time spend by the production planner on a short term change caused by demand or caused by supply, this takes respectively 7,0 minutes and 6,5 minutes. During the semi-structured interviews the production planners indicate that this time includes the eventual communication with the market, a closer look at the specific item and at the production schedule, the check whether packaging material is available
and the communication with the scheduler. Most short term changes takes place at the beginning and the end of the week as shown in Figure 23. This is explainable, because on Mondays the new forecasts are uploaded in the system and the performance of the production line in the weekend become visible.

![Workload of short term changes](image)

**Figure 23: The workload of short term changes**

Besides the decision to adjust the production plan requires actions of other departments as well:

- The Inbound department has to check the availability of the packaging material. However, as indicated by the production planners during the semi-structured interviews, this check can be performed by him/herself as well via the pick list that shows the available packages for items that are planned to be produced in the current week. It is indicated that a check via the pick list takes less time than contacting the packaging department and therefore some production planners perform this check via the pick list instead of contacting their colleagues. The data collection shows that in 22% of the changes the Inbound departments is contacted (see Figure 24);

- The scheduler has to adjust the production schedule according to the short term change and communicates the adjustment to the people of the factory. For this reason the scheduler is contacted in 100% of the changes (see Figure 24);

- The workload of the people in the factory is increased as well. The scheduler of value stream 2 (including production lines A, B and C that show the most short term changes) indicates that changes within one week mainly impact the planning of temporary associates. Difficulties arise when the short term change concerns an item that was not included in the original production schedule or when the short term change has to be implemented within 8 hours. In the first case, the item has to be added to the documents that are used by the employees of the factory and an extra set up is required. In the second case many communication is required. Therefore the implementation of a short term change asks even more time from the scheduler and the factory employees than from the production planner.

Furthermore, some short term changes includes contact with the market or the raw material department as shown in Figure 24. The market is contacted in 27% of the short term changes. However, some noise in the data collection is expected, because this part of the standard form is only filled in 90% of all short term changes. Still it can be noted that the market is not always contacted in case that the short term change is caused by demand uncertainty. This can be explained by the fact that the short term changes that are initiated by the production planner do not require any contact with the market. In 93% of the times that the market is contacted, the market has taken the initiative and only in 7% that the market is contacted, the production planner has taken the initiative. The raw material department is contacted rarely, this is only in case that the short term change includes a recipe change. These type of changes are undesirable, because of the small inventory stocks of raw materials.
Summarized, most short term changes result in an increased production quantity of an item at the production plan. Around half of all short term changes involve less than 1000 cases. In terms of workload, the production planners spend on average 6.8 minutes to enable a short term change. Most of this workload takes place on Monday. Besides, the workload of the scheduler is increased as well, because all short term changes are communicated to the scheduler. Furthermore the market, raw materials and packaging department are sometimes contacted as well to enable a short term change.

5.5 Current decision tree
Currently, every production planner considers his or her own arguments when taking the decision whether to adjust the production plan or not. These arguments are not structured in the sense that department-wide guidelines are defined. Nevertheless, the semi-structured interviews showed that the main arguments to take this decision are similar. However, the factors that influence the decision differ between the production planners. In Figure 25 the decision process is represented, starting by a market request that arrive at the production planner.
Subsequently, the production planner checks whether there is stock available at the hub. In case that there is stock available, it is important that the truck will depart as soon as possible to fulfill the request. To ensure that the requested item will be transported in the next truck, the item is filled in at the Last Minute Service List (LMSL). The next day the European Outbound Logistics Team (EOLT) will fulfill the requests that are on the LMSL and the day after the item will be send to the customer. In total this will take around 3 days. In case that there is not enough stock available at the hub, the production planner will check whether there is capacity on the production line to produce the market request as soon as possible. When the capacity is sufficient, the availability of the required packaging materials will be checked. When both, the capacity and the packages are available the production plan will be adjusted. However when one of them is not available no changes will be made and the request will not be fulfilled.

During the decision process different factors can influence this decision: the urgency and the size of a market request and the current production schedule. The influence of these factors depends per production planner. First, the urgency of the market request can influence the decision. The production planner estimates this urgency based on the gathered information as shown in Figure 26.
Firstly, experience has an important influence in determining the urgency of a market request, as indicated by all production planners during the semi-structured interviews. Based on their experience they are able to classify the urgency of a market request with regard to different markets. Based on previous requests the production planners knows which markets only send a request when there is a real issue and which markets tend to send a request before there is a real issue. Next to their experience, some production planners determine the urgency of a market request via the planning system. The net inventory of the requested item of the specific market can be viewed in detail. This provides insights in the urgency of the request, because the moment (in terms of days) that an out of stock will occur is visible. Another way that is used by some production planners, next to their experience, is to challenge the urgency of the request with the market. The market will be challenged when the request is needed, via questions as “I don’t have enough capacity to fulfill your request this week, will next week be ok with you?”, “When do you need the items?” or “Would it be possible to split the request?” Based on these responses the production planner have insights whether the item is currently out of stock, is expected to be out of stock soon or whether there is an extra opportunity to sell more cases of an item. In case of a current or an expected out of stock, the production planners indicate that this is always a reason to adjust the production plan in order to prevent an out of stock. In case of extra sales, the capacity of the production line is leading.

Figure 27 shows the urgency that is estimated by the production planners of short term changes regarding market requests that has taken place during the data collection. As can be seen most short term changes are performed to prevent out of stocks. However, some short term changes are performed to protect the safety stock. The production planners indicate during the semi-structured interviews that this type of short term changes is performed to minimize the risk of going out of stock, mainly initiated by a request of the market. Here the courage of the production planner to take a risk influence the decision whether to adjust the production plan.

Besides, the size of a market request can influence the decision. When a small number of extra cases are requested by the market, there is less capacity requested and an adjustment on the production schedule is simpler to implement.
Finally, the current production schedule can influence the decision. When the requested item is already produced in the current week, the decision to adjust the production plan results in an extra set up. However, when the requested item should still be produced in the current week, the production quantity of the planned item can be increased without causing an extra set up. When looking at production lines that produce different recipes, the current production cycle can become even more important. For example, when recipe A is produced in the current week and recipe B in the next week the production planner is restricted in his possibilities to fulfill a market request. This could be a reason to fulfill a market request of recipe A in the current week, because the next production run of this recipe is too late to prevent an out of stock.

In general, all production planners indicate that when there is capacity and packages available, a market request will always be fulfilled, because extra sales result in extra turnover. Besides the customer service is an important performance measure, as mentioned by some production planners: “Customer is King”.

The described decision tree takes the request from a market as an input. The same decision tree is applicable when the production planner realizes that the available stock of an item is less than desired. In this case the urgency is determined in advance by the production planner via the planning system and will not influence the decision anymore. However, the current production plan and the size of the request can still influence their decision. The decision tree is not applicable when the production planner receives a request from supply, because these requests relate to plan adjustments (e.g. when there is no packaging material available or the production line produces more or less cases than expected). Therefore the decision tree, as shown in Figure 25, describes the decision making process when the request is related to the market. There are three possible outcomes: add the item on the LMSL, make a plan adjustment or do not make any changes. As explained in the research method it is only possible to provide some insights about the number of times a plan adjustment has taken place and the number of times that an item is added to the LMSL. These numbers are represented in Table 6. Here the number of plan adjustments refers to the short term changes that are caused by higher or lower sales than expected at a market or a system issue, both the market as the production planner can be initiator. In Appendix IV is described how the number of items on the LMSL is determined. As can be seen, in more than half of the time the item is add to the LMSL.

<table>
<thead>
<tr>
<th>Week</th>
<th># items on LMSL (per week)</th>
<th># plan adjustments (per week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P10W2</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>P10W3</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>P10W4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>P11W1</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>P11W2</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>P11W3</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>P11W4</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>P12W1</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>P12W2</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>P12W3</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>P12W4</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>P13W1</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>SUM</td>
<td>123</td>
<td>99</td>
</tr>
<tr>
<td>AVG</td>
<td>10,25</td>
<td>8,25</td>
</tr>
</tbody>
</table>

Table 6: The use of the LMSL compared to the plan adjustments
6. Forecast-based inventory policy

6.1 The (T, S_k) policy

The forecast-based (T, S_k) inventory policy is a periodic review model with a dynamic order-up-to-level as represented in Figure 28 (Babai & Dallery, 2005).

In the article of Babaï and Dallery (2005) the demand is specified in uncertain forecasts: the forecast value and probability distribution of the forecast uncertainty of each period is known in advance for a longer time horizon.

The order-up-to-level (S_k) is determined at the beginning of every review period: the length of each review period is T. The dynamic order-up-to-level is equal to the sum of the demand forecasts and the maximal forecast uncertainty during the protection interval: the length of the protection interval (PI) is equal to the lead time L plus the review period T. In case the inventory position at the end of the previous period (I_{k-1}) is less than the order-up-to-level (S_k), a quantity (Q_k) is ordered to increase the inventory up to the order-up-to-level (S_k). The dynamic order quantity (Q_k) is equal to the sum of the forecasts during the protection interval. The dynamic safety quantity (SQ_k) is used to cover the forecast uncertainty during the protection interval given a target service level CSL.

The parameters of the (T,S_k) policy as defined in the article of Babai and Dallery (2005) are taken as a starting point. However these parameters are adapted to the situation at the company to mimic their inventory model as close as possible.

In order to define the parameters of the (T,S_k) policy the sequence of events that occur is important to take into account (Atan, 2012), because this can influence the value of the parameters (e.g. does the order arrive after or before the demand fulfillment?). The sequence of daily events:

- The inventory level is observed;
- The demand is satisfied to the extent possible and excess demand are backordered;
- Orders are received at the warehouse;
- In case that the inventory is expected to be insufficient to fulfill the demand before the next delivery, an extra production and/or extra delivery is arranged.

