UNIVERSITY OF TWENTE.

Master thesis:

Tactical stock target setting

"Setting rolling horizon aggregate stock targets based on operational characteristics and requirements"

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Master thesis report

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Master Industrial Engineering and Management

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BU Professional Lamps Europe,
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Management Summary

This master thesis provides a model to estimate aggregate stock levels for upcoming periods of major parts of Philips Lighting's supply chain. The model is developed to support business unit management in setting realistic stock targets for whole product groups as well as to predict medium term stock fluctuations. Based on this model, we analyzed the performance and potential of the supply chain parts under study. Important outcomes of these analyses are:

- The stock targets of several product groups are currently set higher than needed, while others are set far too low.
- The current supply flow of sourced products from China to Europe performs as good as structurally inferior to all other studied supply flow options. The best performing alternative requires on average 12% less total stock, while also being far more robust.
- Shipping supply from China to Europe by train instead of by sea requires on average 10% less physical stock and over 50% less goods in transit stock.
- The currently used methods to estimate demand uncertainty results in an average 27% underestimation of necessary safety stock levels.
- At least 80% of the targeted physical stock levels of supply from China are currently required to neutralize the effects of forecast inaccuracy on service level performance.

The motivation for this research arises from the manner in which business unit management currently sets stock targets for whole product groups. This is mainly based on historically achieved results and an ongoing pressure to improve performance. Business unit management concludes that the current manner is too empirical and desires a better way to set these targets. They also desire an analytic tool to gain deeper insights in the characteristics and performance of their supply chain. This contributes strongly to the identification of improvement possibilities. We developed a model that delivers both.

The model is based on operational characteristics and requirements. It calculates the stock levels that are, from a mathematical perspective, at least necessary to obtain the required service levels. It calculates these levels on a weekly basis for the rolling horizon of the medium term forecast. The model takes amongst others into account supply chain configuration, forecasting accuracy, seasonality, replenishment strategy, postponed allocation of replenishment, and production related restrictions such as capacity, minimal production quantities, and production wheels. The model next consolidates the outcomes of all products to the aggregate level of whole product groups. By this, it estimates the stock levels of whole product groups for the complete medium term forecast based on operational characteristics and requirements. We conclude that this is a realistic way to set stock targets and consequently predict medium term stock fluctuations.

We developed specific software to conduct the complex set of necessary calculations. It exports the resulting data on each required consolidation level and splits the stock in accordance to the stock type. With this software, we provide a very usable platform for gaining further insights in the characteristics and behavior of supply flows and product groups as well as for performing in-depth scenario analyses.

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Preface

This report is the finalization of my graduation assignment for the master program Industrial Engineering and Management at the University of Twente. The underlying project and research were conducted within the surroundings of Philips Lighting's headquarters at Eindhoven. Here, I express my sincere gratitude to the many people, who accompanied me along this journey with their insights, support, and enthusiasm.

First of all, I thank my supervisor Hylke de Cock for the opportunity to conduct this assignment at his department. His vision, professionalism, and pioneering spirit were truly inspiring. Furthermore, I thank him for his trust and efforts in supporting my further career.

I am also indebted to my supervisors from the University, Johann Hurink and Marco Schutten, for their academic insights and especially their support in the finalization of this master thesis.

Next, I thank my internal coach Lonneke Driessen, for her personal support as well as the structure and guidance she provided to the project. I am also grateful to the representatives of the supply groups TL/CFL-ni and Halogen, Marco Bachrach and Johan van der Werf, for their insights, sparring, and commitment to the project.

Of course, my full thanks goes to all the colleagues at the Supply Chain Competence Center, for providing an utmost pleasant atmosphere during the seven months that I stayed in their midst. Of them a particular thanks to Hans Vaessen and Ieke le Blanc, for the long walks through uncharted parts of Eindhoven city and the good conversations, and Cynthia van den Elsaker, for her humor and most enjoyable company.

A last, but certainly not least, thanks to my family, friends, and of course my girlfriend for their unconditional support, their interest, and their never ending appealing to my conscience.

August 2012,
Robin Boerrigter

Chapter 1 Problem description

This chapter describes the problem at hand. Section 1.1 contains an introduction to the company and environment at which we conducted this research. Next, Section 1.2 elaborates on the motivation for this study. Section 1.3 formulates the problem, which we transform in the research goal. In Section 1.4, we determine the scope of the research. Section 1.5 defines the research questions and elaborates on the research design. Appendix II contains the formal project description that we used at the organization internally.

1.1 Introduction

Nowadays, almost every company feels the ongoing pressure to improve its supply chain performance. Topics such as reducing inventory costs and increasing service levels to the end customers receives more and more attention. This is no different for the company at which this master thesis project was performed: Philips Lighting.

Philips Lighting is one of the three sectors of Royal Philips Electronics, a global leader in healthcare, lighting, and consumer lifestyle with revenues of € 23 billion over the year 2010 and headquartered in the Netherlands. Philips Lighting employs approximately 53,000 people worldwide and runs manufacturing operations in 14 countries. This master thesis is oriented on the supply chain performance of one of its business groups: Lamps Europe.

The supply chain of this business group is extensive, complex, and dynamic. It contains many production facilities, special purpose plants, and warehouses of different types. Supply flows in numerous ways through the supply chain and a large part of the portfolio is also sourced from external suppliers mainly located in the Far East. Over recent years, a lot of projects were conducted to improve the operational supply chain performance of the business group. Projects to decrease order cycle times, to set appropriate reorder points & quantities, to select supply flows, and to find a good trade-off between production quantities & frequencies and inventory levels, all have been performed over recent years. Lately, even a newly developed and better suiting replenishment policy was rolled-out.

While operational supply chain improvement received sufficient attention, at the managerial level questions rises about the way to set stock targets and evaluate supply chain performance on the more tactical level. In this context, with tactical level we mean complete product groups on a medium term time interval. Whenever we use the term operation level, we mean the level of individual products on the short term / current time interval. Management currently sets such tactical targets empirically, by which a relation to the real supply chain characteristics seems missing. They feel deprived of an analytic way to gain deeper insights in amongst others the relationship between related stock and service levels as well as a way to set appropriate tactical stock targets.

This master thesis assignment investigates the possibilities to build a mathematically supported method for setting tactical stock targets based on operational characteristics and requirements. We also use its outcomes to analyze the supply chain under study, gain deeper insights, and identify improvement possibilities.

1.2 Research motivation

We split the motivation for this research into two aspects: 1) the lack of a reliable way to set appropriate tactical stock targets and 2) the lack of a reliable way to analyze supply chain performance and characteristics at the tactical level. Both are perceived as lacking reliability by business unit management, who defines this as an undesirable situation. This section elaborates on the motivation and provides background information.

This master thesis is about inventory management. The main interest of this field is the determination of optimal stock levels within a supply chain. Which stock levels are optimal depends mainly on the criteria and targets set by management (e.g. service level, production flexibility). Within the business group Lamps the most important inventory related targets are on service and stock level. Management aims to obtain the lowest stock levels possible while still meeting service level requirements. This implies that stock level is a dependent variable in this environment. Whenever we refer to service level, we mean a measurement that is in line with the one used internally by the organization. Both the measurements for service and stock levels are in Section 2.3.

Setting stock targets for operational usage is researched extensively over the last sixty years. A lot of methods came available that can be used to set related stock targets. However, business unit management is more interested in the overall performance and target setting for complete product groups on the medium term period. The organization has no mathematical methods available that can embrace this to the full extent. They feel tied to set their tactical stock targets empirically, mainly based on historically achieved results, rules of thumb, and the ongoing pressure to reduce stock levels. A grounded base for setting such targets is missing.

The supply chain environment under study encloses several production facilities, a network of distribution warehouses, and special purpose plants. Products flow in numerous ways through the supply chain and production is partly outsourced to external suppliers. Replenishment policies change over time, the product portfolio is growing, production lines are reallocated, minimum order quantities frequently alter, forecast accuracy of demand is low at the operational level, and products are subjected to seasonal demand patterns. Business unit management perceives this environment as complex and dynamic. This makes it much more difficult to justify the use of and the working with empirically set stock targets. As a result, targets are not commonly accepted and are often a point of debate. Consequently, the company also misses a way to estimate which tactical stock levels are realistically achievable.

With this as background, business unit management wishes to get better support in setting appropriate tactical stock targets. They also desire an analytic way to study the supply chain on the tactical level. This provides in further insights, can quantitatively support related decision making, and might identify improvement possibilities. Business unit management states that a profound mathematical model, that estimates the optimal tactical stock levels, meets their needs when it is based on 1) required service levels and 2) operational requirements and characteristics. They perceive that the outcomes of such model can be used as a realistic and appropriate way to set their stock targets, analyze the supply chain environment, and increase acceptance over these targets.

1.3 Problem formulation

In this section, we formulate the main question of this master thesis and transform it into our research goal. To provide a more complete picture, we also elaborate further on several of their aspects and related subjects. Based on the motivation and background of this research, we formulate the problem as follows:

> ***Problem statement:***
> *In which mathematically supported way can business unit management get better insights in setting tactical stock targets and conducting related analyses on supply chain performance?*

The term tactical stock targets needs further clarification, as it can be interpreted in various ways. Within this research, we mean those stock targets that are set for whole product groups on a medium term time period. These targets are set separately for each individual time interval of such period and encloses one week. This implies that a different stock target is required for every week of the medium term future. On the same level, business unit management desires thorough analyses of her supply chain. They want a mathematical tool to estimate future stock level fluctuations and to evaluate the impact of changes in the supply chain. This provides support in related decision making. Examples of such changes are on service levels, lead times, supply flows, and accuracy of demand forecast.

The goal of this research is twofold and as follows:

> ***Research goal:***
> 1) *To provide a mathematical model that estimates optimal tactical stock levels based on operational supply chain characteristics and service level requirements.*
> 2) *To provide stock level analyses on the current situation and several scenarios based on the developed model in this research.*

There are two important constraints on the model. First, it must be able to deal with a changing environment and seasonality. As described in Section 1.2, the characteristics of this supply chain alter frequently due to amongst others changing supply flows, replenishment policies, and production capacities. Exactly this, together with the strong seasonal demand patterns, is a major motivator for business unit management to desire a less empirical way of setting targets. It implies that the model must operate with changing input parameters over time. Consequently, the method must also provide stock targets that change over time. Second, the method must be in line with the new replenishment strategy of the organization called ‘Integral Supply Planning’. Over recent years, this strategy has been rolled out for many product groups. It will soon replace all the remaining policies still in use within the organization.

The model must calculate stock levels for each product separately and consolidate the outcomes to the higher product group level. In other words, it must be based on the stated operational supply chain characteristics and requirements. While calculating this for each product separately, it must also consider the impact of possible correlations between products (e.g. on minimum order quantities or postponed allocation of replenishment). Business unit management feels that such a model provides them with the required realistic and appropriate way to set tactical stock targets.

It is not a target of this research to deliver a ready-to-use tool for operational usage. The development of amongst others the underlying software requires much additional resources not available to the project team. On forehand, it was not known whether such a model could be developed neither whether it could be translated into an easy-to-use tool. The decision to make such a tool is postponed until after the project. Based on the experience, lessons learned, developed model, and the analyses of this project, a more solid decision can be made.

1.4 Project scope

The business group under consideration is too large and complex to be included completely into this project. Scoping is therefore needed. This section discusses the scoping decisions that we made at the start of the project.

Organization in scope:
As mentioned in Section 1.1, this project is conducted within the business group Lamps Europe. This business group is divided into two business units: Consumer Lamps Europe and Professional Lamps Europe. Both business units consist out of groups oriented on the market side (e.g. sales offices) and groups oriented on the supply side (e.g. factories). A more detailed description of these groups and their role in the supply chain can be found in Section 2.1. We decided that the scope of this project is on two so called supply groups: TL/CFL-ni and Halogen. The first supply group is part of the business unit Professional Lamps Europe. Our focus within this group lies on the supply flow from own production. This means that the related products are produced by company owned factories and reach the end customer through the organization's network of distribution centers. The second group is part of the business unit Consumer Lamps Europe and here the focus lies on the Buy-for-Resale flow. This means that the related products are bought from external suppliers, shipped to the distribution centers of the organization by which they reach the end customer. By scoping the project this way, both business units, with strongly different characteristics, are included.

Products in scope:
Within Philips Lighting, products are grouped in so called Committed Aggregation Groups (CAGs). Such a group contains comparable products that are committed to the same resource such as production line or Buy-for-Resale flow. Identical products that are produced in different factories belong to different CAGs. The groups are further bundled into Article Groups (AGs). Whenever we use the term product group further on in this research, we refer to Committed Aggregation Group as used internally within the organization and described above.

Several product groups are selected to be in scope of the project. For the own production flow, there are six product groups selected, belonging to two Article Groups. The related products are produced at three different facilities. There are two main reasons for selecting these groups: the products belonging to these groups have relative stable markets combined with large volumes and they are produced on production lines that are almost completely dedicated to these groups only. This implies a high representative value and a more defined capacity picture. Two product groups from the Buy-for-Resale flow were selected, belonging to different Article Groups. These groups also have a relatively stable and mature market.

Processes & Characteristics in scope:
Numerous factors influence supply chain performance on the operation level. Including too many factors into the project makes it too complex to develop a workable model. Including too few makes the model too rough for reliable target setting. We selected several factors of which we believe that they have a significant impact on stock levels and by this on the quality of the model. Such factors will be included into the calculations of the model. These factors are: sales forecast, forecast accuracy, supply chain configuration & flows, supply capacity, minimum production & order quantities, lead & transport times, replenishment strategies, and service level. Chapter 2 provides background information on each of these factors.

Out of scope:
Besides the not selected supply groups and products, several factors are excluded from this project. This project focuses only on the supply chain flow from production or sourcing till the distribution centers. All materials, components, and semi finished products are out of scope. Delivery from the distribution centers to the customers is out of scope. Production planning and scheduling including set-up times etcetera is out of scope. As mentioned earlier, development and implementation of a ready-to-use operational tool is out of scope.

1.5 Research questions

We described the goal of our research in Section 1.3. To achieve this goal, a set of underlying research questions needs to be answered. In this section, we define these questions. We further elaborate on the design as well as the plan of approach of the research. This section concludes the first chapter.

In Figure 1, we first show the research model. The vertical arrows illustrate the confrontation (or interaction) aspect. The horizontal arrows illustrate conclusions that can be drawn from these confrontations. At the start of this research, we perceived that the resulting model would become both complex and extensive. To perform the required analyses on the supply chain, specific software needs to be programmed first. The software is not a deliverable of the project, but essential to the underlying calculations.

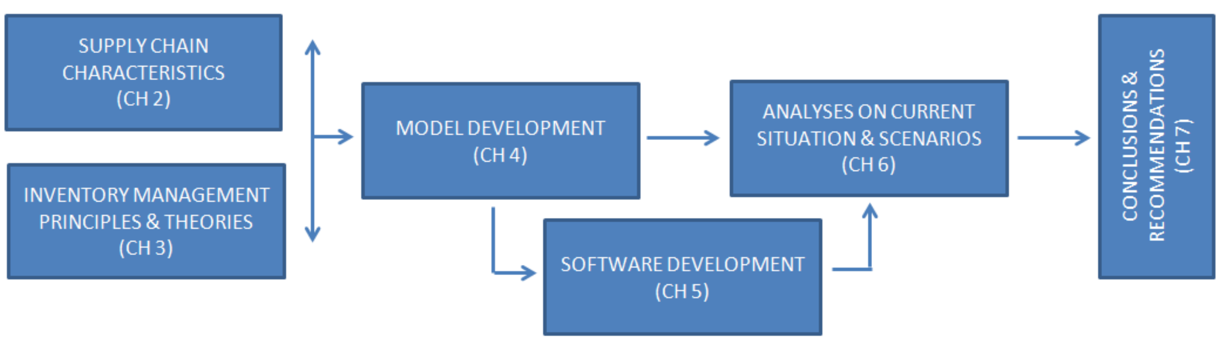


Figure 1: Research model including chapter indication

Research questions:

1) *What are the key characteristics of the supply chain and its environment?*

In order to develop a reliable model, it must be based on the real situation of the supply chain under consideration. Elements that have a key impact on the required stock levels need to be identified and later on included into the model. By answering this question, we obtain this essential background information.

2) *Which theories and methods are available in related literature that can contribute to our research?*

This research lies in the field of Inventory Management. By answering this question, we gain essential insights in the available theories, methods, and principles. It provides the necessary background for the development of a good mathematical grounded model.

3) *How does a model look like, that meets the requirements of this research?*

This model must provide a mathematical supported way to estimate optimal tactical stock levels. The combined insights of the first two research question deliver us the necessary background for the development of such model. However, we anticipated that existing literature cannot fully enclose all aspects. This expectation is mainly based on the complex and dynamic nature of the supply chain as well as the large number of variables that we take into account. As a result, we expect that different complementary methods from literature need to be combined with our own insights to achieve the main goal of this research.

4) *What can we learn from analyses based on the outcomes of the developed model?*

Business unit management requires analyses on both the current supply chain situation as several related scenarios. These analyses must be based on the outcomes of the model that we develop in this research, as business unit management perceives this as a realistic and reliable way to set targets. We divide this main question into two sub questions:

a) Which tactical stock levels can be expected for the current supply chain situation, using the model developed under research question 3?

As described in Section 1.4, this project includes product groups that use two different supply flows: own production and Buy-for-Resale. Separate analyses on both must be conducted.

b) Which tactical stock levels can be expected for different scenarios on the supply chain, using the model developed under research question 3?

Business unit management desires quantified support in their supply chain decision making. Based on their current interests, they desire further insights in the impact of changing service levels, lead times, supply flows, and forecast accuracy of demand. The scenarios mentioned in this research question relate to these subjects.

5) *Which conclusions and recommendations can be drawn from our research?*

Based on the answers of the previous research questions, we draw our final conclusions and propose our recommendations to business unit management. For this, we divide this question into three sub questions. Each one is oriented on a specific part of our research.

a) *Which conclusions and recommendations can we draw from the developed model?*

b) *Which conclusions and recommendations can we draw from our analyses on the current situation of the supply flow?*

c) *Which conclusions and recommendations can we draw from our analyses on different scenarios on the supply flow?*

To reach the formulated goal of the research, we set up the following research design. Figure 1 illustrates a research model to provide the necessary structure to walk through the process step-by-step. The model consists out of five phases.

In the first phase, we collect the background information that is necessary for our further research. We study and describe the supply chain at hand as well as relevant parts of its environment. We gain our insights on this subject by interviews, documents, operation procedures, related project reports, calculation sheets, and data from the ERP-software. Next, we conduct a literate study within the field of Inventory Management and select theories, methods, and principles that might be of use. The literature and supply chain study together provide the input for the next phase.

In the second phase, we develop the mathematical model that estimates optimal tactical stock levels. First, we determine the requirements for the model. These requirements are based on the demands from business unit management, available resources, and our own insights. Next, we develop the model. We start with a basic method and extend it step-by-step to meet the full set of requirements. As we do not assume that available methods can fully enclose the problem at hand, we expect that some gaps need to be bridged by our own insights. We conclude this phase by describing the impact of our assumptions made during the development of the model.

In the third phase, we develop specific software needed to perform the full set of calculations of the model. We estimate that the model becomes both extensive and complex. This makes it unlikely that the calculations can be performed in a basic spreadsheet environment. Although programming such software requires a large part of our time available, it is not a deliverable of the project. This software together with the model itself forms the input for the next phase.

In the fourth phase, we perform the analyses on the current situation of the supply chain as well as several scenarios. We require the software and a large set of input data for the underlying calculations. Examples of this input data are: minimum production quantities, lead times between facilities, and forecast accuracy. We obtain this data from interviews and the ERP-software. Whenever this is not sufficient, we derive input data ourselves based on the data and insights available to our team. The outcomes of the calculations are sets of tactical stock levels. In this phase, we analyze these outcomes and state amongst others the minimum, maximum, and average stock levels that are theoretically obtainable. As we obtain stock levels for each time interval, we can also analyze the stock fluctuations over the medium time period. Besides these basic analyses, we investigate the reasons behind the outcomes thoroughly. From this, we gain interesting insights in the supply chain characteristics. These insights are impossible to obtain or prove without a mathematically grounded model.

In the fifth phase, we draw the final conclusions of our research. We provide business unit management with our recommendations based on the conclusions and the insights gained during this research. These conclusions and recommendations relate to the model as well as the conducted analyses, as both are essential parts of our research goal. At the end of this phase our research goal is met.

In this chapter, we created an overview of the way the research will be executed. The motivation for this study arises from the lack of an analytic way to set tactical stock targets, as perceived by business unit management. The main goal for this study is to provide such analytic way to set these targets as well as to perform related analyses on the supply chain under study. The research questions describe how to solve the problem using studies on literature and supply chain, develop the desired model, program specific software for the calculations of the model, perform analyses, and draw final conclusions and recommendations.

The remainder of this thesis includes the following content. Chapter 2 describes the supply chain under study. In Chapter 3, we conduct the literature study which supports our research with the necessary theoretical background. In Chapter 4, we develop the model. The model is based on the literature study, the characteristics of the supply chain, and, where needed, our own insights to bridge gaps. In Chapter 5, we briefly describe the development of the required software. An extensive description on this subject is not desired and surpasses the goal of our research. Chapter 6 provides the analyses that we perform on the current situation of the supply chain and the different scenarios. Finally, Chapter 7 elaborates on the conclusions we draw from our research and the recommendations we provide to business unit management.

Chapter 2 Supply chain characteristics

This chapter describes the supply chain under consideration. We discuss the organization, the supply chain concept & flows, relevant key performance indicators, forecasting methods for demand, product portfolio & demand characteristics, replenishment policies, and relevant production related topics such as minimum production quantities. Overall, this chapter provides sufficient background information to understand and evaluate the choices made during this project with respect to model building and analyses.

2.1 Organization

A normal business unit at Philips Lighting consists out of two types of groups: market groups and supply groups. The market groups focus on the end part of a supply chain. They orientate on a specific market and are responsible for the sales, marketing and after sales to that market for all products of the business unit. Regional sales offices (internally called Customer Sales and Marketing Units) are the major part of these groups. The supply groups focus on the front end of the supply chain. They are clustered based on product (ion) characteristics and carry the responsibility for the production and/or procurement of the products.

As mentioned in Chapter 1, the scope of this project lies within two selected supply groups. One of these, the supply group TL/CFL-ni, contains three production facilities. They are located in the Netherlands (Roosendaal), Poland (Pila), and France (Chalon). Within the organization, these facilities are called International Production & Logistics Centers. Whenever we mention production facilities further on, we refer to these facilities. The other group, the supply group Halogen, has no company own production facilities, but sources all its products. These, so called Buy-for-Resale, products are mainly sourced from suppliers located in China. This specific Chinese flow is coordinated by a dedicated internal sourcing agency called the China Sourcing Group. Whenever we mention Sourcing Agency in our research, we refer to the China Souring Group.

Philips Lighting has company owned distribution centers across Europe. There are five larger regional distribution centers (or RDCs). They are located in Poland (Pila), France (Villeneuve Saint Georges), the Netherlands (Eindhoven), Great Britain (New Hampshire), and Turkey (Istanbul). The RDCs deliver to different and designated regions. Most sales are made within the regions of the first three distribution centers. These centers are also located close to important production facilities and are the main regional distribution centers. There are also several smaller distribution centers (or DCs). They cover only a small part of the regions designated to the larger distribution centers and are amongst others located in Spain, Greece, and Russia. The smaller distribution centers are normally supplied by dedicated large regional distribution center, not directly from the production facilities.

Philips Lighting has a special distribution center that handles major parts of the Buy-for-Resale flow, located in Poland (Pila). The motivation for this center lies with the need for extra quality inspections as well as the benefits of consolidated flows and postponed allocation of products. It replenishes other distribution centers in the same way a production facility does. Within the organization, this center is called the International Buying & Logistic Center. Whenever we use the term Sourcing DC, we refer to this distribution center.

Products are often stamped and packaged directly after production, both in an online and offline environment. However, Philips Lighting also has facilities that are fully dedicated to these processes. They are supplied with technical finished but unpacked and unstamped products by the production facilities. They convert these products into commercial finished products. By using such facilities, the allocation of technical finished product to commercial finished products is postponed. We discuss the benefit of such postponement in Section 2.2.2. Within the organization, these facilities are called Post Manufacturing Packaging Centers. Whenever we use the term packaging center later on, we refer to such a facility. The organization has two packaging centers, located in France (Dijon) and Poland (Pabianice).

Figure 2 provides a geographical overview of the different facilities mentioned above.

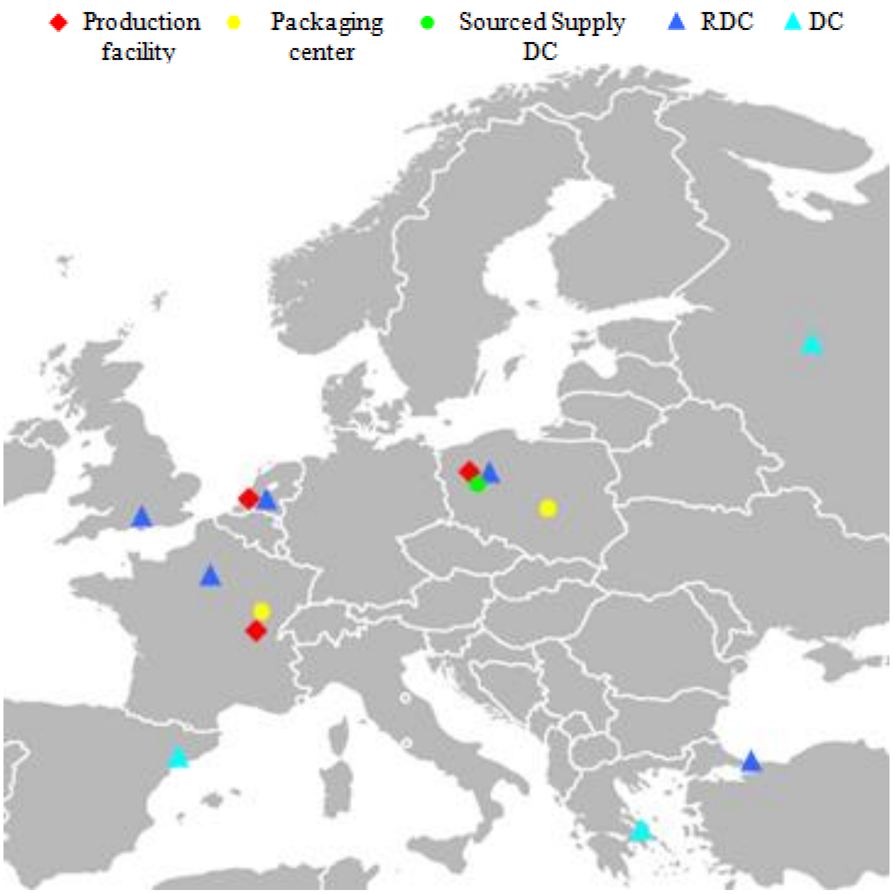


Figure 2: overview of facilities across Europe

2.2 Supply chain concept

In Section 2.1, we described the organization and facilities that Philips Lighting uses in its supply chain. This section elaborates on the lay-out of the supply chain and the usage of the previously described facilities. The two supply groups that are in scope of the project make use of six different supply flows. As this section describes the way in which the supply chain is configured, Section 2.6 describes the policies by which the supply chain is replenished.

2.2.1 Supply group TL/CFL-ni

The supply group TL/CFL-ni has three production facilities. Finished products flow from the warehouses of these facilities to the end customer. For the product portfolio in scope, this can be achieved by using one of three available supply flows.

1) Products flow from the production facilities, through the RDCs, to the end customers. This is the main supply flow and it is used for the largest part of the products.
2) Products flow from the production facilities, successively through the RDCs and the DCs, to the end customer.
3) Products flow from the production facilities directly to the end customers. As this flow fully bypasses the network of distribution centers, it is called a direct delivery.

Figure 3 displays a schematic overview of these three different supply flows.

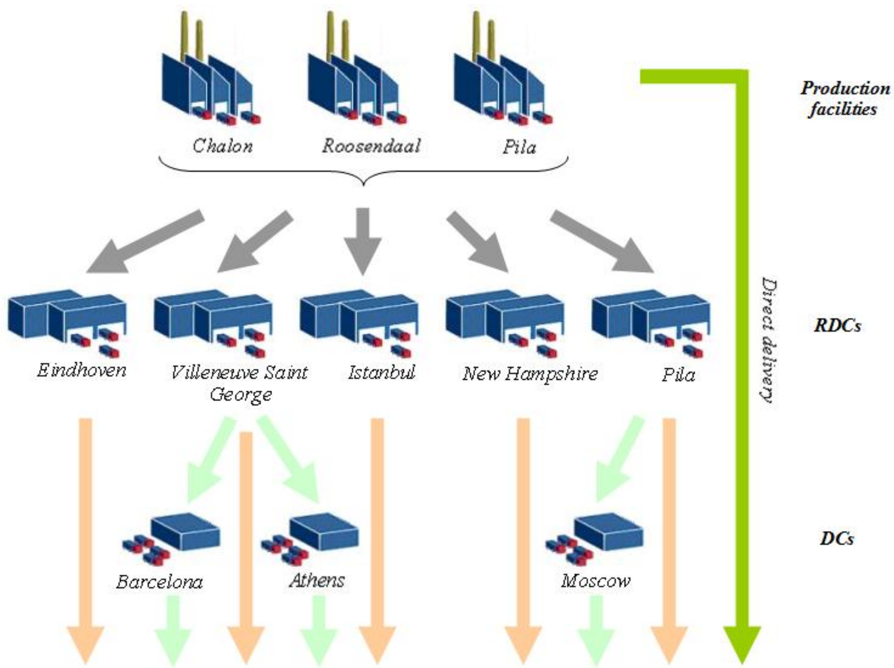


Figure 3: the different supply flows of TL/CFL-ni

Stock is located throughout the supply chain. Based on location, the organization classifies it either as industrial or commercial stock. Stock located at the (R)DCs is directly available for sale and delivery to the end customer. Except for direct deliveries however, stock located at the production facilities is not, for it must first flow through an (R)DC. Hence, stock located at the former is called commercial stock; stock located at the latter is called industrial stock.

Based on replenishment policy, the organization classifies its products as either stock-type or order-type. For a stock-type product, stock is kept at the (R)DCs. It is used to meet sales orders instantly and replenishment is initiated before its depletion. For order-type products, no such stock is kept. Only after a real sales order is placed, the product is pulled from the production facility. These order-type products are often characterized by a low or lumpy demand pattern, which makes them financially unattractive to be kept on stock. As there are minimum quantity restrictions on transportation, stock of these products might however remain at the (R)DCs after the initiating sales orders are fulfilled.

DCs only get supplied by RDCs and not directly from production facilities. The main reason for this construction lies with the otherwise low quantity of products that uses such flow. At the RDCs, products from different sources destined for the same DC can be consolidated into lesser and cheaper shipments. This construction may lead to longer lead times, which has its drawback on supply chain performance. A DC is only supplied by one designated RDC: the one in which region it is located. For example the DC located in Spain is only being supplied by the RDC in France, of which the region is South-Europe.

Deliveries directly to the end customer take place on an occasional basis and are a very small percentage of the total supply flow. The major part of these direct deliveries are large orders or rush orders. The included portfolio of this supply group does not contain customer specific orders, which can otherwise also be a reason to decide for direct deliveries.

Each of the three production facilities can manufacture all the products that are in scope of the project. Although this implies that each facility can provide each RDC with a specific product, a RDC sources its products from a designated production facility. If this facility however is not able to supply the product (e.g. due to insufficient capacity), one of the remaining two can supply the RDC with identical products. These so called support deliveries are also used to level the capacity of the production facilities in accordance to the overall business strategy.

At the start of the project, several changes of the supply chain were under investigation. To conclude this section, we briefly describe these changes.

1] As industrial stock is not instantly commercially available, it cannot contribute directly to service level performance. Because of this, management is pushing the organization to eliminate industrial stock. To achieve this goal, a whole new replenishment strategy is developed and largely implemented throughout the organization. This replenishment strategy, called Integral Supply Planning, plays a major role within our research. We describe this strategy in detail in Section 2.6.2

2] Stock-type products that are characterized by a small demand mainly located at a specific RDC may be managed in the near future by a so called ‘Central Stock Distribution Point’-strategy. Within this strategy, the total manufactured quantity of a product flows directly to the RDC that sells the larger part of that product’s demand. At this RDC the product is kept as a stock-type product, while it replenishes the remaining (R)DCs as order-type products.

3] An RDC sources a specific product from a designated production facility. Currently, a project is in progress to eliminate this restriction. This enables a better utilization and synchronization of the overall production capacity of the supply group.

2.2.2 Supply group Halogen

The supply group Halogen has no company owned production facilities at its disposal. It sources the full portfolio of the project from external suppliers. These so called 'Buy-for-Resale'-products are all sourced from China. All sourcing activities from this country are managed by an internal sourcing agency located in Shanghai: the China Sourcing Group. It is at the Sourcing Agency were the flow of this supply chain starts.

At the beginning of our research, products went through the supply chain by using one specific supply flow. However, business management is considering the use of two other supply flows as well. We include both the current supply flow and the considered supply flows into our research. The outcomes of our analyses can provide business unit management with desired support in related decision making. Figure 4 displays a schematic overview of the three flows.

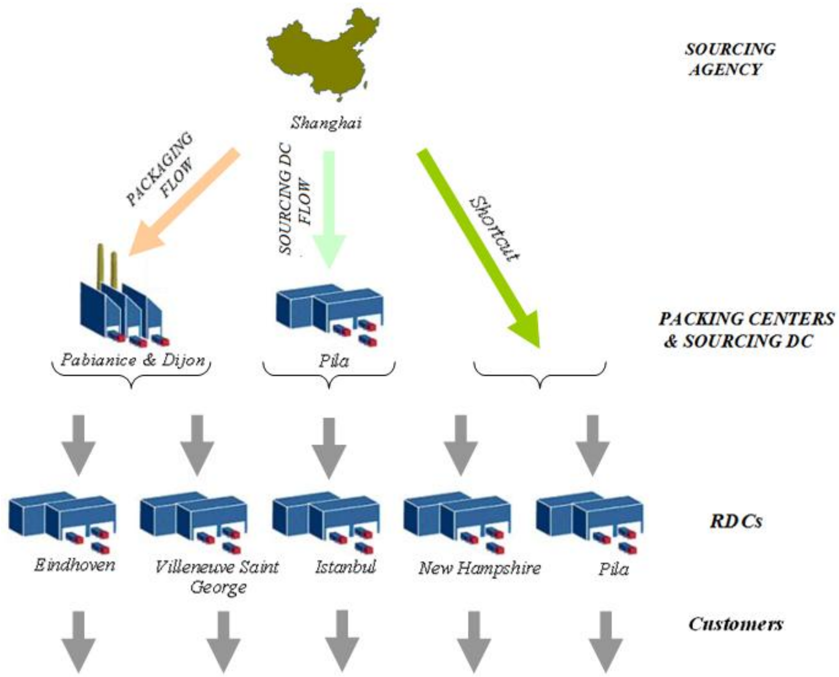


Figure 4: the different supply flows of Halogen

We describe these three different supply flows as follows:

> ***Sourcing DC Flow*:** This flow originates at the Sourcing Agency, goes successively through the Sourcing DC to the network of RDCs, from which the products are shipped to the end customer. Currently, this flow is the only one in use at the organization.
>
> ***Packaging Center Flow:*** This flow originates at the Sourcing Agency, goes successively through the Packaging Centers to the network of RDCs, from which the products are shipped to the end customer.
>
> ***Shortcut Flow:*** In this flow, products go from the Sourcing Agency directly through the network of RDCs, from which they are shipped to the end customer. This flow bypasses both the Sourcing DC and the Packaging Centers.