6.1.1 Forecast values

The forecast is updated every week and does not include a probability distribution of the forecast uncertainty. The demand planner of the Dutch market has provided insights in the composition of the forecast values and the relation between the forecast values and actual sales. The forecast of items that are sold at the Dutch market is composed of three different levels:
- Level A: This level refers to the forecast made for the next year for all customers of the Dutch market (national level). The forecast is shown in tonnage.
- Level B: This level refers to the forecast made for the current year for all customers of the Dutch market (national level). The forecast is shown in cases.
- Level C: This level refers to the forecast made per customer in cases. The sum of the forecasts per customer equals to the forecast as made on Level 3.

The forecasts of Level B and C consist of base line and promotions. The demand planner is responsible for the base line forecast, that includes seasonality and the sales department is responsible for promotional sales (e.g. a discount promotion at the supermarket). The forecast is updated once a week and the rule of thumb is that the forecast values are “frozen” over the upcoming two weeks to prevent extreme changes in the forecast that are caused by promotions. In case that an extra promotion is desired, the production planner needs to be informed to check the feasibility as indicated by the demand planner of the Dutch market: “Wij hebben als Nederlandse markt de regel dat er binnen 2 weken eigenlijk niks meer veranderd mag worden, en dan meer in de zin van extra promoties bij klanten. Indien de afdeling sales een extra promotie in wil plannen, dan gaat dat altijd in overleg met productie planning.”

Furthermore the demand planner needs to indicate that the forecast and actual sales are likely to differ strongly. The forecast and sales values of 41 items that are sold on the Dutch market and produced on production line A, B, C, D and E are compared over 16 weeks by the formula:

\[
\frac{\text{Sales value} - \text{Forecast value}}{\text{Forecast value}}
\]

The \((T,S_k)\) inventory policy requires forecast values as an important input. However, the historical forecast and sales values are not available for a time horizon longer than 16 weeks as confirmed by the demand planner of the Dutch market. To run numerical experiments, some data will be lost by the warm up period (to decrease the effect of the set start inventory levels). Besides, some data will be lost at the end of the time horizon, because the order-up-to-levels, safety quantities and order quantities are based on forecast values. For these reasons it is decided not to use the historical data as an input of the \((T,S_k)\) inventory policy, because the time horizon is too short to analyze the effects on the costs. Therefore, it is decided to generate the forecast values based on a theoretical method, where the available data is used to approximate the parameters of the theoretical method.

There are two options taken into consideration to generate the forecast and sales values:

A. The sales values will be generated via a normal distribution (that allows non-stationarity and seasonality in the data) and the forecast values will be generated via a time series forecast method: Moving Average.
B. The forecast values will be generated via a normal distribution (that allows non-stationarity and seasonality in the data) and the sales values will be calculated based on the available forecast accuracy.

An important criteria to generate the forecast and sales values is that the forecast bias and sales forecast accuracy (SFA) approximates these at the company as accurate as possible. At the company the forecast of an item per market equals to the sum of the forecasts at the retailers of that particular market. This forecasting method is hard to imitate by one of the theoretical forecasting methods (e.g. Moving Average, Exponential Smoothing, Linear Regression). For this reason it is decided to generate the forecast and sales values according to method B.

The forecast values are generated via the demand process as used by De La Vega (2012) assuming a normal distribution to include a non-stationary demand pattern:

\[
F_1 = \mu + \varepsilon_1 \quad t = 1
\]
\[ F_t = \mu + \sum_{j=1}^{t-1} \alpha^{t-j} \varepsilon_j + \varepsilon_t \quad t = 2,3, ... \]

The variable \( \alpha \) varies between \( 0 \leq \alpha \leq 1 \) and refers to the level of stationarity (\( \alpha = 1 \) stands for non-stationary demand). The variable \( \mu \) refers to the average demand and is greater than zero (\( \mu > 0 \)). The variable \( \varepsilon \) refers to the variance of the demand noise: \( \varepsilon \sim N(0, \sigma^2_\varepsilon) \). The forecast values of the last two weeks are “frozen” as indicated by the demand planner of the Dutch market.

The sales values are determined based on the forecast accuracy and equal to \( x\% \) more or less than the corresponding forecast value:

\[ D_1 = x \times F_1 \]

Here the range of percentages \( x \) is determined based on the available data provided by the Dutch market. It is assumed that this data, over a time horizon of 16 weeks, is representative for a time horizon of 52 weeks. The sales values as provided by the company do not take into account out of stocks. However, it is assumed that the service level of 98,5% is met and therefore these differences are negligible.

### 6.1.2 Replenishment level

The dynamic replenishment level \( (S_k) \) is equal to the sum of the forecasts during the protection interval (PI) and the safety quantity.

\[ S_k = \sum_{i=1}^{L+T} F_{k+i-1} + \text{safety quantity} \]

In this formula \( k \) refers to the period; e.g. \( S_1 \) refers to the order-up-to-level of period 1. The protection interval is defined as the period that one has to rely on the safety stock to prevent out of stocks (Krajewski, Ritzman & Malhotra, 2010). In the \((T, S_k)\) policy the protection interval (PI) is equal to the replenishment lead time (L) plus the review period (T).

\[ PI = L + T \]

### 6.1.3 Safety Stock

Twice a year the safety stock level per item per market is determined in terms of days. The production planners determine this level based on a comparison between the current safety stock level and the statistically calculated safety stock level. The statistically calculated safety stock level is calculated according to the standard base formula (Silver, Pyke & Peterson, 1998):

\[
\text{Safety Stock} = \text{Safety factor} \times \sigma_X \\
X = \text{total demand during the lead time} \\
D_p = \text{demand of period P} \\
L = \text{(replenishment) lead time}
\]

In case that both uncertainty in demand and uncertainty in lead time are assumed (this means that \( D \) and \( L \) are independent random variables) \( X \) is equal to:

\[ X = D_1 + D_2 + \cdots + D_L \]

According to the theory of Ross (1983) the expected total demand during the lead time, the variance and the standard deviation of the total demand during the lead time equals to:

\[
E[X] = E[L] \times E[D] \\
\text{Var}[X] = E[L] \times \text{Var}[D] + E[D]^2 \times \text{Var}[L]
\]
\[ \sigma[X] = \sqrt{E[L] \cdot \text{Var}[D] + E[D]^2 \cdot \text{Var}[L]} \]

This results in the standard base safety stock formula in case of demand and lead time uncertainty (Silver, Pyke & Peterson, 1998: 283):

**Safety Stock** \(_{\text{cases}} = \text{Safety factor} \cdot \sqrt{E[L] \cdot \text{Var}[D] + E[D]^2 \cdot \text{Var}[L]} \)

In case that the length of the lead time extends the length of the forecast period, the forecast period is added (to calculate \( \text{Var}[D] \) based on the number of periods equal to the lead time):

**Safety Stock** \(_{\text{cases}} = \text{Safety factor} \cdot \sqrt{\frac{E[L]}{\text{Forecast period}}} \cdot \text{Var}[D] + E[D]^2 \cdot \text{Var}[L]} \)

The safety stock level in terms of cases is translated to the safety stock level in terms of days:

**Safety Stock** \(_{\text{days}} = \frac{\text{Safety factor} \cdot \sqrt{E[L]} \cdot \text{Forecast duration} \cdot \text{Var}[D] + E[D]^2 \cdot \text{Var}[L]}{\text{Average demand}} \)

This statistical calculated safety stock is shown in an Excel tool even as the current safety stock level. Production planners determine new values of the safety stock levels based on this comparison and the experience with the specific item. When the current safety stock is lower than the calculated safety stock, the current safety stock level is in most of the times retained as indicated by the production planners. In case that the current safety stock is higher than the calculated safety stock, the current safety stock is in most of the times decreased according to the production planners. Here the experience of the production planner is taken into account as well, for example when more out of stocks has occurred during the last half a year on a specific item, the safety stock is increased. In the \((T,S_k)\) inventory policy the safety stock is included as an input variable, because the statistical safety stock is not always applied in practice. Besides, this provides the opportunity to vary the safety stock level and analyze the impact on the total cost.

The \((T,S_k)\) policy as described by Babaï and Dallery (2005) assume a fixed lead time. However, the safety stock calculation as used by the company assumes lead time variability. Therefore a closer look is taken to the statistical safety stock calculation to determine the impact of lead time variability. The statistical safety stock is calculated twice for 73 items, one time including lead time variability and one time excluding lead time variability:

1. **Safety Stock** \(_{\text{days}}(\text{demand} + LT) = \frac{\text{Safety factor} \cdot \sqrt{E[L]} \cdot \text{Forecast duration} \cdot \text{Var}[D] + E[D]^2 + \text{Var}[L]}{\text{Average demand}} \)
2. **Safety Stock** \(_{\text{days}}(\text{demand}) = \frac{\text{Safety factor} \cdot \sqrt{E[L]} \cdot \text{Forecast duration} \cdot \text{Var}[D]}{\text{Average demand}} \)

These calculations show that the impact of lead time variability is very low as shown in Figure 29.