Reasons for the usage of the Sourcing DC were mainly the need for extra quality inspections for products from inferior countries. The consolidated flow from the Sourcing Agency to one single location in Europe made sourcing also easier and reduced transportation costs to Europe. Recently, the quality of sourced products has reached an acceptable level, which makes extra quality inspections redundant. Together with the pressure to eliminate industrial stock, this development brought the usefulness of the Sourcing DC under consideration. This is one of the main reasons for business unit management current interest in the benefits of the Shortcut Flow and the Packaging Center Flow. The Sourcing DC is used as a stock point similar to the production facilities; it replenishes the RDCs in an equal manner. Due to market conditions there are however no order-type products present in this supply chain.

The Packaging Centers enable shipping products from the Sourcing Agency to Europe that are only technically finished. At these facilities the products are stamped and packed, which are the last two steps of the production process. A technically finished product can be stamped and packed into numerous different finished products. By using Packaging Centers, not only the allocation of products to RDCs can be postponed, but also the allocation from a technical to a commercial finished product. The benefit of such postponement becomes larger when more different commercial products can be made out of one technical product. The benefits of using consolidated flows to a single location in Europe also remain when using a Packaging Center.

In the Shortcut Flow, both the Sourcing DC and the Packaging Centers are bypassed. RDCs are directly replenished from the Sourcing Agency. Such a supply flow gives no possibilities to postpone allocation or consolidate products from China to a single stock point. However, by bypassing these facilities, industrial stock is automatically eliminated from the supply chain and total lead times are reduced.

Until now, we did not elaborate on the lead times within both supply chains. To provide some basic background on the subject, we briefly describe them in this paragraph. All shipments between the European facilities are carried out by truck. Transportation between the facilities normally takes two to six days, mainly depending on the transportation interval and distance. Shipments from China are carried out by boat, which takes on average six weeks. As the products are of high volume / low value, shipping by air is no option. The time between order placement at the Sourcing Agency and actual transportation to Europe is around four to five weeks. For the production facilities, this takes between one and four weeks, mainly depending on the type of product (e.g. fast mover, slow mover). Section 2.7 describes the production characteristics and times in further detail.

2.3 Product and demand characteristics

For this research, we differentiate between technically and commercially finished products. Technically finished products are products that are ready-to-use but not yet stamped or packed. Commercially finished products are both ready-to-use and ready-to-sell. A technical identical product can be sold under different brands and in different packages (for linguistic, quantity, governmental, and commercial reasons). This implies that a technically finished product can be transformed into numerous commercially finished products. Whenever we mention the term product, we refer to a commercially finished product unless indicated otherwise.

As described in Section 1.4, we selected products from two different business units. The products belonging to the business unit Consumer Lamps Europe are Halogen products. They are sold mainly to the consumer market. The demand of this market is strongly affected by seasonality. Demand during the high season, approximately from September to January, can be up to almost two times the volume of months in the off-season. The amount of different packages for identical technical products is large in this market, as customers (retailers) often have specific requirements on packaging and brand (e.g. home brand). The selected product groups have a relatively stable market compared to other groups of this business unit.

The products belonging to the business unit Professional Lamps Europe are standard bulk TL-lamps. They are sold mainly to the professional European markets. They are also sold to internal customers (company owned luminaries factories) and exported to markets outside Europe. The demand of these products is less sensitive to seasonal influences, as they mainly find practical usage in offices and factories. Demand in the high season period is around fifty percent higher than the demand during the off-season months. As the professional markets are less interested in different packages and brands, the ratio between technically and commercially finished products is relatively smaller.

The professional market is more stable than the ‘faster’ consumer market, which is much more dynamic and is strongly influenced by for example promotional actions. Products that are not delivered on demand can often be backlogged in the professional market. In the, less forgiving, consumer markets it often results in lost sales. Therefore, required service levels are higher in the consumer market than the professional market.

2.4 Key performance indicators

Philips Lighting uses numerous performance indicators to measure and evaluate as good as every part of its supply chain. Two of these indicators lie at the heart of the organization and business unit management sees them as the key indicators to evaluate the overall performance in a brief and simple way. These indicators measure the stock level and service level. Both indicators, which are of high importance for our research, are described below.

Customer Requested Delivery Date (or CRDD)
The CRDD-indicator measures service level performance based on order line fulfillment. An order line is part of a sales order and contains a quantity of identical products with the same delivery date. When a customer places an order, he includes the date at which he wishes the products to be shipped from the (regional) distribution center. Within the organization, this date is known as the Customer Requested Delivery Date. The percentage of order lines that is shipped before or on this requested date gives the CRDD-performance level. Whenever we mention the term service level in our research, we refer to this measurement.

$$CRDD\,\% = \frac{\#\,order\ lines\ shipped\ on\ time}{Total\ order\ lines}$$

There are several reasons why an order line cannot be shipped on time and by this negatively influences the CRDD-performance. Within Philips Lighting, these reasons are divided into two groups: those that are sales office related (e.g. negative credit check) and those that are supply group related (e.g. no stock available). This project solely focuses on the latter. This implies that an order line is ‘missed’ when the full quantity of an order line is not timely available. The targeted CRDD-performance of the supply group TL/CFL-ni is 95%. That of the, more demanding, supply group Halogen is 98%.

Moving Annual Total % (or MAT%)
The stock level is measured and monitored intensively throughout the supply chain. Dividing the stock level of a period by the amount sold during the previous 12 months, results in the indictor that is most used and common amongst business unit management. This indictor is known as the ‘Moving Annual Total’-percentage.

$$MAT\,\% = \frac{\#\,goods\ on\ stock}{Moving\ Annual\ Total\ of\ goods\ sold}$$

Within the organization, there are also two other indicators commonly used to measure stock level performance. One measures the performance in so called stock turns. This is done by dividing the amount of goods sold over a period by the average stock level of that period. The other measure is called demand coverage. It calculates the time that the stock on hand can cover expected demand. Measuring the stock level by MAT%, stock turns, or demand coverage each has its own benefits. Within this project, the stock level is measured and evaluated in all three ways, largely depending on the specific demands as well as the preferences of the different persons involved.

2.5 Forecasting / medium term planning

For effective decision making in inventory management and production planning, a supply chain needs predictions (or forecasts) of the demands in future periods. At Philips Lighting, such forecast is called a Medium Term Plan. In this section, we briefly describe how this MTP is updated and used throughout the supply chain.

Sales offices carry the responsibility for the medium term planning process. They monthly provide the organization with their predictions of what they plan to sell in their own region. Each office does this per product separately per month for the upcoming eighteen months. As each sales office is linked to a fixed distribution center, the MTP-figures are consolidated based on these links. This consolidation gives the estimated demand per product per distribution center. Further consolidation gives the estimated demand at the level of the production facilities, Sourcing Agency, Packaging Centers, and / or Sourcing DC. Table 1 displays a part of a Medium Term Plan.

		Fiscal year/period	010.2007	011.2007	012.2007	001.2008	002.2008
			MTP	MTP	MTP	MTP	MTP
CAG	12NC	Plant	PCE	PCE	PCE	PCE	PCE
041010	928048003364	GB01	4.043	3.583	3.081	3.296	2.637
041010	928048003364	PE01	3.907	4.112	2.846	3.791	4.046
041010	928048003364	VS01	11.412	9.624	12.032	9.609	9.938

Table 1: part of a Medium Term Plan

The consolidated MTP-figures are very important to the organization. At RDC level, they support operational decision making regarding the deployment of products to the RDCs. They are also important input for calculations to determine and update replenishment parameters and setting operational stock targets. At the level of the production facilities, the MTP is used when making the operational production planning, when making decisions on production capacity and seasonal stock build-up, and to provide material forecasts and orders to suppliers.

The quality (or accuracy) of the MTP is highly important. It forms essential input to many decisions and unreliable MTPs have a strong negative influence on supply chain performance. The organization puts a lot of effort into the medium term planning process to get a good and reliable MTP. The realized forecast accuracy is also extensively measured. The formula mostly used within the organization for measuring forecast accuracy is displayed below:

$$Forecast\ accuracy = \frac{MTP - |\,real - MTP\,|}{MTP}$$

Within this formula, the real sales of a month are compared to the forecasted sales of that month, given a month earlier. Most products have forecast accuracies below 55% at the sales office level. The consolidation to the RDC or production facility level brings the accuracy to a level that is perceived as workable by the organization.

2.6 Supply planning

This section describes the policies that the organization uses to replenish the supply chains of this project. Section 2.6.1 describes the replenishment policies that were in use at the start of the project. Business unit management aims at replacing these policies by a new policy that better fits their view (e.g. be forecast driven) and the supply chain environment. Section 2.6.2 describes the replenishment policy that business unit management aims to roll out shortly after the start of our research. The outcomes of the project and the model need to be in line with this later policy. This implies that the philosophy behind and working of this policy is of high importance to our project, for which we elaborate on it more extensively.

2.6.1 Current policies

This section briefly describes the two replenishment policies that were in use at the start of the project. The organization uses the first policy to replenish the network of distribution centers. It uses the second policy for all sourced supply from the Sourcing Agency.

Order-point, order-quantity system

The most popular and mostly used replenishment policy of the project's supply chain is based on a so-called order-point, order-quantity system. In this system a fixed quantity is ordered whenever the inventory position drops to or below a chosen reorder point. Safety stock is included in the reorder point quantity to be able to realize the required service level. The policy is used to replenish all (regional) distribution centers from the production facilities, Packaging Centers, and the Sourcing DC. The organization sets reorder points and quantities by using simple formulas or rules of thumb. This policy has the benefit that it is easy to understand and to work with and that it provides mostly a reasonable outcome (although not optimal). As this policy is reactive, its performance deteriorates when used in less stable / predictable environments.

Materials requirements planning

To replenish products from the Sourcing Agency to the Sourcing DC, the organization uses a policy that can be best compared to a form of Materials Requirements Planning. Over the next periods of time a quantity of products is ordered based on the inventory position and the estimated demand. For this, a simple excel-file is used for the calculations instead of the advanced and more logical choice of the available SAP-software. By using such a concept, replenishment takes place based on deterministic instead of stochastic demand (e.g. no safety stock calculations). A sort of safety buffer is however in use. This buffer is not based on any mathematics, but only on the experience / insights of the concerned logistics planner.

2.6.2 Integral Supply Planning

The ongoing pursuit of higher management to further improve the supply chain of Philip Lighting resulted in the development and roll out of a new and advanced replenishment policy, called Integral Supply Planning. In this thesis, we abbreviate this policy as the ISP-policy. This policy is completely forecast driven. Replenishment is pushed through the supply chain based on relative (forecasted) inventory position of the different (R)DCs. Its key characteristics are:

Forecast driven	- Production and replenishment through the supply chain is based on forecasted demand instead of real sales orders. The Medium Term Plans, as described in Section 2.5, are used as input for this forecasted demand.
Push-strategy	- Replenishment is pushed through the supply chain instead of being pulled. Shipment to the RDCs takes place immediately after production. This eliminates industrial stock completely and makes all products available for sale and delivery to the end customer as soon as possible.
Pro-active	- The target stock levels, inventory levels, and replenishment orders are calculated for the whole medium term forecast period. This implies that for the next 18 months all supply chain information is available. It enables the system to proactively build up seasonality stock and to cope with future events such as production stops.
Integral knowledge	- Forecast information is available throughout the supply chain for the upcoming 18 months. This information is directly translated through the supply chain and gives all the production facilities, distribution centers, and suppliers a full transparent and similar view of the expected future demand over the medium term forecast period.

For business unit management, the most important characteristics of this policy are the elimination of industrial stock, which is in their philosophy not adding any value to the business, and the forecast / demand driven orientation.

Working of Integral Supply Planning at RDC-level

To get a sufficient understanding of the working of ISP at the lowest echelon, an insight in the buildup of the target stock level is important. A target stock level is based on the following three elements:

Demand (forecast and real)

As mentioned, the ISP-policy is forecast driven. This means that replenishment is based on expected rather than real sales. Forecast information, which is available for the upcoming 18 months, is divided into buckets. This system of so-called forecast buckets is one of the key assets of the policy. The buckets differ in size depending on their placement in time: the forecast of the next week is divided into day-size buckets, the forecast of the next 6 months is divided into week-size buckets, and the remaining forecast is divided into month-size buckets.

Whenever a sales order is placed, it reduces the size of the related forecast bucket with a quantity that equals that of the sales order itself. Because of this, the total quantity of the bucket and the sales orders together remains equal to that of the initial bucket. This implies that the total demand of the related period also remains equal. When a bucket is fully depleted, the policy starts reducing the size of an adjacent bucket. The system is currently set to let sales orders reduce the size of buckets in the range +/- 2 weeks of their own delivery date. Within the organization, this process is called forward and backward consumption. It is possible that all buckets within this range are fully depleted while a part of the sales orders' quantities are not met. In such case, the remaining quantity of the sales orders is add on top of quantity of the initial bucket. This raises the total demand of the related period, which results in a higher target stock level and consequently a higher replenishment request.

The main thought behind forward and backward consumption lies in the assumption that forecasted demand will probably not be met on the given date for sure, but more likely within a certain time interval. With the chosen time interval of +/- 2 weeks, it is assumed that forecasted demand will be realized within those five weeks. When all buckets of this time interval are fully depleted, the real demand must be higher than the forecast. Consequently, the target stock level and the replenishment must be raised to obtain the required service level.

Safety stock
Equal to other replenishment policies, safety stock is held at the locations to maintain a certain service level while coping with uncertainties in demand and supply. Within ISP, the safety stock parameter is given in days rather than in amounts. This means that when the safety stock is set at two days, the safety stock level equals the forecasted demand over the next two days. Such demand is derived from the demand forecast of the next month. This adaption to forecast levels makes the ISP-policy proactive. After all, when the forecasted demand alters, the absolute safety stock levels alter in unionism. Business unit management perceives this as a large benefit of the ISP-policy.

Safety stock levels are currently calculated based on the standard deviation during the lead time of historical demand. The organization sets the safety stock in days by dividing this amount by the average historical demand per day. As the philosophy of ISP is fully focused on forecast driven replenishment, we perceive this way of calculating safety stock levels as inappropriate. Since the policy replenishes on forecasted demand, the difference between forecasted and real demand is important, not the difference between real demand of various periods. Safety stock levels based on the standard deviation of forecast errors during lead times fits this policy better.

Target Days of Supply
Except for the demand and safety stock elements, the target stock level also contains the element Target Days of Supply. This element enables creating higher target stock levels manually and is used in practice to cope with temporary capacity shortages, seasonality buildup, and production stops. When for example a production stop for two weeks is planned, the Target Days of Supply in the weeks / months prior to this stop are set from zero to two weeks. At the start of the production stop, the target inventory level consists out of forecasted demand, safety stock, and additional stock that equal the forecasted demand for the next two weeks. This enables handling a production stop or other event in a smooth way. As ISP calculates the impact of all these figures for the whole upstream supply chain, the higher echelons (including suppliers) receive their forecasted demands based on these events automatically.

The target stock level is compared to the inventory position (inventory at hand + in transit) and a replenishment order is generated whenever the inventory position in a period (bucket) is below the target stock level.

Working of ISP at the production facility / Sourcing DC level

The replenishment orders from the RDCs are consolidated at the next echelon: the production facilities, Packaging Centers, and / or the Sourcing DC. These replenishment orders are created to maintain inventory positions that equal the target stock level for every time period of the upcoming 18 months.

Production takes place at the production facilities based on these replenishment orders. At the Sourcing DC, the replenishment orders are consolidated to one replenishment order to the Sourcing Agency. After production, the products are however not being shipped to the RDCs based on the initial replenishment orders, but on their current inventory position. This implies that the real allocation of the products only takes place after completing production. This is called postponed allocation of replenishment and, as becomes obvious in Chapter 3, has a large positive effect on the height of the stock levels necessary to obtain required service levels.

Whenever the realized production is not equal to the current demand from the RDCs, the replenishment is allocated based on the relative inventory position of each RDC. This implies that each RDC receives that amount of products that brings their inventory position to an equal percentage of the target stock level. This allocation holds to both a scenario of a surplus as well a scenario of shortage of products. The allocation-policy does not differentiate between real demand (sales orders) and forecasted demand. The thought behind this lies in the philosophy that forecasts are leading and forecasted demand will eventually become real sales.

Summary

The ISP-policy can be seen as a system in which replenishment takes place to bring inventory positions at the RDCs up to their target stock level. The system is periodical reviewed and performs the calculations per period for the upcoming 18 months. The target stock level consists out of forecasted demand, Safety Stock, and Target Days of Supply. Production is based on the replenishment orders and real allocation only takes place just before shipping. The real allocation is based on the relative inventory positions of each RDC.

2.7 Production planning

The production process and planning are important parts of a supply chain and can have large influences on the stock levels that are necessary to obtain certain service levels. As the supply group TL/CFL-ni has its own production facilities, it is important for this project's outcome that their main characteristics are taken into consideration. This section provides background information on these characteristics.

2.7.1 Capacity

The supply group TL/CFL-ni has three production facilities at its disposal, which are located in Poland, France, and the Netherlands. Each facility has several production lines available at which it can produce the full product range of the supply group. The products that are included in this project are however produced on a dedicated set of production lines. No other products are produced on these lines.

Sufficient production capacity is available to meet the total yearly demand. As indicated in Section 2.3, the demand is however not evenly balanced over the year but influenced by seasonality. There is a small capacity shortage during the high season and a larger capacity surplus during the off season. To cope with this imbalance between supply and demand, the organization builds up stock prior to the high season and reduces capacity in the off season. The build-up of stock also takes place prior to production stops (due to maintenance and holidays), whenever the remaining production lines are not able to meet the full demand by themselves. We call the stock that is necessary to cope with seasonality and production stops anticipation stock. It has a large impact on average stock and service levels.

The supply group Halogen sources all its products from the Sourcing Agency. For this research, we assume that no related capacity restrictions are relevant to the project.

2.7.2 Production wheel

Production at the supply group TL/CFL-ni is characterized by set-up costs that differ largely based on the type of changeover. The costs of a changeover to a product of the same length are small, while the costs (and time) of a changeover to a product of another length are very high. Because of this, the organization plans products together based on length. These different lengths are planned in a fixed sequence and time schedule, which is internally called a production wheel. Table 2 displays an example of such a production wheel with a sequence of four weeks. After week four, the sequence is repeated.

		week			
		1	2	3	4
length	y1	x		x	
	y2		x		x
	y3		x		
	y4	x			
	y5	x	x	x	x
	y6			x	

Table 2: Example of a production wheel

The production wheel at the Dutch production facility has a length of four weeks. The other two production facilities have production wheels of two weeks. Due to these constraints, some products can be replenished every week, while other products can only be replenished every two or even four weeks. As this implies larger review times, it has a negative impact on the stock levels necessary to obtain required service levels. Production wheel related constraints are not present at the Buy-for-Resale flow from the Sourcing Agency to the Halogen groups.

2.7.3 Minimum quantities

Two types of minimum quantities are in use within the supply chain flows of this project: minimum order quantities and minimum production quantities. The organization uses these to minimize the total costs of production, transportation, and holding.

Minimum order quantities are used when replenishing the RDCs and the Sourcing DC. Earlier studies of Philips Lighting showed that it is not cost efficient to replenish a product to a RDC more than once a week. As a result, most minimum order quantities are set to an amount that roughly equals the average weekly demand of a product rounded up to an easy to handle packaging configuration (e.g. box, layer, or pallet).

Minimum production quantities are in use at the Packaging Centers and the production facilities and differ per product and location. These quantities are a result of earlier studies based on set-up and holding costs and production wheels. A minimum production quantity at a production facility can be, and often is, much larger than the related minimum order quantity at an RDC. Whenever a consolidated replenishment order of a product from the RDCs to a production facility is smaller than the minimum production quantity, the latter is produced. The ISP-policy allocates the whole production to the total set of RDCs. This allocation takes place in such way that each RDC receives that amount of products that brings its inventory position to an equal percentage of its target stock level in relation to the other RDCs.

Based on the experience of this project's participants as well as the outcomes of other Philips Lighting projects, we expect a large impact on stock levels from the minimum production and order quantities currently used in practice.

In this chapter, we described the supply chain under study. We elaborated on the organization, the supply chain concept & flows, relevant key performance indicators, forecasting methods for demand, product portfolio & demand characteristics, replenishment policies, and relevant production related topics such as the production wheel. Overall, this provides the background information required to understand and evaluate the choices made during this project with respect to model building and analyses. By this, we answered research question 1 as described in Section 1.5.

Chapter 3 Theoretical framework

In this chapter, we provide an overview of theories and methods within the field of Inventory Management that are relevant to our research. As stated in the research design, we derive the model based on the outcomes of this literature study combined with the supply chain characteristics described in Chapter 2, and our own insights.

In Section 3.1, we elaborate on the four policies most commonly used to replenish stock. The next sections zoom in on key aspects by which these policies can be extended. Section 3.2 provides insights in the multi echelon environment and various rules to allocate stock to distribution centers. In Section 3.3, we elaborate on stochastic demand distributions. Section 3.4 describes differences between steady state and non-steady state systems. In Section 3.5, we study adapting demand distributions to time-varying demand. Section 3.6 concludes the chapter with describing different ways to measure service objectives.

3.1 Basic replenishment policies

The supply chain under study is subjected to stochastic demand patterns. In accordance, this implies that we must also focus our literature study on stock replenishment control systems with stochastic demand. The fundamental purpose of such control system is to resolve three main issues:

1) How often should the inventory position be determined
2) When should a replenishment order be placed
3) How large should the replenishment order be

To respond to these three fundamental issues, we need to find answer the following two main questions:

a) Which the inventory policy should be chosen?
b) What specific service object should be set?

In this section, we elaborate on both questions. We study various existing basic policies to replenish a stock point as well as different service objects that management can set. According to Silver, Pyke, and Peterson [1998], there are four basic inventory control policies for replenishment based on stochastic demand patterns. Next, we describe these four along with some advantages and disadvantage of each. Our discussion of the latter will be rather general, as it depends on the specific environment in which the policy is used. First, we explain important terminology related to the categorizing of inventories:

On-hand stock is stock that is physically on shelf; it can never be negative. This quantity is relevant in determining whether customer demand can be directly satisfied from the shelf.

Inventory position = (On hand) + (On order) – (Backorders) – (Committed)
On-order stock is stock that has been requested but not yet received by the stock point under consideration. Committed stock is stock that cannot be used for other purposes in the short run (e.g. already sold and to be delivered at a later date).

Net stock = (on hand) – (Backorders)
This quantity can become negative when there are backorders.

Safety stock is defined as the average level of net stock just before replenishment arrives. A positive safety stock provides a cushion or buffer against larger-than-average demand during the effective replenishment lead time. Choosing safety stock levels is the key to achieving targeted service levels in a stochastic demand environment.

The four basic stock replenishment policies are:

Order-Point, Order-Quantity (s, Q) system
This is a continuous review system. This implies that the inventory position is always known and acted upon accordingly. A fixed quantity *Q* is ordered whenever the inventory position drops to or below the reorder point *s*. The inventory position, and not the net stock, is used to trigger an order. Because it includes the on-order stock, it takes proper account of products requested but not yet received from the supplier. Advantages of this policy include: it is simple to understand, errors are less likely to occur, and production requirements are predictable for the supplier. The primary disadvantage of this policy is its limited ability to effectively cope with situations of large individual transactions.

Order-Point, Order-Up-to-Level (s, S) system
This system also assumes continuous review. Replenishment is made whenever the inventory position drops to or below the reorder point. However, in contrast to the previous policy, a variable quantity is ordered to raise the inventory position to the order-up-to-level *S*. This policy can be seen as a sort min-max system because the inventory position remains between a minimum value *s* and a maximum value *S*. The best (s, S) system has lower total costs of replenishment, holding, and shortage than the best (s, Q) system. One small disadvantage of this system is the variable order quantity, as suppliers often prefer the predictability of a fixed order quantity.

Periodic-Review, Order-Up-to-Level (R, S) system
This is a periodic review system, which implies that the inventory position is reviewed every R units of time. At each review moment, a replenishment order of a variable quantity is made to raise the inventory position back to the order-up-to-level. Because of the periodic review property, this system is much preferred to order point systems in terms of coordinating the replenishment of related products. The coordination afforded by a periodic review system can provide significant savings. In addition, the (R, S) system offers a regular opportunity (every R units of time) to adjust the order-up-to-level. This makes it better suitable to deal with demand patterns that change over time. The main disadvantage of the system is that its carrying costs are likely to be higher than that of continuous review systems.

Periodic-Review, Order-Point, Order-Up-to-Level (R, s, S) system
This system is a combination of (s, S) and (R, S) systems. The inventory position is checked at each review moment. If it is at or below the reorder point, a variable quantity is ordered to raise the inventory position to the order-up-to-level. It can be shown (Scarf, 1960) that, under quite general assumptions concerning demand pattern and cost factors involved, the best (R, s, S) system produces a lower total cost of replenishment, holding, and shortage than any other

system. However, the effort to obtain the best values of the three parameters is more intense than that for other systems. This system is also more difficult to comprehend than the other mentioned systems.

When demand is stochastic, there is a chance of not being able to satisfy some of the demand directly out of stock. If demand is unusually large, a stock out may occur. On the other hand, if demand is lower than anticipated, replenishment arrives earlier than needed and excess inventory is carried. Managers have different perspectives on how to balance these two types of risks. The selection of parameters in the discussed replenishment policies depends strongly on the objectives or targets set by management. Silver et al. [1998] describes three possible service objectives:

1) **Safety stocks based on minimizing total costs**
   The idea behind this approach is to minimize the total costs of replenishment, holding inventory, and shortage. Although very popular, this approach has the difficulty of assigning costs to shortages. As these costs are often assigned subjectively, optimal parameter setting based on this objective may become open for debate.

2) **Safety stocks based on service level**
   The idea behind this approach is that service level becomes a constraint in establishing the safety stock level of products. For example, minimize the stock levels of a product subject to satisfying a chosen percentage of all demand from stock. There is a considerable choice in the selection of service measurement. Consequently, what management exactly perceives as service level has a large impact on minimum required stock levels. Section 3.6 elaborates on various ways to measure service level performance.

3) **Safety stocks based on aggregate considerations**
   The idea behind this approach is to establish safety stock levels of individual products, using a given budget, by providing the best possible aggregate service across a complete product group. The selection of individual safety stocks is meant to keep the total holding costs as low as possible while meeting a desired aggregate service level.

So far, we have discussed the basic policies to replenish stock and several approaches to set service objectives. Each of the policies assumes a single stock point environment. The supply chain under study contains multi echelons with multi stock points. The stock points interact with each other and stock allocation is based on their relative inventory position compared to each other (see Section 2.6.2). For this, we study available literature on the allocation of replenishment in multi echelon environments in Section 3.2. In stochastic environments, the way in which uncertainty is estimated is essential to the quality of supply chain performance. Therefore, we address Section 3.3 to common ways of estimating demand uncertainty. The basic policies also assume environments in which no time-varying changes occur (e.g. on forecast or capacity). In our research, we must assume that time-varying changes do occur, as our research is focused on establishing stock targets on medium term time intervals. In Section 3.4, we elaborate on these so called non-steady state environments. In Section 3.5, we study the impact of adapting demand uncertainty estimations to time-varying average demand.

3.2 Multi echelon & stock allocation

As described in Chapter 2, the supply flows under study have multiple echelons, except for the Shortcut flow. Each of these flows can be seen as a two layer system. The top layer contains a production facility, Packaging Center, or the Sourcing DC. The bottom layer contains the set of regional distribution centers. Replenishment of a specific product from the higher to the lower echelon is always done by a designated facility. According to Silver et al. [1998], this type of supply flow can be described as a *two-echelon divergent system*. Consequently, we focus our literature study on this type of system. In this section, we describe different options for the system and various related decision rules.

Local versus integral control

Inventory control in multi echelon environments can be performed by local or integral systems. Based on van der Heijden and Diks [1999a], we briefly address both. In a local system, only the information available at a single stock point is used to set control parameters and determine stock allocation. Local systems aim at optimizing performance of a single location, regardless of its influences on that of others. Integral systems use all information available throughout the supply chain. Integral systems aim at optimizing (and balancing) the performance of the whole supply chain. Van der Heijden and Diks [1999a] prove that an integral system always perform at least equal, and often far superior, to a local system. The differences in performance between both systems relate strongly to the locations that stock is allowed to be placed, the possible benefits of postponing allocation of replenishment, and the rules by which stock is allocated when confronted with supply shortages.

Central versus no central stock

We differentiate between systems that allow holding stock at the higher echelon and those that do not allow it. In the latter, the higher echelon facility acts as a “break-bulk” facility. It orders goods in bulk, and upon receipt, breaks it into smaller amounts for immediate shipment to the stock points of the lower echelon. Silver et al. [1998] and Van der Heijden and Diks [1999a] provide various methods for calculating optimal stock levels for both central and non central stock two echelon divergent systems. They prove that a system that allows holding central stock always performs at least equal to a system that forbids central stock. The difference in performance between both relates strongly to the magnitude of demand uncertainty and lead times between the echelons. Larger demand uncertainties and shorter lead times are beneficiary to holding at least some stock at the higher echelon.

Postponed allocation of replenishment

Replenishment orders generated by the individual local stock points are combined at the higher echelon facility. When central stock is available at this facility, corresponding quantities are immediately shipped as replenishment. When no such stock is available, replenishment orders are consolidated and forwarded to the supplying entity. When this quantity arrives, the question of stock allocation arises. After all, the relative inventory positions of individual stock points have altered in the mean time. Based on Van der Heijden et al. [1999b], we differentiate two main strategies:

No postponement	Local stock points are replenished based on their initial replenishment orders.

Partial postponement Local stock points are replenished based on their actual relative inventory positions instead of their initial orders.

Partial postponement implies that the allocation of stock to the local stock points is postponed until a moment later in time, preferable until just before shipping. It consolidates a part of local demand uncertainty at the aggregate level, which is the key benefit over a no postponement strategy. This part corresponds to the time between the placements of replenishment orders by the local stock points and the allocation of stock to these stock points. We refer to this as the shared lead times of the local stock points. This, so called risk pooling, is a main contributor to the superior performance of integral systems over local systems. Benefits of partial postponed allocation get larger when:

1) The number of local stock points gets larger.
2) The local demand uncertainty gets higher.
3) The shared lead time gets longer.

A special case of partial postponement arises when the higher echelon facility can perform a product altering process. In such case, the local stock points order replenishment of a final product, the higher echelon facility orders semi finished products at its supplier, converts these into final products, and ships the final products to the local stock points. In this case, there are two moments at which allocation can be postponed: 1) allocation from semi finished to final products and 2) allocation from final products to the local stock points. The former has shared lead times equaling the time from placing replenishment orders up till allocating semi finished products to final products. The latter has shared lead times equaling the time from converting to final products up till the moment before shipping to the local stock points. In such case, the benefits from partial postponement get also larger when:

4) The number of specific final products in which a semi finished product can be converted to gets larger.

Allocation rules

When applying a partial postponement strategy, stock is allocated to local stock points based on their relative inventory position. In such case, and also when supply shortages or surpluses occur, one must decide how to allocate stock to the local stock points. Van der Heijden and Diks [1999a] describe five options:

1) First fill all backorders and next fill the replenishment orders from the local stock points in the order of arrival (First Come, First Serve).
2) Allocate the available stock to the local stock points using fixed allocation fractions, for example based on the average demand per period.
3) Allocate to all local stock points equal fraction of their replenishment order sizes.
4) Allocate stock based on balanced customer service levels, i.e., try to raise the local inventory positions such, that the degree by which service level objectives will be met are balanced equally over the local stock points.
5) Allocate such, that the total relevant costs, consisting of holding and shortage costs, are minimized.

In this section, we elaborated on the available literature for multi echelon environments. We studied two echelon divergent systems, as the supply flows under study can be classified as such. Based on the outcomes of our study, we can select methods appropriate to our research by asking four related questions:

1) Is inventory controlled locally or integrally?
2) Is central stock allowed?
3) Can allocation of replenishment be partially postponed?
4) Which allocation rule is used when supply shortages or surpluses occur?

3.3 Stochastic demand distributions

The supply chain under study is subjected to demand uncertainty. As described in Section 2.6, the organization aims to cope with this uncertainty by creating safety stocks at the local stock points. A good estimation of the demand distribution is essential for reliable outcomes, as it has major impact on safety stock calculations. Most estimators used in practice are based on demand distributions during the lead time of historical demand or forecast error. We briefly describe both:

Historical demand Estimating the demand distribution based on historical demand is the best known and most commonly used basis for choosing safety stock parameters. Its easiness to comprehend and calculate is the main contributors to its popularity. Its suitability deteriorates rapidly when demand patterns become less stable or are more subjected to trends. Being based on historical data, it has a fully reactive nature. This implies that it should only be used in reactive replenishment policies. Silver et al. [1998] describe the related basic formula, based on a normal distribution, as follows:

$$MSE = \frac{1}{m}\sum_{t=1}^{m}(D_t - {\textstyle\sum_{t=1}^{m} D_t}/_{m})^2 \qquad\qquad \sigma = \sqrt{MSE}$$

<u>*Notations:*</u>
t = time interval index (every interval of historical period) *MSE = mean square error*
σ = standard deviation of demand *D_t = real demand in interval t*

Forecast error The forecast error is based on the distribution between real and forecasted demand over a historical period. Its adaptive nature is its main advantage. When applied in policies that actively use forecasted demand, for example when using it as input to determine order-up-to-levels, safety stock levels will alter in unionism with the demand forecast. This makes demand estimations based on forecast error more suitable in unstable or trend subjected environments. Using this approach requires extra efforts, as the usefulness of a forecast error as a demand estimator deteriorates rapidly when the quality of the forecast declines. Silver et al [1998] describe the related basic formula, based on a normal distribution, as follows:

$$MSE = \frac{1}{m}\sum_{t=1}^{m}(D_t - E[D_t])^2 \qquad\qquad \sigma = \sqrt{MSE}$$

<u>*Notations:*</u>
t = time interval index (every interval of historical period) *MSE = mean square error*
E [D_t] = forecasted demand in time interval t *D_t = real demand in month t*
σ = standard deviation of forecast error in demand

In the formulas described above, we assumed that demand (or forecasts error) is normally distributed. Other distribution types might be more suitable as basis for demand uncertainty estimators. The selection of an appropriate distribution type has a major influence on the performance of the replenishment policy. Safety stock levels based on inaccurate estimations of demand patterns (or forecast errors) cannot obtain service objectives in an optimal matter in the long run. Next, we describe two most commonly used distribution types for estimating demand patterns: normal distribution and gamma distribution. We refer to Silver et al. (1998) for an extensive overview of other distributions and related literature studies.

Normal distribution This distribution often provides a good empirical fit to the observed data, it is convenient from an analytic standpoint, and the impact of using other distributions is normal quite small, see for example Fortuin [1980] and Tyworth and O'Neill [1997]. However, the larger the ratio between the standard deviation and average demand gets, the higher the probability of negative values of demand. This leads to underestimating necessary safety stock levels. According to Silver et al. [1998], whenever this ratio is larger than 0.5, a distribution other than normal should be considered. However, as long as this ratio is less than 0.5, the normal distribution is probably an adequate estimation.

Gamma distribution This distribution often provides a good fit when the demand distribution (or forecast error) is skewed to the right or the ratio between the standard deviation and average demand is larger than 0.5. Two parameters are required when using this distribution type: α and β. Silver et al. [1998] derive both parameters from the standard deviation of a normal distribution by using the following formula:

$$\alpha = \frac{D(L+R)^2}{\sigma[X]^2} \qquad \beta = \frac{\sigma[X]^2}{D(L+R)}$$

<u>*Notations:*</u>
σ = standard deviation of demand or forecast error *L = total lead time*
D = forecast demand *R = review period*

In this section, we elaborated on available literature on stochastic demand distributions. We addressed the estimation of demand uncertainty based on historical demand and forecast error. Also, we described the two best known and most useable distribution types for estimating demand uncertainty. Based on this section, we can select methods appropriate to our research by asking two related questions:

1) Is the demand uncertainty estimation based on historical demand or forecast error?
2) Which distribution type approximates demand uncertainty or forecast error best?