<table>
<thead>
<tr>
<th>Safety Stock composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead time variability</td>
</tr>
<tr>
<td>Demand variability</td>
</tr>
<tr>
<td>4%</td>
</tr>
<tr>
<td>0%</td>
</tr>
<tr>
<td>40%</td>
</tr>
<tr>
<td>80%</td>
</tr>
</tbody>
</table>

Figure 29: The part of the safety stock that is used to deal with lead time and demand variability

The part of the safety stock that is hold on stock to cover the lead time uncertainty is only 4% of the safety stock that is hold on stock to cover both demand and lead time uncertainty. This means that
even 96% of the safety stock is held on stock to cover the demand variability! For this reason it is concluded that the assumption of a fixed lead time as applied by Babai and Dallery (2005) is justified.

6.1.4 Order quantity
The order quantity \( Q_k \) is dynamic, because it depends on the dynamic replenishment level \( S_k \) and the inventory position at the end of last period \( I_{k-1} \).

\[
Q_k = \max\{S_k - I_{k-1}, 0\}
\]

The order quantity is not restricted by the pallet size or a minimum or maximum order quantity. The inventory position is defined as (Silver, Pyke and Peterson, 1998: 233):

\[
\text{Inventory position} = \text{Inventory on hand} + \text{Inventory on order} - \text{Backorders}
\]

With

\[
\text{Inventory on hand} = \text{Inventory that is physically on the shelf}
\]

\[
\text{Inventory on order} = \text{Inventory that is requested but not yet received}
\]

6.1.5 Short term changes
A short term change refers to an extra production and extra delivery moment to prevent an eventual out of stock. To add the option of a short term change to the \((T, S_k)\) inventory policy some assumptions are necessary.

Firstly, the minimum time that is required to perform a short term change needs to be determined:

\[
\text{Min time} = \text{Maturation} + \text{Transport time} + \text{Loading/unloading time} + \text{Planning time}
\]

The maturation time equals three days and is needed to ensure the quality of the products. During these days it is allowed to transport the products already to the market warehouse, but the products need to stay in the market warehouse until the maturation time is passed. This means that in case of a short transportation time of one day, the products need to stay in the market warehouse for two more days before selling the products to customers to ensure the quality of the products. The transportation time refers to the time it takes till the truck arrives at the market warehouse. Before and after the transportation time, the truck needs to be loaded and unloaded, this loading and unloading time is equal to 1 day. In case of a short term change it is assumed that the transport time and loading/unloading time takes place during the maturation and therefore equal to 3 days. The planning time takes normally, when making a weekly planning on Wednesday, at least 4 days. However, in case of a short term change, it is assumed that this takes at most 2 days. This sum up to the minimum time that is required to enable a short term change equal to 5 days.

Secondly, the quantity of the short term change needs to be determined. It is assumed that the capacity of the production line and the capacity of the transport mode are not restricted. Under this assumption the order quantity is not restricted and will cover the difference between the expected net inventory and the safety stock level. This means that the short term change increases the net inventory up to the safety stock level.

\[
\text{Extra order quantity} = (\text{Desired safety quantity} - \text{Expected net inventory})
\]

\[
\text{Expected net inventory} = \text{Current net inventory} + \text{Expected orders} - \text{Expected demand}
\]

Finally, two decision variables need to be studied in order to determine the effectiveness of short term changes on the production plan. The time horizon needs to be studied: How many days ahead do we need to check the expected net inventory to make an effective adjustment on the production plan?
This decision point will be analyzed in the numerical experiments. Besides, it is important to investigate a decision point to compare the expected net inventory over $x$ days with. This decision point will be determined as a percentage of the safety stock level. This results in the following guideline, where $x$ and $y$ are the decision variables:

*An adjustment on the production plan is effective when the expected net inventory over $x$ days drops below $y$ percent of the safety stock level.*
6.2 Numerical experiments
The numerical experiments are performed to analyze the effect of short term changes on the customer service level and the total costs at the market warehouse per item. Here the decision point when a short term change is profitable or not is studied. This decision point refers to an expected net inventory level, where it is assumed that the expected net inventory over eight days is computed to determine whether a short term change is required or not. To find the decision point, the numerical experiments compares two inventory models. In the first inventory model it is assumed that there are no short term changes allowed and in the second inventory model these are allowed when the expected inventory level drops below the decision point. The comparison of these two inventory models provides insights in the effect of short term changes on the inventory levels and therefore on the costs. In both models a warm up period of 10 working days (i.a. two weeks) is included to decrease the influence of the starting inventory. Furthermore the inventory levels are calculated for a time horizon of 52 weeks.

The input parameters are determined based on the information as provided by the items that are sold on the Dutch market and the data that is collected to describe the current situation. It is important to note that orders can arrive at the warehouse from Monday till Friday. The Dutch market warehouse delivers the orders to the customers from Monday till Friday as well. Therefore it is decided to calculate the inventory model in working days, where Monday till Friday is defined as working days. The impact of this decision on the costs is that the net inventory that is hold on Friday is hold on Saturday and Sunday as well. These costs are taken into account in the total costs. One other assumption that is made in order to run the numerical experiments is that the market warehouse is only allowed to order whole cases. Table 7 provides an overview of the set parameters.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Definition</th>
<th>The company</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T )</td>
<td>Review period</td>
<td>The review period is equal to one week</td>
<td>5 working days</td>
</tr>
<tr>
<td>( L )</td>
<td>Replenishment lead time</td>
<td>The replenishment lead time varies per market warehouse, because of the transportation time; on average this equals 1,5 week = 8 working days</td>
<td>8 working days</td>
</tr>
<tr>
<td>( PI )</td>
<td>Protection interval</td>
<td>( PI = T + L )</td>
<td>13 working days</td>
</tr>
<tr>
<td>( \mu )</td>
<td>Average demand</td>
<td>The data collection shows that most short term changes occur on “small items” (a small item refers to less than 100,000 kg per year)</td>
<td>20 cases /working day</td>
</tr>
<tr>
<td>( \sigma^2_\varepsilon )</td>
<td>Variance of the demand noise</td>
<td>( \sigma^2_\varepsilon ) and ( \alpha ) are set in such a way that the standard deviation of the forecast values matches to the standard deviation of the forecast values of the data provided</td>
<td>10</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>The level of stationarity</td>
<td>The level of stationarity</td>
<td>0,55</td>
</tr>
<tr>
<td>( SQ )</td>
<td>Safety quantity</td>
<td>The safety quantity is determined via the statistical method</td>
<td>8 working days</td>
</tr>
<tr>
<td>( Weight )</td>
<td>Weight of one case</td>
<td>The weight of one case differs per item, on average the weight of the items that caused short term changes during the data collection equals 7 kg</td>
<td>7 kg</td>
</tr>
</tbody>
</table>

Table 7: The input parameters of the \((T, S_k)\) policy

In Figure 30 and Figure 31 an example is represented with the input parameters as in Table 7 and the assumption that a short term change is made when the expected net inventory over 8 days drops below 70% of the desired safety stock level. The values of \( \sigma^2_\varepsilon \) and \( \alpha \) are chosen in such a way that the standard deviation of the demand is similar to the average standard deviation of the demand of the items that are provided by the Dutch market.
When comparing these two scenarios, the short term changes has prevented out of stocks as can be seen in Figure 31 where the net inventory level remains positive (in contrast to Figure 30 where the net inventory levels shows negative values as well). Subsequently, the inventory model that allows short term changes shows a higher net inventory level. In this example coincidence could influence the results and therefore numerical experiments are introduced where 30 runs are performed to decrease this influence. Subsequently, a sensitivity analysis is performed to determine the decision variable when a short term change is profitable or not and come up with a guideline in the trend of:

An adjustment on the production plan is effective when the expected net inventory over x days drops below y percent of the safety stock level.

Firstly, the decision variable x is studied to determine when the expected net inventory should be considered to decide whether to adjust the production plan or not. The minimum value of decision variable x is equal to five days, because it takes five days to enable a short term change. Therefore, the options that are considered are five, six, seven or eight days ahead as shown in Table 8.

<table>
<thead>
<tr>
<th>y=0%</th>
<th>y=10%</th>
<th>y=20%</th>
<th>y=30%</th>
<th>y=40%</th>
<th>y=50%</th>
<th>y=60%</th>
<th>y=70%</th>
<th>y=80%</th>
<th>y=90%</th>
<th>y=100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>x=5</td>
<td>90,1%</td>
<td>94,9%</td>
<td>95,1%</td>
<td>95,8%</td>
<td>96,3%</td>
<td>96,6%</td>
<td>97,0%</td>
<td>98,5%</td>
<td>98,4%</td>
<td>99,2%</td>
</tr>
<tr>
<td>x=6</td>
<td>90,1%</td>
<td>94,0%</td>
<td>94,2%</td>
<td>95,4%</td>
<td>96,0%</td>
<td>96,4%</td>
<td>96,8%</td>
<td>98,2%</td>
<td>98,4%</td>
<td>99,0%</td>
</tr>
<tr>
<td>x=7</td>
<td>90,1%</td>
<td>94,2%</td>
<td>94,7%</td>
<td>95,9%</td>
<td>95,8%</td>
<td>96,2%</td>
<td>96,1%</td>
<td>98,1%</td>
<td>98,4%</td>
<td>98,9%</td>
</tr>
<tr>
<td>x=8</td>
<td>90,1%</td>
<td>93,5%</td>
<td>93,2%</td>
<td>93,1%</td>
<td>93,3%</td>
<td>93,8%</td>
<td>95,0%</td>
<td>95,8%</td>
<td>97,7%</td>
<td>98,1%</td>
</tr>
</tbody>
</table>

Table 8: The effect of short term changes when the expected net inventory over x days drops below y percent of the safety stock level
As can be seen, in most cases the decision variable $x$ equal to five working days results in the most effective plan adjustments, because here the CSL is increased the most. Therefore, in order to determine the optimal value of decision variable $y$, the decision variable $x$ is set to five working days. The decision variable $y$ varies between 10% and 100% of the desired safety stock level. Figure 32 and Figure 33 represent the results with regard to respectively the inventory and number of stock outs.