3.4 Non-steady state systems

So far, we focused our literature study solely on so-called steady state systems. These systems assume supply chains and stochastic demands that do not vary over time. A key element of our research goal is that the model must be oriented on the medium term time interval (see Section 1.5). Consequently, the model needs to cope with time-varying data such as changing forecasts and capacity availability. This implies that a steady state model cannot suffice. For this, we now consider study non-steady state systems. According to Silver et al. [1998], an exact analysis of time-varying and stochastic demand is too complicated for routine use in practice. Therefore, they advice the use of heuristic approaches in which the replenishment parameters such as R, s, and S (see Section 3.1) are recalculated for each time interval. Next, we describe two of these approaches:

> **Kaufman [1977]** developed an approach that calculates replenishment parameters in a particular time interval using the demand (forecast) information over the immediately next interval of duration Review + Lead Time, while still using an underlying steady state system. Basically, they use existing methods for steady state systems in which they calculate the related parameters for each interval. This approach is easy to comprehend and to apply, as it can be used with every steady state system. Tests, conducted by Kaufman [1977], proved that this approach performs quite well.
>
> **Bollapragada and Morton [1993]** developed a myopic approach that is very fast and accurate. Their heuristic involves pre-calculating replenishment parameters for various values of mean demand. Next, they average the non-stationary demand over an estimate of the optimal time between replenishment orders (obtained from methods for steady state systems). In essence, they also approximate a non-steady state system by a steady state system. They state that this approach is easy to implement, but should be avoided if demand is expected to decline or rise rapidly.

Both approaches use methods for steady state systems to deal with time-varying changes in demand. However, they do not elaborate on time-varying changes in available capacity of the supplying entity. The supply chain under study is subjected to such restrictions, as capacity at the production facilities is limited (see Section 2.2.1). This implies that demand rates can expected to get higher than available capacity at moments in time. This leads to shortages of supply, and a drop in performance of the service objective, when no additional stock is placed a priori. Although methods coping with capacity restrictions in a deterministic environment are available, we did not found such methods for stochastic environments.

Above, we described two heuristic approaches to approximate the non-steady nature of our research environment by steady state methods. Although both approaches cope with time-varying changes in demand, neither they nor the other studied methods are capable of coping with capacity restrictions at the supplying entity. This implies that, to obtain a key objective of our research, we must develop an approach ourselves to include capacity restrictions.

3.5 Time-varying demand uncertainty

In Section 3.4, we addressed the time-varying nature of our research environment. We derived that assuming a steady state system cannot suffice when the research focus lies on the medium term. The same applies to estimating stochastic demand variations. As the average demand rate (or forecast) changes over time, the standard deviation σ of demand (or forecast error) will also vary. This implies that using a fixed σ with a changing demand (or demand forecast) may result in wrong estimations of safety stock levels necessary. In this section, we study appropriate ways for estimating σ in time-varying environments.

An appealing approach is to assume that the standard deviation of demand or forecast error at a specific time can be estimated by calculating the related standard deviation over the next interval of duration Review + Lead Time. In other words, assume that $\boldsymbol{\sigma_{t,t+R+L} = \sigma_{R+L}}$. However, Silver et al. [1998] prove that this assumption cannot be used as an appropriate estimation for the problem. Bollapragada et al. [1993] describe a pragmatic approach in which the standard deviation is assumed have in a constant ratio with the mean. In other words, when demand (or demand forecast) over the immediately next interval of duration Review + Lead Time rises with a factor x, the related standard deviation rises with this same factor. We mathematically describe this assumption as $\boldsymbol{\sigma_{t,t+R+L} = C\, X_{t,t+R+L}}$ where $\boldsymbol{X_{t,t+R+L}}$ is the forecast, made in period t, of total demand over the next Review + Lead Time period, and C is the constant ratio. Bollapragada et al. [1993] prove that using the ratio between the historical forecast error and average forecasted demand as the constant ratio C provides a good fit to most situations.

In our further research, we will often use the terms correlation variant and adapting sigma. As both terms relate to demand estimation in time-varying environments, we define these terms in this section:

Correlation Variant The ratio between the standard deviation of historical demand and the average historical demand *or* the ratio between the historical forecast error and the average historical demand forecast. The correlation variant is used as the constant ratio C in the formula described above. We can calculate a correlation variant for each product at each location separately.

Adapting Sigma The standard deviation on demand or forecast error that adapts to the time-varying environment. In other words, when the demand or forecast over a next period alters, the sigma alters as well. The adapting sigma is based on the correlation variant on demand or forecast over the interval of duration Review + Lead Time. This adapting sigma can be calculated for each product at each location at each time interval.

3.6 Measurement of service objectives

In Section 3.1, we described three different service objectives for supply chains. The selection of parameters in replenishment policies depends strongly on the type of objective and the way the objective is measured. In this section, we elaborate on different ways to measure service objectives. Silver et al. [1998] describe several measurements per objective as follows:

1) **Safety stocks based on minimizing total cost** The idea behind this approach is to minimize the total costs of replenishment, holding inventory, and shortage.

   a) ***Specified fixed cost (B_1) per stock out occasion***
      This measurement assumes that the only cost associated with a stock out occasion is a fixed value B_1, independent of the magnitude or duration of the stock out.

   b) ***Specified fractional charge (B_2) per unit short***
      This measurement assumes that a fraction B_2 of the value of a unit is charged per unit short.

   c) ***Specified fractional charge (B_3) per unit short per unit time***
      This measurement assumes a charge B_3 per unit short per unit time.

2) **Safety stocks based on service level** The idea behind this approach is that service level becomes a constraint in establishing the safety stock level of products.

   a) ***Specified probability (P_1) of no stock out per replenishment cycle***
      P_1 is the fraction of replenishment cycles in which a stock out does not occur. A stock out is defined as an occasion when the on-hand stock drops to the zero level. P_1 is often called the cycle service level.

   b) ***Specified fraction (P_2) of demand to be satisfied from shelf***
      This measurement is often called the fill rate service level. It is the fraction of customer demand that is met from shelf.

   c) ***Specified fraction of time (P_3) during which net stock is positive***
      This measurement is often called the ready rate service level. It is the fraction of time during which the net stock is positive; that is, there is some stock on the shelf.

3) **Safety stocks based on aggregate considerations** The idea behind this approach is to establish the safety stock levels of individual products, using a given budget, to provide the best possible aggregate service across a complete product group.

   a) ***Allocation of a given total safety stock amongst different items to minimize the expected total stock out occasions per year***

   b) ***Allocation of a given total safety stock amongst different items to minimize the expected total value of shortages per year***

This chapter provided an overview of theories, methods, and principles within the field of Inventory Management that are relevant to our research. We elaborated on the four basic replenishment policies, the multi echelon environment, various rules to allocate stock, stochastic demand distributions, non-steady state systems, the impact of time-varying demand, and different ways to measure service objectives. This gives us the required theoretical background. By this, we answered research question 2 as described in Section 1.5. Combined with the supply chain study of Chapter 2, we obtained the information needed to develop the mathematical model and to successively analyze the supply chain.

Chapter 4 Model development

In this chapter, we describe a model to calculate optimal tactical stock levels. We derive the model based on the outcomes of the literature study, supply chain characteristics, and own insights. At the end of this chapter, we realized the first part of our research goal (see Section 1.3). First, we describe the requirements the model must meet to gain acceptance of the business unit management in Section 4.1. Next, we built the basis of the model in Section 4.2 by selecting appropriate methods and theories from literature. In Section 4.3, we elaborate on the outcomes of Section 4.2 from a mathematical perspective and present a formal description of the model. Section 4.4 is devoted to the heuristics we developed to cover parts of the requirements for which no existing methods or theories are available. We describe the full set of input and output parameters of the model in Section 4.5. This provides a more thorough understanding of its complexity and contributes to its reproducibility In Section 4.6, we elaborate on the differences in the calculations of the model for the various supply flows. Section 4.7 addresses the expected influences of assumptions made on the quality of the model's outcome. Finally, Section 4.8 describes possibilities to further extend the model to increase its accuracy or increase the insights into the characteristics of the supply chain.

4.1 Model requirements

This section describes the requirements that the model must meet to get accepted by business unit management. The requirements are based on the insights, the theoretical knowledge, and the operational understanding of the business unit management and other participants in our research. Next, the requirements are described:

Bottom-up / characteristics at operational level
The most important requirement is that the model is bottom-up built. In other words, that the model uses characteristics and calculations of the lowest possible level: the product / location level. Successively, the model must consolidate these outcomes to the product group level to get the results available at the required tactical level.

Service level
Together with the stock level, service level is the most important supply chain performance indicator used within the organization. The requested service levels must be used as a fixed, independent parameter. Within the organization, service levels are calculated based on order line fulfillment (see Section 2.4). For this model however, business unit management decided that service level calculation based on unit fulfillment would suffice (the P_2-measure; see Section 3.6).

Rolling horizon
In the dynamic supply chain environment under study, stock level calculations based on a single point in time, or steady state, is of negligible value. A key asset of the model must be that it calculates stock levels for the periods to come based on forecasted changes (e.g. supply capacity and demand forecast). The model must provide weekly outcomes for the next 18 months (the length of the medium term forecast).

Replenishment policy

The model must be based on the new replenishment policy rolled out throughout the organization: Integral Supply Planning. Several key characteristics must be included in the model (see Section 2.6.2):

- Replenishment is initiated to bring the inventory position in line with the targeted inventory position.
- The targeted inventory position is calculated based on demand forecasts, safety stock, and a third parameter used to cope with supply shortages.
- Orders for replenishment are consolidated at the higher echelon
- Replenishment is allocated after production based on the actual relative inventory positions
- Available stock is pushed to the lowest echelon.

One key characteristic is not included: forward & backward consumption.

Supply flows

The model must cope with the different supply flows of the supply chain under consideration (see Section 2.2). For the supply group TL/CFL-ni, only the main supply flow is included (from the production facilities to the network of RDCs). The other two supply flows are mimicked as equal. For the supply group Halogen, all three described supply flows must be included. This is because, business unit management is eager to compare the impact of using different flows on the possible stock levels of sourced products.

Demand forecast

The model must be based on the demand forecasts at the lowest echelon for the upcoming 18 months. This means that the model must deal with a changing demand forecast for different periods in the time ahead. Demand forecasts are available at the month / product / RDC-level. They are split in equal weekly forecasts to fit the model's requirement to calculate stock target levels on a weekly basis.

Forecast accuracy

The uncertain difference between forecasted and realized demand is the main contributor to the need for safety stocks within the organization. Because of this importance, forecast accuracy must be included in the model. The forecast accuracy should be determined at the lowest echelon level (product / RDC).

Lead times

Lead times must be included in the model as they have a major impact on the stock levels necessary to realize the requested service levels. They differ largely based on the supply flow and location of the facilities used. To be able to include the partial postponement part of the ISP-policy into the model, lead times must be broken up in three different types: 1) production / procurement times, 2) waiting before shipment time, and 3) transportation times.

Production Cycle / Wheel

Within the supply group TL/CFL-ni, production is bound to a so-called production wheel, which means that a product can only be produced at given time intervals (see Section 2.7.2). The model must be able to deal with this constraint for every product separately. For the supply group Halogen, no such constraint is present; production / review time is equal for all products.

Minimum production / order quantities

Every product within the organization has minimum quantities for production, ordering, and shipping. These quantities can be very large in comparison to demand. This implies that they also can have a large potential impact on stock levels. Business unit management expects minimum production quantities at the production facilities and package centers and minimum order quantities at the Sourcing Agency cannot be neglected. Because of this, the model must be able to include these minimum production and order quantities.

Supply capacity

The production facilities of the supply group TL/CFL-ni are subjected to capacity restrictions, reallocations of equipment, planned production stops, and seasonal demand patterns. As a result, they are not capable of always meeting the demand in time. To cope with expected supply shortages, sufficient stock must already be available within the supply chain to guarantee requested service levels. The model must include this and must build up the target stock levels accordingly in the preceding periods. Within this project, we refer to this type of stock as anticipation stock, as it is in place in anticipation of further events related to the demand / supply synchronization. For the supply group Halogen, no supply capacity has to be included in the model; the Sourcing Agency is seen as having infinity supply capacity.

Analysis

The model must provide business unit management with a mean to analyze the current situation through different angles as well as different scenarios. To support this, the model must provide the following data on a weekly basis: service levels, stock levels, and capacity utilization. This data must be available at different consolidation levels: on product / RDC-level, on RDC / supply flow level, and on the whole product group level. Further, the target stock level must be split-up between the different reasons for which the stock is necessary: cycle stock, safety stock, minimum quantity stock, and anticipation stock. The model must also provide the goods in pipeline and goods in transit levels.

We and business unit management are convinced that, by meeting the requirements stated above, the model can lead to a reliable bottom-up built way to calculate tactical stock levels. This means that, by achieving a model according to this set of requirements, the first goal of our research is met. One might argue that more requirements can or should be added to the model to make it more realistic / accurate (e.g. lead time uncertainty). Although this is certainly true, we and business unit management share the opinion that the described set of requirements is sufficient to meet the research goal.

4.2 Model selection

This section describes the creation of the basic model. We develop the model by selecting methods and theories from the literature that fit the supply chain characteristics and the model requirements. During the literature study, we did not find a mathematical model that fits the set of stated requirements properly. With this in mind, the challenge is to develop such a model ourselves by starting with an appropriate basic inventory model and extend it step-by-step to include the complete set of additional requirements. In this section, we first select our basic inventory control model. Next, we extend this model by selecting multi echelon and partial postponement features. We choose appropriate estimators for demand uncertainties and select ways to let the model cope with time-varying medium term environments. In Section 4.3, we describe the model in mathematical terms and formulas. As two requirements (related to quantity and anticipation stock) are not in the model description of Section 4.3, we include these requirements by developing heuristic approaches based on our own insights and theoretical knowledge. We elaborate on them in Section 4.4. In our further research, we refer to these approaches as add-ons to the basic model.

4.2.1 Basic inventory control policy

The model must be based on the new replenishment policy rolled out throughout the company: Integral Supply Planning. In this policy, RDCs place replenishment orders for products to raise their inventory position to the target inventory position. This characteristic is in line with order-up-to-level parameters as described in Section 3.1. As production is subject to so-called production wheels, there is a review period that equals the time interval between two possible moments to make a product. For supply that flows from the Sourcing Agency, replenishment orders can only be placed once a week. This implies that both can be classified as having a periodic review restriction. Further, the ISP-policy uses no reorder points or fixed quantities.

When combining the above, we conclude that the ISP-policy has two characteristics that relate to the basic inventory control policies: 1) order-up-to-level and 2) periodic review. Based on these characteristics, one of the basic inventory control policies may be useable: *a periodic-review, order-up-to-level (R, S)-system.* As described in Section 3.1, the pro-active nature of this policy makes it very suitable for choosing safety stock and order-up-to-levels based on demand forecast. This implies that the policy also meets the requirement of being forecast driven. With the service level requirement based on unit fulfillment (fill rate), we select the following basic inventory control policy:

Inventory control policy:	Periodic-review, order-up-to-level (R, S)-system
Service objective:	Safety stocks based on service level
Service measurement:	Specified fraction (P_2) of demand to be satisfied routinely from shelf; unit fill rate service level

In Section 3.1, we discussed three other inventory control polices as well. We conclude that these policies are less suitable to our problem, as they are based on continuous review periods and / or order point based replenishment. The selected model encloses a large set of the requirements stated in Section 4.1: it is in line with the replenishment policy, production wheels are included, it is forecast driven, and service levels are measured based on unit fill rate. This supports our motivation for selecting this model. The following requirements are not included: it is in line with the supply flows (multi echelon), it includes minimum quantities and supply capacity restrictions, and can be used for a rolling horizon environment. In the remainder of Section 4.2, we extend the model further to include these requirements.

4.2.2 Multi echelon & stock allocation

In the previous section, we selected the basic replenishment policy for our model. This policy assumes a single stock point environment. The supply flows under study contain multiple stock points at different echelons. As described in Section 3.2, we classify these supply flows as two-echelon divergent systems. In this section, we select theories to extend the basic model with the requirements related to this multi echelon environment.

Local versus integral control

The first question we ask is whether inventory is controlled by a local or an integral system. After all, when inventory is controlled locally, a method assuming single stock point environments suffices. As the model must be based on the ISP-policy, and this policy allocates stock based on relative inventory positions of the local stock points, aims at improving (and balancing) overall supply chain performance, and uses information available throughout the supply chain in its decision making (see Section 2.6.2), our model must be an integral control system.

Central versus no central stock

As described in Section 2.2.1, business unit management pushes the organization to eliminate stock at the higher echelon facilities. The ISP-policy is in line with this objective. It pushes stock to the lower echelon stock points the moment the stock becomes available. With the ISP-policy, no stock is held at the production facilities, Packaging Centers, or the Sourcing DC. For this, we select a method that assumes that no central stock is allowed.

Postponed allocation of replenishment

The ISP-policy allocates stock to local stock points just before shipping. It bases this allocation on the actual relative inventory positions of the local stock points. At the Packaging Centers, the ISP-policy also allocates semi-finished to finished products just before starting the packaging process (see Section 2.1). Again, allocation is based on the actual relative inventory positions of the related finished products at the local stock points. This implies that we must include partial postponement of stock allocation into our model. For the production facilities and the Sourcing DC, there is one such moment: the allocation of stock to local stock points, just before shipping. For the Packaging Centers, there are two such moments: 1) the allocation of semi-finished to finished products, just before starting the packaging process and 2) the allocation of finished products to local stock points, just before shipping.