![Effect of short term changes (inventory)](image)

Figure 32: The effect of short term changes with regard to the average net inventory level

![Effect of short term changes (OOS)](image)

Figure 33: The effect of short term changes with regard to the number of out of stocks

As can be seen, the net inventory level of the inventory model that allows short term changes increases exponential as more short term changes are performed. A logical result is that when the net inventory level increases the number of out of stocks decreases. To determine the optimal point when to allow a short term change, the number of cases is translated to costs and customer service level as shown in respectively Figure 34 and Figure 35.

![Effect of short term changes (costs)](image)

Figure 34: The effect of short term changes with regard to the total costs
Figure 35: The effect of short term changes with regard to the CSL

In order to determine the optimal decision point to allow a short term change the customer service level is leading: the optimal decision point is chosen in such a way that the customer service level is met. Under these specific input parameters and the condition that the CSL needs to be met, a short term change is profitable when the expected net inventory level drops below 70% of the desired safety stock level. Besides, the influence of the weight of one case on the total costs is studied. In case that the weight is up to eight times (56 kg) as high, the decision point in the cost figure remains the same. However, in case that the weight of one case is very low (equal to 1 or 2 kg), the cost figure changes: a short term change is beneficial when the expected net inventory over five working days drops below 50% of the safety stock level (instead of 70%). This is due to the fixed costs per change (independent of the weight of a case). When the inventory and stock out costs decrease at a lower weight per case, the costs per change are having more impact. In that case, based on the costs it is preferred to perform less short term changes, but based on the CSL the results remains unmodified.

Furthermore, the safety stock level is incorporated in the numerical experiments, because a higher safety stock level leads to less short term changes. In terms of costs it is interesting to evaluate whether it is preferable to set a higher safety stock level to respond to demand variability or to set a lower safety stock level and adjust the production plan to respond to demand variability. For this reason the numerical experiments are performed for different levels of the safety stock. In case that the safety stock level increases with one day (from eight to nine days), a short term change is profitable when the expected net inventory level drops below 60% of the desired safety stock level. Compared to the scenario where the safety stock level is equal to eight days, the total costs decrease slightly, but even more important less short term changes are required. In Figure 36 the total costs at different safety stock levels is shown: the total costs correspond to the lowest possible costs under the condition that the customer service level of 98,5% is met. Table 9 represents the corresponding decision points when a short term change is needed.

Figure 36: The total costs of the (T,Sk) policy at different levels of the safety stock
<table>
<thead>
<tr>
<th>SS (days)</th>
<th>Decision point</th>
<th># of changes</th>
<th>CSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>100%</td>
<td>9,4</td>
<td>98,1%</td>
</tr>
<tr>
<td>7</td>
<td>100%</td>
<td>8,6</td>
<td>98,2%</td>
</tr>
<tr>
<td>8</td>
<td>80%</td>
<td>6,9</td>
<td>98,6%</td>
</tr>
<tr>
<td>9</td>
<td>60%</td>
<td>4,4</td>
<td>98,5%</td>
</tr>
<tr>
<td>10</td>
<td>20%</td>
<td>1,3</td>
<td>98,6%</td>
</tr>
<tr>
<td>11</td>
<td>10%</td>
<td>0,8</td>
<td>98,5%</td>
</tr>
<tr>
<td>12</td>
<td>10%</td>
<td>0,5</td>
<td>98,7%</td>
</tr>
<tr>
<td>13</td>
<td>0%</td>
<td>0,0</td>
<td>98,6%</td>
</tr>
<tr>
<td>14</td>
<td>0%</td>
<td>0,0</td>
<td>98,9%</td>
</tr>
<tr>
<td>15</td>
<td>0%</td>
<td>0,0</td>
<td>99,2%</td>
</tr>
</tbody>
</table>

Table 9: The decision point, number of changes and CSL of the (T,Sk) policy at different levels of the safety stock

As can be seen from Table 9, the more safety stock is available, the less short term changes are required to meet the CSL (i.e. the decision point to make a short term change decreases). Also in terms of costs, an increased safety stock level is desired under these specific input parameters. It is profitable to set the safety stock level in such a way that most demand variability can be covered by the safety stock and that less short term changes are required. In Figure 36 and Table 9, it can be seen that the lowest costs are achieved at a safety stock level of ten days, where on average 1,3 short term changes are required to achieve the CSL.

It is important to emphasize that these results depends on the input parameters. In this model the forecast and sales values are an approximation of the values at the company and therefore the results are an approximation as well. Besides the input parameters cannot be generalized over all items over all markets, because each item per market has different forecast values and forecast accuracy. These parameters need to be set per item per market to draw a conclusion. It is expected that short term changes becomes more profitable when demand variability increases and the other way around a higher safety stock level becomes more profitable when demand variability decreases.

In order to make the results of the numerical experiments more applicable in practice, it is decided to perform numerical experiments for eight items that are produced in the factory for the Dutch market. The production planners that have planned these specific items have experienced several case fill issues or short term changes. The forecast values per week for the year 2014 are taken as input values, where it is assumed that the forecast accuracy remains the same as in 2013.

The effectiveness of short term changes on the production plan differs per item. This can be explained by the variability in the forecast values. When the forecast values show small differences over the year, it is profitable to increase the safety stock level in order to decrease the number of short term changes. For these items it is desired to increase the safety stock level till at most one short term change is required. Here a short term change is profitable when the expected net inventory level over five days drops below 30% of the desired safety stock level. This means that most demand variability is covered by the safety stock, but in case of extreme sales values compared to forecast values a short term change is necessary. However, when the forecast values differ strongly over the year, caused by promotions, it is profitable to use short term changes instead of safety stock as a response to demand variability. Here a short term change is profitable when the expected net inventory level over five days drops below 60% of the desired safety stock level. This is an important finding, because it is expected that the number of promotions at the Dutch market will increase in the upcoming years. Besides, most extreme sales values compared to the corresponding forecast values are cause by promotions. This is an important finding, because extreme sales values compared to the corresponding forecast values are mainly caused by promotions.
Finally, it could be interesting to investigate the effect of the length of the protection interval (consisting of the replenishment lead time and the review period) on the effectiveness of short term changes. Since this does not belong to the scope of this project, it is decided to argue this effect instead of performing numerical experiments. First of all, a shorter protection interval would decrease the safety stock level and therefore results in lower costs. Besides, it is expected that a shorter protection interval results in less short term changes. In case of a shorter protection interval, it is possible to react earlier on extreme sales values that differ from the corresponding forecast values. An option to decrease the protection interval is to shorten the planning cycle, since this will decrease the replenishment lead time. However, a shorter planning cycle will results in more set ups and taken the high utilization of the production lines into account, this would decrease the production volumes. Therefore, it is expected that a shorter planning cycle will not be the optimal solution here.
7. Conclusion and recommendations
In this chapter the conclusions and recommendations are stated.

7.1 Conclusion
The conclusion will provide answers to the different research questions.

7.1.1 Research question I
First, some insights are provided in the frequency, causes and effects of short term changes in the current situation to answer the first research question:

I. What are the main causes and effects of short term changes on the production plan and how are these currently handled by production planners?

Firstly, the frequency of short term changes on the production plan is studied. The opening stock and the number of items that is planned per production both significant influence the frequency of short term changes. A lower opening stock than target stock and/or more items planned than average on a production line results in significant more short term changes on the production plan. Overall, the total number of short term changes during the data collection equals 174 changes. In perspective of the number of items that is produced on the production line, at most 10% of the items changes.

Secondly, the main causes of short term changes on the production plan are identified and it is found that most short term changes are caused by CRP markets that experiences higher sales than expected. In total 44% of all changes are caused by higher or lower sales than expected by CRP markets. Besides, the line performance causes 27% of the short term changes on the production plan. It is interesting to note that half of the short term changes are caused by items that are categorized as small: small refers to an annual sales volume that is less than 100 ton. These items, with a small volume, are therefore more sensitive to fluctuations in demand.

Thirdly, the effect of short term changes is analyzed with regard to the workload and the final production plan, as specified in the first sub question:

I.1 What is the effect of short term changes on the production plan on the workload of the production planners and the final production plan?

The short term changes require actions from the production planner and other departments. The production planner spends on average 6.8 minutes, where most of this workload is at the beginning of the week when the forecast and inventory levels are updated based on the sales and line performance in the weekend. Most short term changes result in a changed production quantity, even 71% results in an increased production quantity. Here the total number of cases that is involved in the short term change is in approximately 50% of the time less than 1000 cases. Next to the production planner, the scheduler is involved in all short term changes to adapt the production schedule and communicate the changes to the people of the factory. Furthermore, the packaging material needs to be checked. In 27% of all short term changes the Inbound department is contacted to perform this check, but mainly this check is performed by the production planner itself via the pick list. It is noted that the market is contacted only in 22% of all short term changes; where in 93% of these times the market has taken the initiative.

Fourthly, the current decision making process of the production planners, whether to adjust the production plan or not is taken into account. It is found that in the current situation the main arguments to take this decision are similar. First the available stock at the hub is considered. In 55% of all requests that are related to demand changes, the available stock at the hub was send to the market
warehouse via the LMSL. In case that there is not stock available at the hub, the capacity of the production line and the availability of the packaging material are considered in the decision whether to adjust the production plan or not. However, three factors can influence this decision: the urgency of the request, the size of the request and the current production schedule. The urgency of the requests answers the second sub question:

I.II Are there different levels of urgency with respect to demand requests?