Allocation rules

The ISP-policy allocates stock based on relative inventory positions. It allocates such that the inventory position of each local stock point rises to an equal percentage of its target inventory position. By this, the policy aims to raise the local inventory positions such that the target fill rates are balanced equally over the local stock points. We conclude that this way of allocating stock is in line with the following allocation rule (see Section 4.2): *allocate stock based on* *balanced customer service levels*. After all, both try to raise the local inventory position such that target service levels are balanced. We further refer to this rule as the *"balanced Stock allocation"*- rule.

In this section, we extended the basic model of Section 4.1 such that it meets the requirements related to the multi echelon aspect of our research. This includes an inventory replenishment system that is integrally controlled, allows no central stock, and partially postpones allocation of stock using the '*balanced stock allocation'*-rule.

4.2.3 Demand distribution

In this section, we select methods to appropriately include demand uncertainty into our model. As described in Section 2.6.2, the ISP-policy calculates targeted inventory positions based on three parameters: demand forecast, safety stock, and a third parameter to cope with supply shortages. The first parameter, demand forecast, makes the ISP-policy forecast driven. For this, demand uncertainty must be estimated on forecast instead of historical demand. Based on the literature studied in Section 3.3, we select the following estimator of demand uncertainty for our model: *standard deviation between forecasted and realized demand*. We refer to this estimator as the *forecast error* and use the related formulas described in Section 3.3.

With the type of estimator selected, the type of distribution needs to be chosen next. In Section 3.3, we described two commonly used distributions: normal and gamma distribution. A normal distribution often provides a good empirical fit to observed data and the impact of using other distributions is normally quite small. However, the larger the ratio between the forecast error and forecasted demand gets (correlation variant), the less adequate this distribution becomes. From our literature study, we learned that whenever this correlation variant is larger than 0.5, a distribution other than normal should be considered. In most cases, a gamma distribution will provide an adequate approximation. We found that for a large set of products under study the correlation variant was indeed above 0.5. We discuss these findings extensively in Section 6.1, which is dedicated to forecast error calculations of the product included into our research. Because of this high correlation variant, we select a gamma distribution as the most adequate distribution for estimating the forecast errors of our model. Related formulas can be found in Section 3.3.

The product portfolios under study were selected based on their representative value. Because of this, we expect also that the correlation variants of the forecast errors are larger than 0.5 for a large set of the excluded products. Within the organization, all estimators of demand uncertainty assume that the demand patterns are normally distributed. This makes it likely that a significant part of safety stock levels are chosen based on inappropriate estimators. With this, and the second part of our research goal in mind, we decide to further develop the model based on both normal and gamma distributed forecast errors. During the analyses phase, we compare the outcomes of the model for both distributions with each other. Hereby, we provide business unit management with qualitatively grounded data on the consequences of using inappropriate estimators of the demand (or forecast error) distributions.

In this section, we selected forecast error based on a gamma distribution as the way to include demand uncertainty into our model. For reasons of comparison, we also develop the model further based on a normal distributed forecast error.

4.2.4 Rolling horizon & adapting forecast error

In the preceding three sections, we selected methods and theories for our model while still assuming a steady state environment. In other words, the model developed so far cannot deal with time-varying changes. A key requirement of the model is that must calculate stock levels for the upcoming periods based on time-varying changes such as demand forecast and supply capacity. More precisely, the model must provide in weekly stock and service levels for the whole length of the medium term forecast. We refer to this as the *rolling horizon*, as stock levels and related parameters must be recalculated for each time interval individually.

In Section 3.4, we elaborated on two methods that can be used to include time-varying aspects into our model. Both are heuristic approaches that recalculate replenishment parameters for each time interval, while still using an underlying steady state system. The products included in our research have strong seasonal demand patterns (see Section 2.3). This makes the method of Bollapragada and Morton [1993] less suitable for our model; they state that their method is inappropriate when demand is expected to decline or rise rapidly. The method of Kaufman [1977] provides a better fit to our problem. His method calculates stock levels in a particular period by using the demand forecast information over the next interval of duration Review + Lead time in a steady state model. We use this appealing approach to extend our basic model with the rolling horizon requirement. Below, we show the formula that we deduced to fit our model. With this formula, we calculate the average weekly forecasted demand over the next period of duration Review + Lead Time. We use this outcome as forecast demand input to our model and recalculate the order-up-to-level accordingly per time interval.

$$FC_t = \frac{\sum_{j=t}^{t+R+L-1}(D_j)}{(R+L)}$$

Notations:
t = particular week *L = Lead time*
D_j = forecasted demand at interval j *R = Review period*
FC_t = average forecasted weekly demand over next interval with duration R +L

As described in Section 3.5, when the demand forecast changes over time, the forecast error will also vary. Using a fixed forecast error with a changing demand forecast results in wrong estimations of the safety stock levels necessary. We select the method of Bollapragada and Morton [1993] to tackle this problem (see Section 3.5). In our case, this implies that the forecast error is assumed to differ by a constant factor from the demand forecast. As stated in Section 3.5, we refer to this time-varying forecast error as the *adapting sigma*. We use the correlation variant between the forecast error and the historical demand forecast as its constant. The adapting sigma is used as input variable to our model instead of a fixed forecast error. We use it to calculate the parameters needed for estimating the forecast error based on a gamma-distribution. Section 3.5 shows the related formulas.

The ISP-policy uses demand forecasts of the upcoming periods to determine the relative inventory positions of the local stock points. Although this means that the policy adapts to changing demand over time, it still bases safety stock calculations on a given, fixed sigma. This points out a shortcoming of the policy, as this leads to under- and overestimating safety stock levels at different moments in time. To estimate the impacts of this shortcoming, we create the model such that it can use both a fixed and an adapting sigma.

Summary basic model:
In this section, we selected methods and theories for our model. The model developed so far can be described as a two-echelon divergent system using a periodic-review, order-up-to-level replenishment policy with partially postponed allocation and no central stock. The model uses forecast errors as estimators of the demand distribution and copes with changes over time by using demand forecasts over the next period (review + lead time) and adapting sigmas.

This basic model meets all requirements described in Section 4.1 except two. It uses supply chain characteristics at the operational level. Further, the model includes demand forecasts, lead times, forecast errors, production wheel restrictions, and unit fill rate service levels as input variables. Moreover, it approximates key characteristics of the ISP-policy: order-up-to-level, rolling horizon, partial postponed allocation based on relative inventory positions, no higher echelon stock, and forecast driven. So far, the model however does not enclose the minimum quantity and supply capacity restrictions. To include these requirements, we develop heuristic approaches based on our own insights and theoretical knowledge. We address Section 4.3 to these extensions.

During our research, we learned that the organization chooses most safety stock levels based on fixed sigmas deduced from standard deviations on historical demand. As the ISP-policy replenishes based on time-varying demand forecasts, sigmas based on forecast error that adapts in relation to changing forecasts would produce better estimations (see Section 3.5). As it also became apparent that for the major part of included products the correlation variant between forecast errors and forecasted demand is larger than 0.5, a gamma distribution is more appropriate. With this knowledge in mind, we enable to basic model to use both a gamma and a normal distribution with both fixed and adapting sigmas. Comparing the outcome of the different calculations, provides us with interesting insides in the quality of the safety stock calculations made so far by the organization and, more important, on the magnitude of organization's under- or overestimation of necessary safety stock levels. We conduct related analyses as they are perfectly in line with the second part of our research goal and the fifth research question (see Section 1.5). In Section 7.3 we elaborate on the outcomes and learnings of these analyses.

4.3 Model formulas

In this section, we give a formal description of the developed model. The model is based on a set of methods and theories selected in Section 4.2. We derive the formulas of the model by combining those of the different methods we. In short, we use formulas from the following sources:

Silver et al [1998]	*Two-echelon divergent system with periodic-review, order-up-to-level replenishment policy and unit fill rate service levels; gamma en normal distributed demand*
Van der Heijden and Diks [1999a]	*Partial postponed allocation of stock with a balanced stock allocation rule*
Kaufman [1977]	*Time-varying changes in demand based on steady state environment; rolling horizon*
Bollapragada and Morton [1993]	*Time-varying changes in demand uncertainty (forecast error); adapting sigma*

Before we show the basic model as a complete set of formulas, we first elaborate on the used notation, explain the terminology and introduce the related formulas one at a time. The formulas are based on normal distributed forecast errors. We refer to Section 3.3 for the calculation of the forecast error itself and the way to convert it to a gamma distribution. We refer to Section 6.1 for the outcomes and the analyses of the calculated forecast errors of products included in our research.

We have to calculate the stock and the service levels for each product at each stock point for each time interval over a rolling horizon. To enclose this into our formulas, we use the notation $PS_i^n\ (t)$, in which *i* indicates the product, *n* indicates the stock point, and t gives the time interval. In the shown notation, *PS* stands for Physical Stock in units. In the total set of formulas, we use the following notations:

PS = Physical Stock, in units | *SS = Safety stock, in units* | *BL = Backlog, in units*
CS = Cycle stock, in units | *S = Order-up-to-level, in units* | *PIS = Pipeline stock, in units*
GIT = Goods in Transit, in units | *D = forecast demand, in units* | *P_2 = fill rate, in percentage*
R = review period, in weeks | *k = safety factor* | *L = total lead time, in weeks*
LT = lead time transportation, in weeks | *LP = lead time production* | *P = allocation fraction*
FC = average forecasted weekly demand over interval with duration R +L, in units

G_u (k) = function of normal variable (mean 0, standard deviation 1)
σ = standard deviation of forecast error in demand, in units
n = stock point index (0 for central depot and 1, 2, .. M for local warehouses)
i = product index

Average forecasted demand ($\boldsymbol{FC_i^n}$) is the average demand forecast of a product *i* at a local stock point *n* over the next period of Review + Lead time. We calculate it by dividing the total demand forecast of this period by the number of time intervals (weeks).

$$FC_i^n = \frac{\sum_{j=t}^{t+R_i^n+L_i^n-1}(D_j)}{(R_i^n + L_i^n)}$$

Demand forecast over period R + L ($\boldsymbol{X_i^n}$) is the forecasted demand of a product *i* at a local stock point *n* over the next period of Review and Lead time. It is based on the average forecasted demand of the product during a period of length $L_i^n + R_i^n$ and the total average forecasted demand of the product at a central stock point *0* during a period of length L_i^o multiplied by the allocation fraction of the product at the stock point.

$$X_i^n = FC_i^n(L_i^n + R_i^n) + P_i^n\, FC_i^0\, L_i^0$$

Standard deviation over period R + L (σ [$\boldsymbol{X_i^n}$]) is the standard deviation on the forecast error of a product *i* at a local stock point *n* over the next period of Review and Lead time. It is based on the average forecasted demand of the product during a period of length $L_i^n + R_i^n$ and the total average forecasted demand of the product at a central stock point *0* during a period of length L_i^o multiplied by the allocation fraction of the product at the stock point.

$$\sigma[\,X_i^n] = \sqrt{(L_i^n + R_i^n)\,\sigma_i^{n\,2} + \quad P_i^{n\,2}\, L_i^0\;\sigma_i^{n\,2}}$$

Allocation fraction ($\boldsymbol{P_i^n}$) is the relative part of demand uncertainty of a product *i* at a local stock point *n* that is shared with that of other products / stock points. Its purpose is to minimize imbalance of inventory throughout the supply chain. For this fraction, we use the formula for balanced stock allocation rules of Van der Heijden and Diks [1999a]. The formula bases the fraction on a combination of the relative demand forecast and forecast error of a product I at a local stock point n to related products / stock points.

$$P_i^n = \frac{FC_i^{n\,2}}{2\sum_{j=1}^{m} FC_j^{n\,2}} + \frac{S_i^{n\,2}}{2\sum_{j=1}^{m} S_j^{n\,2}}$$

Safety Stock ($\boldsymbol{SS_i^n}$) is the stock of a specific product *i* placed at a local stock point *n* needed to cope with demand uncertainty. Its calculation is based on the safety factor *k* multiplied by the standard deviation on forecast error over the demand forecast period X_i^n.

$$SS_i^n = k_i^n\,\sigma[\,X_i^n]$$

Order-up-to-level ($\boldsymbol{S_i^n}$) is the targeted inventory position of a product *i* at a local stock point *n*. It is the sum of the demand forecast over the next period Review + Lead time (X_i^n) and safety stock (S_i^n). The order-up-to-level at a higher echelon *0* *(*S_i^0) is the total of the order-up-to-levels of the local stock points below *0*.

$$S_i^n = X_i^n + SS_i^n \qquad S_i^0 = \sum_{j=1}^{n} S_i^j$$

Cycle Stock (CS_i^n) is stock required to cover the forecasted demand of a product *i* at a local stock point *n*. It is set to exactly half of the demand forecast over the review period as this equals the average amount on stock within a review period when no demand uncertainty is present.

$$CS_i^n = \frac{(FC_i^n\ R_i^n)}{2}$$

Physical Stock **(PS_i^n)** is the stock of a specific product *i* that is physically on hand at stock point *n*. It is composed out of a safety stock and cycle stock.

$$PS_i^n = k_i^n\ \sigma[\,X_i^n] + \frac{(FC_i^n\ R_i^n)}{2}$$

Pipeline Stock (PIS_i^n) is the expected total amount of replenishment orders placed for a product *i* at a local stock point *n* that is not yet delivered. As the control policy aims at bringing the inventory position to an order-up-to-level S_i^n, on average it replenish the stock point with an amount of the product that equals the forecasted demand of that time interval. This implies that the total pipeline stock of the product to the stock point can be calculated by multiplying the average forecasted demand with the total lead time.

$$PIS_i^n = FC_i^n(L_i^n + L_i^0)$$

Goods in Transit (GIT_i^n) is replenishment of a product *i* to a stock point *n* that is already shipped from the supplying entity but not yet arrived at the requesting stock point. For local stock points *n*, it is calculated by multiplying the average forecasted demand (FC_i^n) by the transportation lead time from a supplying higher echelon facility *0* (LT_i^n). For a higher echelon facility (GIT_i^0), it is calculated by multiplying the total average forecast demand of all local stock points with the transportation lead time between itself and its supplying entity (e.g. Sourcing Agency).

$$GIT_i^0 = \sum_{j=1}^{N}(FC_j^n) * LT_i^0 \qquad GIT_i^n = FC_i^n LT_i^n$$

Backlog (BL_i^n) is the demand of a product *i* at a stock point *n* that cannot be delivered directly from shelf. Delivery is postponed to a later moment in time when sufficient stock is available again. As our service level is based on unit fill rate, we calculate the magnitude of the backlog by multiplying the forecasted demand during a review cycle with (1 minus the service level).

$$BL_i^n = FC_i^n\ R_i^n\ (1 - SL_i^n)$$

Below, we summarize the formal description of our model. Note that the calculations must be performed for each product, at each local stock point, and for each time interval. The outcomes provide stock and service levels for every time interval of the medium term planning horizon. By consolidating these outcomes, we get stock and service levels for complete product groups at the medium term time periods. In other words, we obtain tactical stock levels.

Basic model

$$PIS_i^n = FC_i^n(L_i^n + L_i^0) \qquad PS_i^n = k_i^n\,\sigma[X_i^n] + \frac{(FC_i^n R_i^n)}{2}$$

$$X_i^n = FC_i^n(L_i^n + R_i^n) + P_i^n\,FC_i^0\,L_i^0 \qquad P_i^n = \frac{FC_i^{n2}}{2\sum_{j=1}^m FC_j^{n2}} + \frac{S_i^{n2}}{2\sum_{j=1}^m S_j^{n2}}$$

$$\sigma[X_i^n] = \sqrt{(L_i^n + R_i^n)\,\sigma_i^{n2} + P_i^{n2}\,L_i^0\,\sigma_i^{n2}} \qquad G_u(k_i^n) = \frac{R_i^n\,L_i^n\,(1-SL_i^n)}{\sigma[X_i^n]}$$

$$SL_i^n = \frac{\sigma[X_i^n]\,G_U(k_i^n)}{FC_i^n\,R_i^n} \qquad BL_i^n = FC_i^n\,R_i^n\,(1-SL_i^n) \qquad SS_i^n = k_i^n\,\sigma[X_i^n]$$

$$S_i^n = X_i^n + SS_i^n \qquad GIT_i^0 = \sum_{j=1}^n (FC_j^n) * LT_i^0 \qquad S_i^0 = \sum_{j=1}^n S_i^j$$

$$GIT_i^n = FC_i^n LT_i^n \qquad CS_i^n = \frac{(FC_i^n R_i^n)}{2} \qquad FC_i^n = \frac{\sum_{j=t}^{t+R_i^n+L_i^n-1}(D_j)}{(R_i^n+L_i^n)}$$

<u>Notations:</u>

PS = Physical Stock, in units	*SS = Safety stock, in units*	*BL = Backlog, in units*
CS = Cycle stock, in units	*S = Order-up-to-level, in units*	*PIS = Pipeline stock, in units*
GIT = Goods in Transit, in units	*D = forecast demand, in units*	*P_2 = fill rate, in percentage*
R = review period, in weeks	*k = safety factor*	*L = total lead time, in weeks*
LT = lead time transportation, in weeks	*LP = lead time production*	*P = allocation fraction*

FC = average forecasted weekly demand over interval with duration R +L, in units

G_u (k) = function of normal variable (mean 0, standard deviation 1)
σ = standard deviation of forecast error in demand, in units
n = stock point index (0 for central depot and 1, 2, .. M for local warehouses)
i = product index

Different supply flows can replenish a local stock point with a specific product (see Section 2.2). These supply flows differ in lead times, review periods, minimum quantities, and partial postponement possibilities for stock allocation. For example, the supply flow using Packaging Centers has a larger potential benefit of postponing allocation than the supply flow using the Sourcing DC. After all, the Packaging Centers also postpone the allocation from semi-finished products to finished products next to the allocation of finished products to local stock points. Consequently, the selection of a supply flow has large influences on the resulting stock levels outcomes. In Section 4.5, we elaborate on the differences between the supply flows.

In this section, we described the model we developed in Section 4.2 in terms of formulas. This model includes all except two of the requirements. We did not include these two, related to quantity and anticipation stock, in our basic model as we did not find useable methods or theories during our literature study. To include these requirements, we develop heuristic approaches based on our own insights and theoretical knowledge. We describe these approaches in Section 4.4.