Different levels of urgency can be defined with respect to demand requests. This urgency is determined by the production planners based on their experience. Besides, some production planners challenge the urgency with the demand planner before taking the decision to adjust the production plan and/or some production planners look in detail at the stock level of the requested item in the planning system. Furthermore, it is expected that the willingness to take risks influence the urgency classification of a request.

7.1.2 Research question II

In the second part of the project, a preferred way to respond to demand variability is investigated. However, it should be noted that the number of short term changes (174) that has occurred is relative small compared to the total number of items that is produced during the period of data collection (equal to about 195 items per week on the production lines A, B, C, D and E). The items that has caused the short term changes during the 12 weeks of data collection, has caused one or two short term changes. Under the assumption that the period over which data is collected is representative for the rest of the year, about 4 to 8 short term changes will occur per item per year, where one item can serve different markets and not all items require short term changes.

Numerical experiments are performed in order to provide insights in the effect of short term demand changes on the production plan with regard to costs and the service level. The dynamic order-up-to policy as proposed by Babai and Dallery (2005) is studied and taken as a starting position to mimic the inventory model as used by the company. The inventory model represents the inventory levels at the market warehouse per item to answer the second research question:

II. What would be a preferred way to handle short term demand changes on the production plan?

Two different options to deal with demand variability are investigated in the research model: flexibility via short term changes and flexibility via safety stock. These two options are compared with regard to the total costs and the service level in order to answer the sub question:

II.I When is it preferable to adapt the production plan and when is it preferable to continue the original production plan with respect to the service level and costs?

In order to determine the optimal decision point to allow a short term change the customer service level is leading: the optimal decision point is chosen in such a way that the customer service level is met. Numerical experiments are performed to determine the decision variable when a short term change is profitable or not and come up with a guideline in the trend of: “An adjustment on the production plan is effective when the expected net inventory over x days drops below y percent of the safety stock level”. Firstly, the decision variable x is studied to determine when the expected net inventory should be considered to decide whether to adjust the production plan or not. The minimum value of decision variable x is equal to five days, because it takes five days to enable a short term change. The numerical experiments show that five days is also the optimal decision variable, because here the CSL is increased the most when performing a short term change. Secondly, the optimal value of decision variable y is determined in terms of a certain percentage of the safety stock level. The
results strongly depend on the input parameters. It is found that under the specific input parameters and the condition that the CSL needs to be met, a short term change is profitable when the expected net inventory level drops below 70% of the desired safety stock level. Furthermore, the influence of the safety stock level is incorporated in order to answer the sub question:

II.II Would it be preferable to use inventory to respond to demand variability instead of changing the production plan?

It is found that if more safety stock is available, less short term changes are required to meet the CSL. Also in terms of costs, an increased safety stock level is desired under these specific input parameters. It is profitable to set the safety stock level in such a way that most demand variability can be covered by the safety stock and that less short term changes are required. Under the set input parameters, it is most effective to set the safety stock level equal to ten days and perform a short term change when the expected net inventory over five working days drops below 20% of the desired safety stock level.

However, it is important to emphasize that these results strongly depends on the input parameters. In order to make the results of the numerical experiments more applicable in practice, numerical experiments are performed for eight items that are produced in the factory for the Dutch market. For these items the forecast values per week for the year 2014 are taken input values, where it is assumed that the forecast accuracy remains the same as in 2013. The numerical experiments show that the effectiveness of short term changes on the production plan depends on the demand variability of an item. When the forecast values of an item show small differences over the year, it is profitable to use safety stock as a response to demand variability. However, when the forecast values of an item differ strongly over the year, due to promotions, it is beneficial to use short term changes instead of safety stock as a response to demand variability. This is an important finding, because extreme sales values compared to the corresponding forecast values are mainly caused by promotions.

7.2 Limitations and recommendations

An important limitation of the research model is that the decision whether to make an adjustment on the production plan or not differs per item. For this reason the guidelines, as provided by the research model, cannot be generalized for all items. This means that it is not possible to provide one guideline that can be applied for all items that are sold at different markets due to two main reasons. Firstly, each market has a different forecast accuracy and in this project the forecast accuracy of the Dutch market is considered. Secondly, each item has a different demand variability (e.g. the forecast values of an item could show small or large differences over the year). Therefore, the found guidelines in this project are only applicable for the items that are sold on the Dutch market and differs for items that show a high or low demand variability.

Still the numerical experiments provide some important insights in the interaction between the two different methods to cope with demand variability: safety stock and short term changes. It is found that the effectiveness of short term changes on the production plan increases when the demand variability of an item increases. For items that show a small variability in the forecast values, it is preferable to determine the safety stock level in such a way that a minimum number of short term changes is required: at most one short term change per year. For these items it is recommended to make a note of specific items that require several short term changes. This indicates that the safety stock level should be increased for these items. For items that show a higher variability in the forecast, promotion items, it is profitable to perform more short term changes. However, a limitation of the numerical experiments is that only one promotion item is studied and therefore it is decided not to generalize this result into a guideline.
In general the number of short term changes that has occurred during the period of data collection is small, what indicates that the production planners already do a good job. As seen in the research model, the introduction of short term changes can significantly increase the customer service level. However it is important that the production planner is aware of the short term adjustments of the production plan. For the production planner it takes a small amount of time, but the scheduler and people in the factory need to adjust the production schedule as well. For this reason it is recommended to determine the urgency of the request before taking any decision. Both, in case of sending available stock in the hub via the LMSL or making a plan adjustment, extra manual actions are required. In the current situation the urgency of the request is mainly investigated when taking the decision to adjust the production plan or not, but it is advised to start with the urgency of the request in the decision making process.

It is found that most short term changes are caused by higher sales than expected of CRP markets. The experience of the production planners learns that some markets send their request to increase the production quantity earlier than other markets. Here it is recommended to challenge the urgency of the demand requests that are initiated by the market. In case that an early production run in the next production plan could solve the request as well, this is preferable instead of a plan adjustment of the production plan of the current week. However a difficulty here is expected, because the markets are used to get “yes” as a response to their request. For this reason it is advised to determine the urgency of a market request as objective as possible via a closer look at the stock level at the market warehouse per item as provided by the planning system.

When challenging the urgency of a market request, the number of short term changes will be minimized. However with regard to the current forecast accuracy, short term changes are essential to cover extreme sales values compared to the forecast values (sometimes these are more than five times as high). The introduction of safety stock is an effective method as a response to a certain level of demand variability. Though, in case of extreme demand variability that occurs once in a while, a high safety stock level is not effective, because of high inventory costs and the freshness of the products. Here the flexibility via short term changes becomes important.

It is desired to decrease the number of times that extreme sales values are experienced compared to the forecast values in order to further minimize the number of short term changes. As indicated by the demand planner of the Dutch market, extreme sales values compared to forecast values are mainly caused by promotions. In order to limit these extreme sales values compared to forecast values it is recommended to provide some insights in the determination of the safety stock level to the markets. Here it important to emphasize that the safety stock is introduced to deal with most demand variability, except for extreme scenarios. It is recommended to discuss guidelines about the maximum percentage of forecast change that is acceptable, because most production lines are highly utilized and face a limited flexibility in the packaging mix. In order to succeed the introduction of guidelines regarding the maximum acceptable percentage of forecast change a translation needs to be made to the customer level. The production planner is more upstream in the supply chain than the customers, because the demand planner takes care of the contacts and good relationship with the customers. It is recommended to determine borders with regard to promotions in which customers are allowed to change their forecast. These borders should limit the demand variability of promotions and therefore increase the reliability of the deliveries to the customers. Recently, the Dutch market has set guidelines with regard to promotions for one of their customers: Albert Heijn was only allowed to change their forecast of promotions with at most 20%. According to the demand planner of the Dutch market this experiment succeeded! My recommendation is to extend this guideline to all promotions of different customers. This becomes even more important when taking into account that the number of promotions at the Dutch market is expected to increase in the upcoming years. Currently, a master project is performed with regard to this topic on the Dutch market.
Moreover, it is evaluated whether there are other options to decrease the safety stock level in order to decrease the inventory costs. The safety stock is introduced to buffer demand and supply variability. The most effective method to decrease the safety stock is to decrease the demand variability as recommended in the previous paragraph via guidelines regarding the forecast changes. Another option to decrease the safety stock level is to decrease the protection interval consisting of the lead time plus the review period. However, here the possibilities are limited. It could be valuable to investigate the advantages and disadvantages to start the production week on Saturday instead of on Sunday. This will decrease the lead time with one day for all items and could therefore result in a significant decrease of the costs. However, the reasons why the production week starts on Sunday are not investigated in the scope of this project and should be taken into account as well, because this will involve a major change and needs more attention.

Summarized, three recommendations are provided:

- The numerical experiments of the research model has shown that when the forecast values of an item show small differences over the year, it is profitable to use safety stock as a response to demand variability. For these items it is desired to increase the safety stock level till at most one short term change is required. It is recommended to make a note of specific items that require several short term changes. This indicates that the safety stock level should be increased for these items.

- Besides, for these items at most one short term change should be sufficient to deal with extreme sales values compared to forecast values. Therefore it is suggested to challenge the urgency of a market request in order to minimize the number of short term changes. It is recommended to determine and challenge this urgency of a market request before taking a decision how to respond to the market request.

- Provides insights about the safety stock level to the markets in order to provide guidelines with regard to the maximum acceptable percentage of forecast change. These guidelines are most beneficial with regard to promotions, because most extreme sales values compared to the forecast values are caused by promotions. It is recommended to determine borders with regard to promotions in which customers of the markets are allowed to change their forecast. These borders should limit the demand variability of promotions and therefore increase the reliability of the deliveries to the customers.

With regard to the future my expectations are that the sales volumes of the POP/WOP markets are going to increase. These markets are mainly situated outside Europe and the products are a luxury good. For this reason, my expectations are that the sales volumes will increase equal to the purchasing power. Therefore it is important to consider the impact of increasing POP/WOP volumes on the production line. Furthermore, when the sales volumes of these markets is increasing it is important to think about the implementation of a desired CSL to these markets.

Further research could improve the research regarding the limitations as noted above. It is interesting to investigate the effect of demand variability on short term changes in more detail. Besides, it would be interesting to analyse the effect of a different forecast accuracy on the effectiveness of short term changes on the production plan.
References


http://topdownleansystems.com/wordpress/quantifying-the-costs-of-incremental-service-level/


Sridharan, V. & Berry, W.L. (1990). Freezing the master production schedule under demand uncertainty. Decision Sciences, 21, 1, 97-120.


List of abbreviations and definitions

**CRP market**  Continuous Replenishment Product market: these products are made to stock (the stock of these products is reviewed continuously)

**CSL**  Case fill: this performance measures represents the number of products (demand) that can be fulfilled from stock and is target at ≥98.5%

**Customer**  The markets are the customers of the factories

**DOC**  Demonstrated Operating Capacity: the most recent operating capacity based on the previous periods

**End-consumer**  The end-consumer buys the chocolates

**EF**  External factory: co-manufactures and co-packers

**Family**  The product family corresponds to a packaging type (e.g. multipack or single)

**FIFO**  First In First Out: this policy is used to send products from stock to customers

**Item**  An item corresponds to a specific package

**Market**  A country or group of countries (e.g. France, North Africa and Levant), where products are sold

**Planner**  The planner is responsible for the production plan of production/packaging lines

**POP/WOP market**  Periodic/Weekly Order Process market: these products are made to order

**Recipe**  The recipe corresponds to the type of product

**Scheduler**  The scheduler translates the production plan to an operational production plan that represents in detail what items have to be produced where and when

**Single product**  A single product is the basis package

**S&OP**  Sales and Operations Planning: this planning is created periodically to analyze utilization and stock levels of a production line

**Stock cover**  A performance measure: the number of days that demand can be fulfilled from stock
Appendix I – Standard form data collection

The standard format to collect data with regard to short term changes consists of three parts. The first part (i.e. the first page) provides instructions when to fill in the form, definitions and the scope of the data collection. The second part (i.e. the second page) includes questions with regard to the production plan of the specific week. The third part includes several boxes to collect data about the short term changes that occurs. Each short term change can be noted in a separate box.

Data collection

<table>
<thead>
<tr>
<th>Week number</th>
</tr>
</thead>
</table>

Instructions

- Each time a short term adjustment takes place, a new box has to be filled in.
- One box is intended for one item. When a short term adjustment involves more than one item, more boxes have to be filled in.
- Each day the adjustments can be noted on a new piece of paper.
- Only once a day the day of the week and the production line has to be filled in.
- Only once a week the number of items that are planned to be produced that week has to be filled in.

Definitions

- **Short term adjustment**
  - *Change of the production plan*
  - *Requires an extra handling of the planner*
  
  Short term adjustments refer to daily changes during the week.

- **Urgency**
  
  Urgency refers to the reason why an adjustment of the production plan is requested or initiated. This could be a demand or supply change.

- **Handling**
  
  Handling is introduced to prevent double counting of an adjustment of the same item. An example: the planner adjusts the production plan on own initiative in the morning (based on the OOS report in the planning system) and afterwards the market requests an adjustment of the same item.

- **Time**
  
  Time includes all time that the production planner needs to handle a short term adjustment.

Scope

- The data collection will start at week 38 (P10W2) and will end at week 50 (P13W2).
- The production lines 1, 2, 4, 5 and 8 will participated in this project.
Questions at the beginning of the week

• What is the week number and period?

• How many items are planned this week?

• How many recipes are planned this week?

• How much tonnage is planned this week?

• Is your production line in a controlled situation?

• How many days of opening stock do you have at the beginning of the week?
<table>
<thead>
<tr>
<th>INITIATIVE</th>
<th>ITEM NR</th>
<th>HANDLING</th>
<th>ITEM NR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own initiative (OOS report Apollo)</td>
<td></td>
<td>1st time</td>
<td>2nd time</td>
</tr>
<tr>
<td>Initiative of supply or market</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAUSE</td>
<td>RESULT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TYPE CHANGE</td>
<td>Supply</td>
<td>Supply</td>
<td></td>
</tr>
<tr>
<td>Demand</td>
<td>Quality issue</td>
<td>Quality issue</td>
<td></td>
</tr>
<tr>
<td>Higher sales CRP</td>
<td>Line performance</td>
<td>Line performance</td>
<td></td>
</tr>
<tr>
<td>Lower sales CRP</td>
<td>Packaging problem</td>
<td>Packaging problem</td>
<td></td>
</tr>
<tr>
<td>Higher sales POP</td>
<td>Raw material problem</td>
<td>Raw material problem</td>
<td></td>
</tr>
<tr>
<td>Lower sales POP</td>
<td>Engineering</td>
<td>Engineering</td>
<td></td>
</tr>
<tr>
<td>System issue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>URGENCY</td>
<td>Prevent OOS</td>
<td>Prevent OOS</td>
<td></td>
</tr>
<tr>
<td>Current OOS</td>
<td>Protect SS</td>
<td>Protect SS</td>
<td></td>
</tr>
<tr>
<td>Prevent OOS</td>
<td>Protect overstock</td>
<td>Protect overstock</td>
<td></td>
</tr>
<tr>
<td>TIME</td>
<td>1-5 min</td>
<td>15-20 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-10 min</td>
<td>20-25 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-15 min</td>
<td>&gt;25 min</td>
<td></td>
</tr>
<tr>
<td>ACTION</td>
<td>Adjust current plan</td>
<td>Adjust current plan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cases moved</td>
<td>cases moved</td>
<td></td>
</tr>
<tr>
<td>CONTACT</td>
<td>Market</td>
<td>Scheduler</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Raw materials</td>
<td>GSS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Packaging</td>
<td>EOLT</td>
<td></td>
</tr>
</tbody>
</table>

Comments:

<table>
<thead>
<tr>
<th>INITIATIVE</th>
<th>ITEM NR</th>
<th>HANDLING</th>
<th>ITEM NR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own initiative (OOS report Apollo)</td>
<td></td>
<td>1st time</td>
<td>2nd time</td>
</tr>
<tr>
<td>Initiative of supply or market</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAUSE</td>
<td>RESULT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TYPE CHANGE</td>
<td>Supply</td>
<td>Supply</td>
<td></td>
</tr>
<tr>
<td>Demand</td>
<td>Quality issue</td>
<td>Quality issue</td>
<td></td>
</tr>
<tr>
<td>Higher sales CRP</td>
<td>Line performance</td>
<td>Line performance</td>
<td></td>
</tr>
<tr>
<td>Lower sales CRP</td>
<td>Packaging problem</td>
<td>Packaging problem</td>
<td></td>
</tr>
<tr>
<td>Higher sales POP</td>
<td>Raw material problem</td>
<td>Raw material problem</td>
<td></td>
</tr>
<tr>
<td>Lower sales POP</td>
<td>Engineering</td>
<td>Engineering</td>
<td></td>
</tr>
<tr>
<td>System issue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>URGENCY</td>
<td>Prevent OOS</td>
<td>Prevent OOS</td>
<td></td>
</tr>
<tr>
<td>Current OOS</td>
<td>Protect SS</td>
<td>Protect SS</td>
<td></td>
</tr>
<tr>
<td>Prevent OOS</td>
<td>Protect overstock</td>
<td>Protect overstock</td>
<td></td>
</tr>
<tr>
<td>TIME</td>
<td>1-5 min</td>
<td>15-20 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-10 min</td>
<td>20-25 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-15 min</td>
<td>&gt;25 min</td>
<td></td>
</tr>
<tr>
<td>ACTION</td>
<td>Adjust current plan</td>
<td>Adjust current plan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cases moved</td>
<td>cases moved</td>
<td></td>
</tr>
<tr>
<td>CONTACT</td>
<td>Market</td>
<td>Scheduler</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Raw materials</td>
<td>GSS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Packaging</td>
<td>EOLT</td>
<td></td>
</tr>
</tbody>
</table>

Comments:
Appendix II – Semi structured interview
The semi-structured interview with the production planners are performed in Dutch.

Interview planners

Data collection

A. Hoe heb je het ervaren om 3 periodes data in te vullen?
B. Opvallend is dat veel wijzigingen 1-5 minuten tijd vragen, klopt dit?
C. Opvallend is dat bij het contact met andere afdelingen soms niets ingevuld is, mag ik dit
   opvatten als contact met de scheduler? Wanneer neem je contact op met Inbound
   (verpakkingen of grondstoffen) om een wijziging door te kunnen voeren?
D. Wat is de reden om een wijziging door te voeren om je safety stock te beschermen?

Decision tree

A. Op grond van welke criteria besluit je om een productie plan wel of niet aan te passen?
   Wat heeft de hoogste prioriteit in het nemen van je beslissing (e.g. case fill,
   bezettingsgraad)?
   Zijn deze criteria gelijk voor POP/WOP en CRP markten?
   Kun je een inschatting maken van wat voor jou de ondergrens is qua aantal dagen Safety
   Stock wanneer het risico te groot wordt (en je wijzigingen gaat doorvoeren)?