4.4 Model extensions

In this section, we extend the basic model with two heuristic methods. By including these methods, we meet the last two requirements, related to minimum quantities and supply capacity, of our model. We derive both methods based on our insights and theoretical knowledge. During our literature study, we did not find related methods that fit the model appropriately. In Section 4.4.1, we focus on the heuristic method we use to include minimum quantity restrictions into our model. In Section 4.4.2, we describe the method by which we include restrictions on supply capacity.

4.4.1 Minimum quantity restrictions

The focus of our modeling effort lies with the minimum order restrictions that we expect to have (by far) the largest impact on supply chain performance: minimum quantity restrictions for replenishment to the higher echelon facilities. These are the minimum order quantities at the Sourcing Agency and the minimum production quantities at the production facilities. We assume that restrictions on the order quantity to the local stock points (RDCs) have only a small but negative influence to total stock levels. Our motivation for this assumption lies with the ratio between minimum quantity restrictions and average demand of the products included in our research; for most products, replenishment orders are far larger than the restrictions on minimum orders quantities. For this reason, we disregard these restrictions further on.

During our literature study, the methods we found were all oriented on deterministic demand. We studied several such methods, for example methods from Wagner and Whitin [1958], Brown [1997], and Silver and Meal [1973]. But as our model must cope with demand uncertainty, these deterministic models are not suitable for our problem. Because of this, we choose to develop an own heuristic to tackle the problem. As basis for our approach, we apply the following rule: in a deterministic environment, a minimum quantity restriction becomes irrelevant when demand during the review period exceeds this quantity. This rule does not hold for our model since the demand is stochastic. But, we use the underlying idea for our heuristic. Altering the review period such that the related total demand forecast exceeds the minimum quantity restriction gives an indication of the impact of this restriction. This approach is both simple and appealing. We expect that it approximates the optimum with a risk of a minor overestimation. The heuristic we use in our model is as follows:

Minimum quantity heuristic method based on review period

1] *Determine the demand forecast over the next interval of review period R.*

2] *If it is smaller than the minimum production / order quantity, determine a review period which length is the smallest multiple of the length of the original review period and has a total demand forecast that is larger than the minimum production / order quantity.*

3] *Determine the total stock level by recalculating all parameters of the basic model based on the new period and use these parameters within the basic model.*

4] *The difference between the total stock level based on this calculation and the original total stock level is the estimation of the impact of the minimum production / order quantity. Formally described, the minimum quantity related stock of a product i at a local stock point n (MOQ_i^n) = (PS_i^n new) - (PS_i^n old).*

In the heuristic, the review period is adapted such that the demand forecast during the period is equal or larger than the minimum quantity restriction. We use this approach because we expect that it cannot underestimate, but only overestimate, the impact of the restrictions. We base our expectation on the fact that the impact of enlarging a review period to let it have a total demand forecast exceeding this quantity must be larger than the real impact of a minimum quantity restriction. The extent of overestimation is influenced by several variables, amongst others: difference in demand forecast between weeks in review period, forecast error, relative difference between quantity restriction, and demand forecast.

4.4.2 Supply capacity restriction

To cope with imbalances between supply capacity and expected demand, the organization builds up stock in anticipation of shortages and shuts down production to prevent surpluses. In our case, the basic thought behind anticipation stock is rather simple: create a stock surplus in advance of expected shortages in such a way that the service level requirements are met with an as low as possible rise in inventory levels. We deduce that this is obtained when such stock is created at the latest moment possible. After all, when one creates such stock earlier than necessary, it only leads to higher stock levels at moments that it can be avoided.

To determine when and to which extent we can expect shortages in supply capacity, we must know the demand for the production facilities. Our model is based on an order-up-to-level system, in which requested replenishment equals expected demand over a review period. This implies that we can set expected demand at the higher echelon equal to that of the total sum of the lower echelon, when taking the lead times into account.

$$FC^0\,(t) = \sum_{m=1}^{n}\sum_{j=1}^{i} FC_j^m\,(t + L_j^m\,)$$

As described in Section 1.4, variances in lead time and production are out of the scope of our research. This means that demand uncertainty is the only remaining stochastic variable at hand. Our model is to be used on complete product groups. As these consist out of over hundreds of products, we make the assumption that the demand uncertainties of individual products level cancel each other out at a higher echelon facility. This implies that local demand uncertainty has limited influence on total demand for supply at a given period. Because of this, we decide to solve the problem on supply capacity using a deterministic approach.

Table 3 shows a simplified representation of this deterministic approach. At the production facilities, we compare the consolidated demand of all products with the available capacity. Based on the difference between demand and capacity, we determine the capacity shortage or excess for each interval. Using backward calculation, we forward shortages to the preceding interval. At that interval, unused capacity is applied to decrease the shortages when available. If the previous interval is also confronted with its own capacity shortage, the accumulated shortage of both intervals is again forwarded to the then preceding interval.

In the example of Table 3, we see that demand exceeds capacity with 9900 – 9600 = 300 units at interval 7. Within the example, lead time between the production facility and the local stock points is one week. This implies that demand requested at the production facility at interval 7 is needed at the local stock points at interval 7 + 1 = 8. As the shortage cannot be produced during interval 7, we forward the shortage to the preceding interval 6. Interval 4, 5, and 6 are also confronted with shortages of 300. Because of this, we see the accumulated shortage rise to 300 x 4 = 1200 units at the start of interval 4. At interval 3, there is capacity available that is not required for meeting its own demand. This excess capacity encloses 9600 – 8700 = 900 units. We use this capacity to reduce accumulated shortages of the succeeding intervals. In doing so, the accumulated shortage is reduced to 1200 – 900 = 300 units at the start of interval 3. Again, interval 2 has also 9600 – 8700 = 900 units of capacity to spare. This is more than required to cover the remaining 300 units of the accumulated shortage. After meeting both its own demand and the accumulated shortages of the succeeding intervals, interval 2 still has 900 – 300 = 600 units of capacity unused.

	1	2	3	4	5	6	7	8	9
Capacity	9600	9600	9600	9600	9600	9600	9600	9600	9600
Demand	8700	8700	8700	9900	9900	9900	9900	9000	8200
Own Consumption	8700	8700	8700	9600	9600	9600	9600	9000	8200
Own Shortage	0	0	0	300	300	300	300	0	0
Own Excess	900	900	900	0	0	0	0	600	1400
Capacity unused	900	600	0	0	0	0	0	600	1400
Acc. shortage	0	0	300	1200	900	600	300	0	0
Anti stock	0	0	300	1200	1050	750	450	150	0
Old stock level	12100	12100	12100	12900	12900	12900	12300	12300	11800
New stock level	12100	12100	12400	14100	13950	13650	12750	12450	11800

Table 3: example of anticipation stock calculation (simplified; LT = 1)

By solving the deterministic problem through this backward calculation, unused capacity is used at the latest moment possible to tackle future shortages. This implies that corresponding extra stock, anticipation stock, is created in the same way. This implies that supply capacity constraints are dealt with while having the lowest impact on inventory levels.

In the example of Table 3, we assume that anticipation stock will arrive at the lower echelon halfway during an interval. This means that the amount of anticipation stock at the local stock points are calculated as follows: Anticipation stock $AS^0(t)$ = 0.5 x own shortage ^{0} $(t - L^0)$ + acc. shortage^0 $(t - L^0 + 1)$. We calculate the resulting new stock level at the lower echelon by adding this outcome to the physical stock level PS_i^n at interval t. At interval 7 of our example, we see that the old stock level equals 12300 units and anticipation stock equals 450 units (300 + 150 units). Combining both, the new stock level, including anticipation stock, is 12300 + 450 = 12750 units.

So far, we consolidated expected demand at the higher echelon and used it for the supply shortage calculations. To establish the impact of the resulting anticipation stock on supply chain performance, we need a break up and translation to the lower echelon again. According to Silver et al. [1998], this type of stock must be created on fast moving products, as there is only a limited risk of obsolescence and a maximal expected tribute to overall performance. The ISP-policy and our model are based on relative inventory positions. This means that ideally the break-up to the lower echelon should be done by dividing the total of anticipation stock at interval t over fast moving products based on their relative inventory position to each other. For computational reasons, we have relaxed this problem by performing the break up based on relative expected demand of the fast moving products instead. After performing the break-up calculations on the anticipation stock and translating it to the new physical stock levels at the local stock points, the final step is calculating the other stock levels and new service level.

In Figure 5, we show a schematic overview of the steps of our anticipation stock calculations. As first step, we consolidate expected demand of the local stock points to the higher echelon facility. In the second step, we solve the capacity problem by backward calculation (see Table 3). In the third step, we split the total amount of anticipation stock produced at the higher echelon facility over fast moving products at the lower stock points. As final step, we recalculate both the stock and service levels of fast moving products at the local stock points.

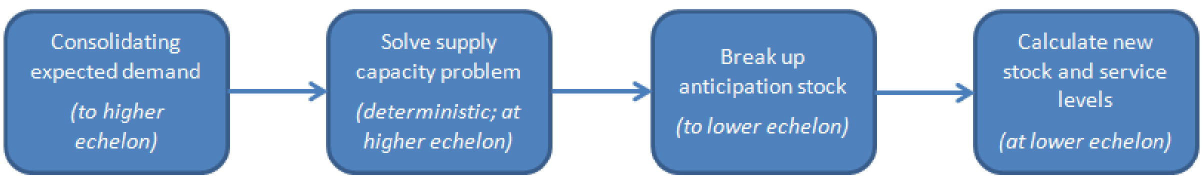


Figure 5: schematic overview of supply capacity calculation

Anticipation stock has a positive impact on service level performance. It raises the inventory level and by this reduces the chance of a stock-out. When service level requirements are set as an average over a larger period, the rise in service level due to anticipation stock at one time can compensate lower service levels at other times. In such case, the average targeted stock level might consequently become smaller than in the case above. As Philips Lighting however requires that its service level targets must be met at a weekly basis, including related calculations in our model is no option.

By extending the model with the minimum quantity and supply capacity requirements, we included all the requirements of the model. By this, we obtained the first part of our research goal (see Section 1.3): *To provide a mathematical model that estimates optimal tactical stock levels based on operational supply chain characteristics and service level requirements.* In Section 4.5, we described the full set of input and output parameters of the model. In Section 4.6, we elaborate on differences in the calculations of the model for the various supply flows. Section 4.7 addresses the expected influences of assumptions made on the quality of the model's outcome. Finally, Section 4.8 describes possibilities to further extend the model to increase its accuracy or increase the insights in the supply chain's characteristics.

4.5 Model in- and output

So far, we have developed a model by which our research goal can be obtained. On its own, this model has a limited contribution to science, as only the developed heuristic on minimum quantities is a supplement to it (see Section 4.4.1). However, the value of our research is not to be found in the stand alone calculations. It lies in the ability of the model to obtain good tactical stock levels by using the whole complexity of, often reciprocal, characteristics and requirements of products at the operational level.

In this section, we elaborate on the complete set of in- and output variables that we use in the calculations. It provides a better understanding of the complexity of the problem as well as contributes to its reproducibility. First, we describe the input variables after which the output variables follow. We divide the set of input variables into three classes based on the type of characteristic: *product, lead time* or *supply capacity*.

Product characteristics
These input variables are related to each specific product at each specific local stock point. We refer to this as the product/RDC-combination. Each such combination has a different set of variables. The product groups that are included in our research contain in total over 1050 product / RDC-combinations.

Product identification
Products are internally identified by a twelve digit numerical code. Within our model, we use this code as identifier. It forms, together with the RDC at which it is located, a unique combination at the lowest echelon. This code is also used to link reciprocal products and combinations (e.g. partial postponement, minimum order heuristic).

Product group
Similar products are grouped together in product groups based on the resource they are committed to. We use this input variable to link products to supply capacity constraints at the production facilities and to consolidate stock levels of products to the tactical level of product groups.

Supply flow
Every product / RDC-combination is linked to a specific supply flow. This flow is translated as allowed linkages between echelons. The same product located at another RDC can use a different supply flow.

Forecasted demand (next 78 + 10 weeks)
The organization has monthly demand forecasts available for the upcoming 18 months. This is translated to a weekly level by dividing each monthly demand forecast equally over the four or five weeks of that month. The resulting weekly demand forecast is used as input variable for the upcoming 78 weeks.

Service level
The required service level is for each product a fixed, independent value. For the TL/CFL-ni portfolio, business unit management sets it at a weekly 95%. For the Halogen portfolio, business unit management sets it at a weekly 98%.

Sigma
The estimation of the demand distributions is based on the difference between real demand and forecasted demand: *forecast error* (see Section 3.3). Within our rolling horizon model, we assume that the forecast error is in a constant relation to the forecasted demand (see Section 3.5). We use the resulting correlation variant to determine the average sigma over the rolling horizon, by multiplying it with the average forecasted demand over this period. This sigma is used as the initial input to our model. By simple deduction, this sigma enables us to use both a gamma and a normal distribution with both a fixed and adapting sigma (see Section 3.3).

Review period
As the production facilities are bound to production wheels, all related products have specific review periods not related to their destination. This implies that review periods are specific to a product not to a product/RDC-combination. Review periods of all products from the Sourcing Agency are equal, as they are not linked to a production facility.

Carrier
Every product / RDC-combination is linked to a specific carrier with its own transportation lead times for each step in the supply flow. This gives us the possibility to estimate the impact of different carriers on local and overall performance. Linking a combination to a carrier also provides us with the possibility to analyze the impact of mixing carriers (e.g. fast movers carrier 1; slow movers carrier 2).

Minimum quantities
Only the minimum quantities that are expected to have the largest impacts on supply chain performance are included in our model: the minimum quantity for replenishment to the higher echelon facilities. These are the minimum production quantities at the production facilities and the minimum order quantities at the Sourcing Agency. These quantities are product specific.

Anticipation stock
This parameter indicates whether it is allowed to build up anticipation stock on a product. As described in Section 4.4, anticipation stock must only be created on fast moving products. The decision if anticipation stock is allowed to be built up on a product (/RDC-combination) is made outside the model.

Lead Time characteristics
These input variables are related to the time it takes to move between different echelons of the supply flows. Lead time is specific for each step and consists out of transportation, waiting before shipment, and production part. As it is not appealing to provide each product / RDC – combination with its own lead time variables, we decide to connect them by creating carriers. Each carrier has its own lead time values per step of each supply flow. The creation of these carriers provides us also with a better mean to analyze the impact of (local) lead time changes on overall supply chain performance, it creates possibilities to mix different carriers, and it probably has the benefit of reduced computation time. Within our setting, we have 6 supply flows in which in total around 70 different routes are possible from the supplying entity to the local stock points.

Supply capacity characteristics

These input variables provide the data necessary to calculate the impact of supply capacity restrictions on overall supply chain performance. For each of the three production facilities, the weekly supply capacity is given for the upcoming 78 weeks. Production stops due to factory holidays, maintenance, and reallocation of equipment are already taken into account. The weekly supply capacities are also given for the previous 10 weeks. This is needed for correctly calculating the level of anticipation stock in the first weeks; for these weeks, supply capacity is required in the past. Product / RDC- combinations of the TL/CFL-ni portfolio are linked to production facilities by the supply flow. The Halogen portfolio is linked to the Sourcing Agency and has an infinite supply capacity in the model.

Output variables

The model provides output variables by which realistic tactical stock levels can be set, based on requirements and characteristics at the operational level. As it provides output variables at the product / RDC-combination level, the target is met when the operational outcomes are consolidated to the product group level. To support in-depth analyses on supply chain performance, we have to calculate all possible output variables. Below, we briefly describe the different output variables. Each of these variables is at a weekly level.

Service level

Although the required service levels are already stated at the beginning of the project, the realized service level can become higher when there is also anticipation stock available at the product / RDC- combination.

Physical stock levels

After running the model, data is available on all five types of physical stock: cycle stock, safety stock, minimum quantity stock, anticipation stock, and total physical stock (see Section 4.3).

Goods-in-Transit stock

Stock has been in transit before arriving at the lower echelon. Within the organization, stock is taken into account from the moment it leaves the supplier (production facility or Sourcing Agency). This means that the GiT-stock has a significant impact on the financial state and performance of the supply groups.

Pipeline stock levels

This type of stock is 'on its way' to the lower echelon. It is the total amount of replenishment that is on order, but not yet delivered. The organization is interested in the size of this stock type as it influences its financial situation.

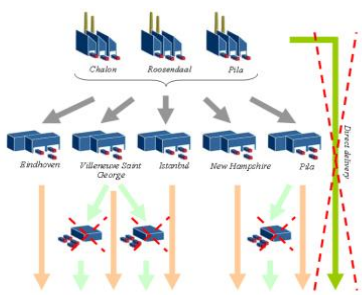
Backlog

Backlog is demand that cannot be met on time and is allowed to be delivered at a later moment. Only for the products of the TL/CFL-ni portfolio backlogging is allowed. For the Halogen portfolio, this amount becomes lost sales.

4.6 Supply flows

The model is based on a two echelon divergent system with partially postponed allocation of replenishment and no central stock. This resembles the most extensive supply flows of our research (see Section 2.2). From the viewpoint of the model, we see these supply flows as almost identical to each other. However, there are, mostly partial postponement related, differences that bear significant influences on resulting stock level outcomes. For this, each supply flow requires a slightly different model approach. In this section, we describe the implications on the model for each of the relevant supply flows.

Supply group TL/CFL-ni

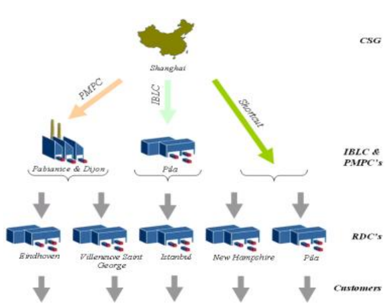


The supply group TL/CFL-ni has three production facilities. By far the largest part of the products flow from these facilities through the RDCs to the end customer. Recall that the other two flows, direct delivery and through local DCs, are mimicked as equal to this main flow. With the ISP-policy, there is no stock at the higher echelon and allocation of stock is postponed until just before shipping to the RDCs.