Voorbeeld: Als een markt vraagt om meer productie en je hebt ruimte, wat is dan je keuze?

B. Hoe schat je de urgentie in van een request van de markt?
C. Welke factoren zijn volgens jou van invloed op het aantal wijzigingen in het huidige productie
   plan (e.g. hoogte van je stock)?
Appendix III – Statistical analysis of frequency of short term changes

In this Appendix the detailed analysis of variables that could have a significant influence on the frequency of short term changes is analyzed. All tests are performed by the statistical program SPSS.

Correlation theory

The correlation matrix represents all possible correlations coefficients; where a correlation coefficient is defined as “a measure of the strength of association or relationship between two variables” (Field, 2009: 783). The correlation coefficient ranges between -1 and 1. When there is no relation between two variables the correlation coefficient is equal to 0. A correlation between -1 and 0 represents a negative correlation, which means that an increasing of one variable results in a decreasing of the other variable. The last option, a positive correlation, ranges between 0 and 1 and describes an increasing of one variable resulting in an increasing of the other variable. The correlation matrices are performed by the statistical program SPSS. Before calculating the correlations between different variables, it is necessary to determine if the variables are normally distributed. When a variable is normally distributed than the Pearson’s correlation coefficient is applicable and otherwise the Spearman’s correlation coefficient is applicable (Field, 2009). These normality tests are performed by SPSS using the 1 Sample Kolmogorov-Smirnov test.

<table>
<thead>
<tr>
<th>Correlations</th>
<th>PSL</th>
<th>Utilization</th>
<th>Planneditems-Avg(perlijn)</th>
<th>Tonnage-aug(avgTonnage(perlijn))</th>
<th>Stock-Targetstock(perlijn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSL</td>
<td>Pearson Correlation</td>
<td>1</td>
<td>.092</td>
<td>.187</td>
<td>-.091</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.143</td>
<td>.153</td>
<td>.526</td>
<td>.341</td>
<td>.004</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Utilization</td>
<td>Pearson Correlation</td>
<td>.092</td>
<td>1</td>
<td>.158</td>
<td>.022</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.483</td>
<td>.227</td>
<td>.805</td>
<td>.394</td>
<td>.012</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Itemschanged</td>
<td>Pearson Correlation</td>
<td>.187</td>
<td>.158</td>
<td>1</td>
<td>.256</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.153</td>
<td>.227</td>
<td>.021</td>
<td>.163</td>
<td>.001</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Planneditems-Avg(perlijn)</td>
<td>Pearson Correlation</td>
<td>-.081</td>
<td>.022</td>
<td>.296</td>
<td>1</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.538</td>
<td>.065</td>
<td>.021</td>
<td>.000</td>
<td>.176</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Tonnage-aug(avgTonnage(perlijn))</td>
<td>Pearson Correlation</td>
<td>.125</td>
<td>.112</td>
<td>.182</td>
<td>.502</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.341</td>
<td>.394</td>
<td>.163</td>
<td>.000</td>
<td>.002</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Stock-Targetstock(perlijn)</td>
<td>Pearson Correlation</td>
<td>-.369</td>
<td>-.323</td>
<td>-.423</td>
<td>-.177</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.004</td>
<td>.012</td>
<td>.001</td>
<td>.176</td>
<td>.002</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.01 level (2-tailed).
** Correlation is significant at the 0.05 level (2-tailed).

Because of normality of the variables (assuming a significance level of 0,10), the Pearson’s correlation coefficient is applied. The correlation matrix with data of all production lines:

<table>
<thead>
<tr>
<th>Correlations</th>
<th>PSL</th>
<th>Utilization</th>
<th>Planneditems-Avg(perlijn)</th>
<th>Tonnage-aug(avgTonnage(perlijn))</th>
<th>Stock-Targetstock(perlijn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSL</td>
<td>Pearson Correlation</td>
<td>1</td>
<td>.092</td>
<td>.187</td>
<td>-.091</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.143</td>
<td>.153</td>
<td>.526</td>
<td>.341</td>
<td>.004</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Utilization</td>
<td>Pearson Correlation</td>
<td>.092</td>
<td>1</td>
<td>.158</td>
<td>.022</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.483</td>
<td>.227</td>
<td>.805</td>
<td>.394</td>
<td>.012</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Itemschanged</td>
<td>Pearson Correlation</td>
<td>.187</td>
<td>.158</td>
<td>1</td>
<td>.256</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.153</td>
<td>.227</td>
<td>.021</td>
<td>.163</td>
<td>.001</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Planneditems-Avg(perlijn)</td>
<td>Pearson Correlation</td>
<td>-.081</td>
<td>.022</td>
<td>.296</td>
<td>1</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.538</td>
<td>.065</td>
<td>.021</td>
<td>.000</td>
<td>.176</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Tonnage-aug(avgTonnage(perlijn))</td>
<td>Pearson Correlation</td>
<td>.125</td>
<td>.112</td>
<td>.182</td>
<td>.502</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.341</td>
<td>.394</td>
<td>.163</td>
<td>.000</td>
<td>.002</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Stock-Targetstock(perlijn)</td>
<td>Pearson Correlation</td>
<td>-.369</td>
<td>-.323</td>
<td>-.423</td>
<td>-.177</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.004</td>
<td>.012</td>
<td>.001</td>
<td>.176</td>
<td>.002</td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>
T-tests

The tested variable is the **openings stock:**
- Group 1: Openings stock is less than the target stock
- Group 0: Openings stock is equal to or above target stock

<table>
<thead>
<tr>
<th>Group Statistics</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Openingsstock(s)</td>
<td>27</td>
<td>1.76</td>
<td>2.577</td>
<td>.496</td>
</tr>
<tr>
<td>33</td>
<td>3.76</td>
<td>2.488</td>
<td>.433</td>
<td></td>
</tr>
</tbody>
</table>

**Independent Samples Test**

<table>
<thead>
<tr>
<th>Levene's Test for Equality of Variances</th>
<th>F</th>
<th>Sig</th>
<th>t</th>
<th>df</th>
<th>Mean Difference</th>
<th>Std Error Difference</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramschanged</td>
<td>.716</td>
<td>.454</td>
<td>-3.018</td>
<td>58</td>
<td>.004</td>
<td>-1.900</td>
<td>.556</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>.716</td>
<td>.454</td>
<td>-3.018</td>
<td>58</td>
<td>.004</td>
<td>-1.900</td>
<td>.556</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td>.716</td>
<td>.454</td>
<td>-3.018</td>
<td>58</td>
<td>.004</td>
<td>-1.900</td>
<td>.556</td>
</tr>
</tbody>
</table>

The tested variable is the **number of items that is planned:**
- Group 0: The number of items that is planned is less than average
- Group 1: The number of items that is planned equal to or above average

<table>
<thead>
<tr>
<th>Group Statistics</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramsplanned(item)</td>
<td>26</td>
<td>3.72</td>
<td>3.069</td>
<td>.566</td>
</tr>
<tr>
<td>31</td>
<td>2.06</td>
<td>2.055</td>
<td>.371</td>
<td></td>
</tr>
</tbody>
</table>

**Independent Samples Test**

<table>
<thead>
<tr>
<th>Levene's Test for Equality of Variances</th>
<th>F</th>
<th>Sig</th>
<th>t</th>
<th>df</th>
<th>Mean Difference</th>
<th>Std Error Difference</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramschanged</td>
<td>4.054</td>
<td>.035</td>
<td>2.495</td>
<td>58</td>
<td>.016</td>
<td>1.660</td>
<td>.668</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>4.054</td>
<td>.035</td>
<td>2.495</td>
<td>58</td>
<td>.016</td>
<td>1.660</td>
<td>.668</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td>4.054</td>
<td>.035</td>
<td>2.495</td>
<td>58</td>
<td>.016</td>
<td>1.660</td>
<td>.668</td>
</tr>
</tbody>
</table>

The tested variable is the **tonnage that is planned:**
- Group 0: The tonnage that is planned is less than average
- Group 1: The tonnage that is planned equal to or above average

<table>
<thead>
<tr>
<th>Group Statistics</th>
<th>Tonnage(s)</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramschanged</td>
<td>36</td>
<td>2.94</td>
<td>2.437</td>
<td>.406</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>2.75</td>
<td>3.096</td>
<td>.632</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Independent Samples Test**

<table>
<thead>
<tr>
<th>Levene's Test for Equality of Variances</th>
<th>F</th>
<th>Sig</th>
<th>t</th>
<th>df</th>
<th>Mean Difference</th>
<th>Std Error Difference</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramschanged</td>
<td>1.045</td>
<td>.311</td>
<td>.372</td>
<td>58</td>
<td>.767</td>
<td>.194</td>
<td>.716</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>1.045</td>
<td>.311</td>
<td>.372</td>
<td>58</td>
<td>.767</td>
<td>.194</td>
<td>.716</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td>1.045</td>
<td>.311</td>
<td>.372</td>
<td>58</td>
<td>.767</td>
<td>.194</td>
<td>.716</td>
</tr>
</tbody>
</table>
The tested variable is the **controlled situation** of the production line:
- Group 0: The production line is not in a controlled situation
- Group 1: The production line is in a controlled situation

### Group Statistics

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items changed</td>
<td>1</td>
<td>3.56</td>
<td>2.778</td>
<td>.499</td>
</tr>
<tr>
<td>0</td>
<td>29</td>
<td>3.17</td>
<td>2.602</td>
<td>.468</td>
</tr>
</tbody>
</table>

#### Independent Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of Variances</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td>Items changed</td>
<td>Equivariances assumed</td>
<td>.491</td>
</tr>
<tr>
<td></td>
<td>Equivariances not assumed</td>
<td>-3.49</td>
</tr>
</tbody>
</table>

The tested variable is the **number of recipes**:
- Group 0: More than one recipe is produced
- Group 1: One recipe is produced

### Group Statistics

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recipes changed</td>
<td>34</td>
<td>3.75</td>
<td>3.104</td>
<td>.309</td>
</tr>
<tr>
<td>0</td>
<td>26</td>
<td>3.73</td>
<td>3.157</td>
<td>.619</td>
</tr>
</tbody>
</table>

#### Independent Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of Variances</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td>Recipes changed</td>
<td>Equivariances assumed</td>
<td>5.850</td>
</tr>
<tr>
<td></td>
<td>Equivariances not assumed</td>
<td>-2.32</td>
</tr>
</tbody>
</table>

The tested variable is the **factory performance**:
- Group 0: the factory performance is less than 100%
- Group 1: the factory performance is equal to or above 100%

### Group Statistics

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>PILB/IN</td>
<td>31</td>
<td>2.35</td>
<td>2.332</td>
<td>.419</td>
</tr>
<tr>
<td>1.00</td>
<td>29</td>
<td>2.41</td>
<td>2.462</td>
<td>.554</td>
</tr>
</tbody>
</table>

#### Independent Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of Variances</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td>PILB/IN</td>
<td>Equivariances assumed</td>
<td>2.878</td>
</tr>
<tr>
<td></td>
<td>Equivariances not assumed</td>
<td>-1.52</td>
</tr>
</tbody>
</table>
The tested variable is the **utilization grade**:
- Group 0: the utilization grade is less than 100%
- Group 1: the utilization grade is equal to 100%

### Group Statistics

<table>
<thead>
<tr>
<th>Utilization Grade</th>
<th>N</th>
<th>Mean</th>
<th>Std Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items planned</td>
<td>8</td>
<td>1.50</td>
<td>1.852</td>
<td>0.655</td>
</tr>
<tr>
<td>Tonnage planned</td>
<td>52</td>
<td>3.08</td>
<td>2.757</td>
<td>0.382</td>
</tr>
</tbody>
</table>

### ANOVA Test

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>7214,117</td>
<td>9</td>
<td>801,569</td>
<td>4,150</td>
<td>.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>9656,733</td>
<td>50</td>
<td>193,135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>16870,850</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonnage planned</td>
<td>3498190330624,188</td>
<td>9</td>
<td>388687815180,465</td>
<td>2,647</td>
<td>.014</td>
</tr>
<tr>
<td>Between Groups</td>
<td>7342865978376,546</td>
<td>50</td>
<td>146857319587,531</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>10841056315000,73</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10841056315000</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Openings stock</td>
<td>475,918</td>
<td>9</td>
<td>62,880</td>
<td>3,183</td>
<td>.004</td>
</tr>
<tr>
<td>Between Groups</td>
<td>830,715</td>
<td>50</td>
<td>16,614</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>1306,633</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2144,630</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controlled</td>
<td>2,763</td>
<td>9</td>
<td>.307</td>
<td>1,256</td>
<td>.284</td>
</tr>
<tr>
<td>Between Groups</td>
<td>12,220</td>
<td>50</td>
<td>.244</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>14,983</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>37,963</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSL</td>
<td>719,192</td>
<td>9</td>
<td>79,910</td>
<td>1,232</td>
<td>.298</td>
</tr>
<tr>
<td>Between Groups</td>
<td>3244,408</td>
<td>50</td>
<td>64,888</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>3963,600</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>719,192</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilization</td>
<td>268,183</td>
<td>9</td>
<td>29,798</td>
<td>.558</td>
<td>.825</td>
</tr>
<tr>
<td>Between Groups</td>
<td>2670,800</td>
<td>50</td>
<td>53,416</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>2538,983</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28,850</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recipes123</td>
<td>6,067</td>
<td>9</td>
<td>.674</td>
<td>1,479</td>
<td>.182</td>
</tr>
<tr>
<td>Between Groups</td>
<td>22,783</td>
<td>50</td>
<td>.456</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>22,783</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28,850</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mediator

The following mediator relationship is tested.

The first step is to test the regression of the independent variable on the dependent variable.

Regression

<table>
<thead>
<tr>
<th>Variables Entered/Removed*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

Variables Entered: Recipes

Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.283*</td>
<td>.080</td>
<td>.064</td>
<td>2.669</td>
</tr>
</tbody>
</table>

ANOVA

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regression</td>
<td>1</td>
<td>34,259</td>
<td>5,925</td>
<td>.029*</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>68</td>
<td>6,865</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>426,933</td>
<td>69</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(Constant)</td>
<td></td>
<td>7.393</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Recipes</td>
<td>-.525</td>
<td>-.293</td>
<td>-2.244</td>
</tr>
</tbody>
</table>

The regression coefficient of the variable recipes is significant, what indicates that a mediator could exist. The second step is to test the regression of the independent variable on the mediator.
The regression coefficient of the variable recipes is significant, what indicates that a mediator could exist. The third step is to test the regression of the mediator on the dependent variable.
The regression coefficient of the variable items planned is significant, what indicates that a mediator could exist. The fourth step is to test the regression of both the independent variable and the mediator on the dependent variable.

**Regression**

```
<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Recipes, Itemplaned</td>
<td>.</td>
<td>Enter</td>
</tr>
</tbody>
</table>
```

a. Dependent Variable: Items planned
b. All requested variables entered.

### Model Summary

```
<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.898</td>
<td>.784</td>
<td>.782</td>
<td>2.232</td>
</tr>
</tbody>
</table>
```

a. Predictors: (Constant), Recipes, Itemplaned

### ANOVA

```
<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regression</td>
<td>2</td>
<td>73.924</td>
<td>14.656</td>
<td>.006</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>57</td>
<td>4.842</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>59</td>
<td>428.733</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

a. Dependent Variable: Items planned
b. Predictors: (Constant), Recipes, Itemplaned

### Coefficients

```
<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Constant)</td>
<td>-.294</td>
<td>.959</td>
<td>.326</td>
</tr>
<tr>
<td></td>
<td>Itemplaned</td>
<td>.098</td>
<td>.018</td>
<td>.551</td>
</tr>
<tr>
<td></td>
<td>Recipes</td>
<td>.444</td>
<td>.022</td>
<td>-.082</td>
</tr>
</tbody>
</table>
```

a. Dependent Variable: Items planned

Only the mediator is significant and therefore in this case there is full mediation.

The same steps are performed to analyze whether the relationship between number of recipes and frequency of short term changes is mediated by the variable openings stock.

This mediation relationship does not exist.
Regression theory

Regression analysis is "a way of predicting an outcome variable from one predictor variable (simple regression) or several predictor variables (multiple regression)" (Field, 2009: 198). The outcome variable, Y is the dependent variable and is related to n independent predictor variables, as represented in the formula:

\[ Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \epsilon \]

The parameters \( \beta \) are the regression coefficients and represents the expected change of the dependent variable Y when the other variables are held constant (Montgomery & Runger, 2007). The parameter \( \epsilon \) is a random error with mean zero and (unknown) variance (Montgomery & Runger, 2007). The regression analyses are performed by the statistical program SPSS too and the significance level is equal to 0,05. This means that the founded relations between the dependent and independent variables are true with 95% reliability.

A regression model is made that include the variables:
- Independent variables: number of items planned compared to average items planned and openings stock compared to the target stock
- Dependent variable: number of items changed

Regression

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Planneditems_Average, Stock-Targetstock</td>
<td>Enter</td>
</tr>
</tbody>
</table>

A. No multi-collinearity;
B. All relevant predictor variables are included;
C. Homoscedasticity: all residuals are from a distribution with the same variance;
D. Linearity: the “true” model should be linear;
E. Independent errors: having information about the value of a residual should not give you information about the value of other residuals;
F. Errors are distributed normally.

The assumptions are tested for the described regression model:
A. There exists no multi-collinearity, because there is no significant correlation between the two independent variables.

<table>
<thead>
<tr>
<th></th>
<th>Plannedtems-Ag(portln)</th>
<th>Stock-Targetstock(portln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>1</td>
<td>1.77</td>
</tr>
<tr>
<td>N</td>
<td>69</td>
<td>60</td>
</tr>
</tbody>
</table>

B. All relevant predictor variables are included in the model, because both the correlation matrix and the T-tests results in a significant influence of the included independent variables on the frequency of short term changes.
C. Homoscedasticity assumption is met.

D. Linearity assumption is met by the scatterplot above.
E. The independent errors assumption can be tested via the Durbin-Watson test. A rule of thumb is a value between 1.5 and 2.5. Therefore the assumption is met.

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>Durbin-Watson</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.480a</td>
<td>.230</td>
<td>.203</td>
<td>2.496</td>
<td>1.677</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant, Stock-Targetstock(portln), Plannedtems-Ag(portln))
b. Dependent Variable: ImmChnged

F. The errors are normally distributed.
Appendix IV – LSML

Determination of the number of times that an item is added to the LMSL is performed as follow.

The LMSL is used for more purposes than described in the scope of this project; therefore a selection is made of the LMSL. First the items that are filled in by the production planners are investigated. Second, the reason why the items are filled in on the LMSL is important, because the LMSL is used for different purposes. In the scope of this project ‘extra orders’ and ‘to be sure’ items are investigated. ‘Extra orders’ are items that should be added to the original transportation planning and are therefore filled in at the LMSL. Items on the LMSL because of the reason ‘to be sure’ are filled in to emphasize the importance of the transportation; i.e. when the truck will depart later, the net inventory of the market warehouse will become negative.