We model this supply flow as the two echelon divergent system with partially postponed replenishment and no central stock. Within the calculations of the model, we must include partial postponement on identical products, located at different RDCs, over their combined production time at the production facilities. This implies that the lead time at a higher echelon *0* (L_i^o), over which the allocation of a product i to the different local stock points *n* can be postponed, equals its production lead time (LP_i^n). Allocation of products to RDCs cannot be postponed over the waiting time before shipment (LW_i^n) and the transportation time (LT_i^n). This implies that the lead time over which allocation of a product i to a local stock point *n* cannot be postponed (L_i^n) equals the sum of LW_i^n and LT_i^n. This leads to the following formulas that must be used in the set of formula described in Section 4.3:

$$\textbf{TL/CFL-ni} \qquad L_i^o = LP_i^n \qquad L_i^n = LT_i^n + LW_i^n$$

Supply group Halogen



The supply group Halogen sources all its products from external suppliers in China. The whole of sourcing activities are managed by the Sourcing Agency, where the flows of this supply chain start. There are three supply flows available by which products can reach the customer. Although only one of these is in active use at the moment, the other flows where included in the project due to their foreseen importance in the near future (see Section 2.2.2).

Within the current supply flow, products flow from the Sourcing Agency through successively the Sourcing DC and the network of RDCs to the end customer. Although this is basically a three echelon system, we translate it to two echelons in our model. This is easily achieved as the higher two echelons have a standard one-to-one relationship; the lead time of the highest echelon is included as part of that of the second. The Sourcing DC acts like the warehouse of a production facility: no stock is held and allocation is postponed until just before shipping to RDCs. This means that identical products have combined lead times over the total lead time of the Sourcing Agency (production, waiting before shipment, and transportation) and the 'production' time of the Sourcing DC. This implies that L_i^o equals the sum of the production time (LP_i^o), transportation time (LT_i^o), and the waiting time before shipment (LW_i^o) between the Sourcing Agency and facility *0* and LP_i^n. Allocation of products to RDCs cannot be postponed over LW_i^n and LT_i^n. This implies that L_i^n equals the sum of LW_i^n and LT_i^n. This brings us to the following formulas, which we must include in the formula-set of section 4.3:

SOURCING DC $\quad L_i^o = LP_i^o + LT_i^o + LW_i^o + LP_i^n \qquad L_i^n = LT_i^n + LW_i^n$

Instead of going through the Sourcing DC, products can also arrive at the end customer by going through one of the Packaging Centers. The lay-out of both supply flows is equal. The function of both facility types however is quite different. While the Sourcing DC functions as a "break bulk"-facility, a packaging center also performs the last steps of the production process. By this, semi-finished products are converted into finished ones. This provides the supply flow with an additional possibility of postponing allocation, next to that of identical products until just before shipping them to the RDCs.

As our model is only suited to deal with one postponed allocation possibility, we made the decision to discard the one having the smallest impact: postponing the allocation of equal products to the RDCs. The length of this period, which equals the production time at the Packaging Centers, was on average only a tenth of the period of postponing the allocation of semi-finished to finished products. This implies that we allocate products to RDCs just before the start of production at the Packaging Centers. Identical semi-finished products have combined lead times over the total lead time of the Sourcing Agency. This makes L_i^o equal to the sum of LP_i^o, LT_i^o, and LW_i^o. Identical semi-finished products have separated lead times over the production time at the Packaging Center, the transportation time, and the waiting time for shipment to the RDCs. This implies that L_i^n equals the sum of LP_i^n, LT_i^n, and LW_i^n. This brings us to the following formulas, which we must include in the formula-set of section 4.3:

PACKAGING CENTER $\quad L_i^o = LP_i^o + LT_i^o + LW_i^o \qquad L_i^n = LP_i^n + LT_i^n + LW_i^n$

In Section 2.2.2, we described the last supply flow of the group Halogen: the Shortcut flow. It bypasses both the Sourcing DC and the Packaging Centers, as products are directly shipped from the Sourcing Agency to the RDCs. Although in theory the allocation of products to the RDCs can be postponed until just before shipping them from the Sourcing Agency, it is not likely that the company realizes this in the nearby future. Therefore, we describe this supply flow as a basic single echelon system; the demand of one product / RDC combination is completely separated from that of others. As this implies that the allocation of products to RDCs cannot be postponed, L_i^o is none existing and L_i^n equals the sum of LP_i^n, LT_i^n, and LW_i^n. This brings us to the following formulas, which we must include in the formula-set of section 4.3:

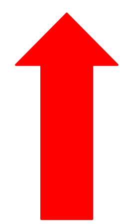
Shortcut $\quad L_i^n = LP_i^n + LT_i^n + LW_i^n$

4.7 Influence of assumptions

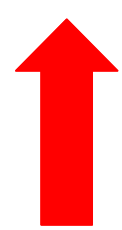
The creation of a model always requires the making of assumptions on and relaxation of the environment. These have their impact on both the accuracy of the model and the reliability of its outcome. Throughout this thesis, we elaborated on the various assumptions that we made while creating the model. This section focuses on the ones that we estimate to have the largest impact on the performance of our model. It describes their expected direction of influence and magnitude on the stock level outcomes. This provides in an estimation of the model's accuracy and its risk of under- or overshooting reality.

Modeling ISP by (R, S)-policy
Within the ISP-policy, replenishment takes place to obtain the targeted inventory position. As evaluation is interval-based, the periodic-review order-up-to-level policy suites very well. The ISP-policy however also uses a so called forecast consumption system to smooth out standard short term demand fluctuations (see Section 2.6.2). Business unit management sees this enhancement as one of the key benefits of the ISP-policy. It is definitely the appraisal of the project team that this enhancement has a strong positive influence on supply chain performance; although it is not proven scientifically (yet). As we did not include it into our model, we expect that the model overestimates the target stock levels regarding this point.

Using fill rate as service level
Service level performance is measured by the organization based on order line fulfillment. Within the model however, we made the assumption that this is done based on unit fulfillment (see Section 4.1). Performance based on unit fulfillment is always higher than or equal to that of order line fulfillment. After all, a shortage will always result in a "missed" order line, but only in a decline of the fill rate equally to the shortage / order size ratio. This means that the model underestimates the target stock levels on this point. Most of the included products have demand patterns that consist out of numerous order lines per time interval. For this, we expect that the influence of this assumption on the consolidated outcome of the model to be to be limited. The influence on a specific product can however be much larger.



Using fixed lead-times
The model uses fixed lead times for production, waiting time before shipment, and transportation. In reality these are all, to an extent, subject to uncertainty. Excluding uncertainty from a model always result in more positive outcomes. Consequently, on this point the model must underestimate the target stock levels. The magnitude of this influence is difficult to estimate, as there is a lack of conclusive data available to us. We presume that the lead times related to Sourcing Agency have a relative high level of uncertainty compared to all other lead times. This is mainly due to less developed external supplies, shipping and harbor uncertainties, and custom clearance (sea trade). We also assume relative uncertainty in transportation time to the different RDCs. Some are influenced by custom clearance (e.g. Istanbul) and / or by underdeveloped road-networks (e.g. Russia).



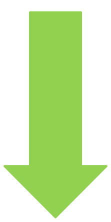
Approximating minimum quantity impact

The model uses a heuristic approach to estimate the impact of minimum production / order quantities on supply chain performance. In this approach, the review period is adapted in such a way that the demand forecast of a period becomes equal or larger than the quantity restriction. This bypasses the restriction in a deterministic problem, but can only be used as estimation in our stochastic model. A mathematical optimum is found somewhere between the outcome of the original and the adapted review period. This implies that the heuristic leads to overestimating the target stock levels. We expect that the magnitude of the difference between the heuristic's and the optimal outcome is limited on the consolidated level. On individual product level, this difference can get much larger. We expect that both a smaller ratio between minimum quantity and demand forecast and a larger forecast error result in relative larger differences.

No inter-RDC

Regular replenishment to the RDCs is accomplished through the six standard supply flows described in Section 2.2. This means that the RDCs normally receive their supply only from higher echelon facilities. As the ISP-policy pushes supply to the RDCs, no central stock remains available in the supply chain. Unexpected large demand at one RDC can result in local shortage without the option to replenish it directly by dispatching central stock. Supply chain planners might react on this by shipping supply between RDCs. This flexibility makes it possible to obtain a higher service level with the same amount of stock (Karmarkar and Patel [1997]). Although inter-RDC deliveries are discouraged by the organization, the existence of these actions makes the model overestimate its outcomes. To which extent is impossible to determine, as it is strongly influenced by the human factor of the related planner.

No stock at higher echelons



Within the ISP-policy, no stock is allowed at higher echelons, as it is not contributing directly to the commercial availability of supply. Previously, we already mentioned that supply chain planners might react on local shortage by allowing emergency inter-RDC deliveries. At times they also tend to hold back stock at a higher echelon facility to provide them with a second possibility to deal with such situations. These experience based actions are often related to slow movers and longer than normal upstream lead times (e.g. due to production shutdown for factory holidays). When performed correctly, they have a high likability of increasing supply chain performance (Silver et al. [1997]. This makes our model overestimate its stock levels. The extent of this influence is not easy to determine, as it depends strongly on both the human factor as well as numerous product characteristics.

In this section, we described six assumptions that we expect to have the largest influence on the accuracy of the model and the reliability of its outcomes. Although we deduce the direction of each, their magnitude is much harder to establish. The consolidated impact of these assumptions and those not elaborated on is not fully marked out. It is our understanding that the assumptions level each other out rather well and the model is capable of realizing the primary goal of the project.

4.8 Extension possibilities

The created model is based on the full set of requirements, has a comprehensive foundation, addresses the influence of assumptions made, and by these provides in a possible way to choose tactical stock levels. However, we experience that some appealing possibilities remain to extent the model. This section describes those that we expect to be the most beneficiary to the accuracy of the model or to increasing insights into the supply chain of the organization. Whenever the decision is made to extent the model, these possibilities are the first in line on our wish list.

Increase accuracy

- A key element of the IPS-policy is its ability to smooth out local short term demand fluctuations by using a so called forecast consumption system (see Section 2.6.2). Enhancing our model by incorporating this system instantly results in more realistic outcomes. To our knowledge, such system has not been modeled before nor is its performance been evaluated. Because of this, realizing it produces a good contribution to science as well. It also provides the company with a long desired insight in and a confirmation of the superior performance of the system. The potential contribution to the accuracy of the model, science, and insights in the supply chain, make this extension the most interesting one.
- The model uses fixed lead times for production, waiting time before shipment, and transportation. We expect that the exclusion of uncertainty in these characteristics likely bears the highest negative influence on the accuracy of our model. Therefore, we obtain the greatest gain in overall accuracy when including lead time uncertainty. Although there is a lack of necessary data available, we expect that research on this part may be very beneficial.

Increase insight

- The ISP-policy allows no stock being held at the higher echelons. This corresponds with the embedded thought at the organization that having all stock commercially available leads to the lowest stock levels. This thought is incorrect from a purely scientific viewpoint, as having the possibility to preserve a part as central stock results in closer to optimal outcomes. By making the model capable to allow stock at higher echelons, we provide the organization with interesting insights in the potential benefits of adapting the ISP-policy in this direction.
- An RDC sources a specific product from a fixed production facility. The three production facilities produce some identical products under different codes. This structure ends in sub optimization as the consolidation of demand uncertainty of identical products is not always possible, minimum quantities restrictions have a larger impact, and there is no embedded way of leveling out mutual supply capacity. Currently, a project is carried out to remove this restriction. Extending our model in a corresponding way provides business unit management with insights on the resulting gain in performance. If the project comes to a completion it also brings our model back in line with the then changed supply chain.
- With the normal supply flows, RDCs only receive replenishment from higher echelon facilities. Although shipping supply between RDCs is discouraged, supply chain planners tend to overwrite this policy and dispatch emergency shipments to cope with sudden local shortage. A possibility to perform such inter-RDC deliveries can in theory lead to improvements in performance. Extending our model to include these actions will provide the organization with a view on its potential benefits. For this, these increased insights support business unit management in further enhancing the ISP-policy.

In this chapter, we described a model to calculate optimal tactical stock levels. We derived the model based on the outcomes of the literature study, supply chain characteristics, and own insights. First, we described the requirements the model must meet to gain acceptance of the business unit management. Next, we build the basis of the model by selecting appropriate methods and theories from literature and give a formal description it. Following, we developed heuristics to cover the parts of the requirements for which no existing methods or theories were available. We described the full set of input and output parameters of the model to provide a more thorough understanding of its complexity and contribute to its reproducibility. Further, we elaborated on the differences in the calculations of the model for the various supply flows. We ended the chapter by addressing the expected influences of the assumptions made and describing the possibilities to further extend the model. By this, we gave answer to research question 3 and consequently realized the first part of our research goal.

Chapter 5 Model software

This chapter describes the software that we developed to perform the complex set of necessary calculations. The software uses the previously derived model and its methods to provide in the required tactical stock level data. We wrote the software as an executable file. The chapter is composed in a brief manner, as a full-fudged description would only surpass the goal of our research. It briefly addresses the development and working of the software. We provide an extensive step-by-step instruction of its usage and several screenshots in Appendixes IV and V.

5.1 Software development

Simultaneously with the literature study, we started to experiment in the standard spreadsheet environment of excel. We tried out the considered and derived methods and used a small, fixed set of products as input. This process provided us with helpful insights in the theory, its practicability as well as the structure in which we can mold the model to perform the real calculations. We always assumed that we could translate the final model to such standard spreadsheet environment. This assumption proved to be wrong. We were early on confronted with the limitations of excel. When a relatively small set of calculations was already over demanding the software, the complete set can never be performed by it as well. Reflected on it afterwards, this was not that surprising. The software after all has to deal with hundreds of products, 70 possible routes, 88 time intervals, forward and backward calculations, reciprocal relationships, and normal and gamma distributed parameters.

Because of this, we made the decision to program the whole problem in a Java based environment, for which we used Borland's Delphi 7. Three months and over two thousand lines of programming later, we had created the software that can perform all calculations by "a single push on the button". It enclosed a standalone Java based executable file supported by excel templates for in- and output data. With the number of lines and complexity growing during programming phase, the quality of the embedded calculations became harder to verify internally. We used the already created basic excel software as a cross reference throughout this phase. By comparing the outcomes of both on the selected set of products, the quality of the executable was covered.

The software was intended to function as a prototype. In other words, we did not focus on making the software suitable for operational usage at the organization. This did not take away our aim to create a stable and easy-to-use executable. It is also important that different sets of input can be interchanged instantly and output data can be consolidated at each desired level. They make easy analyses possible on stock levels and what-if scenarios. The software uses excel based templates as in- and output files and a selection option for the required level of consolidation to meet both requirements. This, together with meeting the most important requirement of providing in quality data on tactical stock levels, makes the software perfectly suitable to deliver the data needed to obtain our research goal and research questions.

The software requires between 15 and 115 seconds of calculation time for the selected product groups on a Pentium 4 2.66GHz processor with 768MB internal storage. Processing time depends mainly on the number of products, ratio of reciprocal relationships, and the supply capacity restrictions.

5.2 Brief working description

The underlying software of the prototype is divided into units. Each unit performs a specific part of the total programming. The master unit describes the layout and functionality of the visible form. It also invokes the procedures that initiate and steer further import, calculation, and export actions. The other units are arranged by functionality. The import unit reads and translates the data input files. It creates records to contain product, lead time, and supply capacity data. Furthermore, it calculates other data that is required as input for the calculations f the model that can be derived from the imported data. The summarizing aim of the import unit is to provide a full set of records with underlying data to perform all the calculations of the model. Data that becomes available later on in the process will be read into the now created records. The basic function unit contains all the basic calculations. Grouping them together results in a more comprehensive structure and prevents redundancy of code. Three other units are devoted to the different steps of the model (the basic model and both extensions). By separating them into three succeeding units, we can easily analyze the impact of minimum quantity and supply capacity restrictions by excluding the related units from calculation. The last unit performs all export related actions. It consolidates at the required level by summing up the related data from the product and supply capacity records. After which, it converts all data to usable export files. By simple (de) activating specific parts of the software, we can easily switch between both a gamma and a normal distribution and a fixed and an adapting sigma.

The software needs different sets of input data for its calculations: related to product, lead time, and supply characteristics separately. For this purpose, we developed three types of excel templates. We designed them to be appealing, understandable, and easy-to-use, which contributes to both reducing the usage threshold of the software and its general acceptance. For programming purposes, the input to the software must be as Comma Separated Values (CSV)-files. We designed the templates such that they transpose their data directly to an underlying worksheet that can be saved as a CSV-file. This structure makes it also possible to make changes in the templates, while maintaining the same, fixed CSV-format needed for correctly functioning of the software. Data is exported as a CSV-file under the same motivation and can be loaded into a template as well. Apart from the other benefits, we designed this template in a way to properly support further analysis of the data.

Opening the executable creates a form that basically consists out of two buttons, a memo field, several checkboxes and some text fields. The buttons initiate the actions of the importing & calculation and the exporting process. A checkbox is available to include supply capacity calculations. The quality of several data aspects is checked during the import phase. The results and some process information are displayed in the memo field. The level of consolidation can be selected after the calculations are finished. This is done by checking different check-boxes; each linked to a different echelon. By pushing the export button, the data is consolidated to the required level and is exported as a CVS-file. By transposing it into the output template, we can start with acquiring, analyzing, and comparing (tactical) stock level data.

We programmed the software redundancy avoiding and we presume that its structure is comprehensible to the average Borland Delphi user. This contributes strongly to the computation time, changing / enhancement possibilities, and maintenance.

Chapter 6 Supply chain analyses

This chapter describes the analyses that we perform together with the conclusions that we derive from them. We conduct analyses on the current situation of both portfolios and several scenarios. This provides the second part of our research goal by giving answer to research question 4. We study the outcomes of the calculations and compare them to the tactical stock targets that business unit management uses. The scenario analyses provide us with additional insights in further risks and opportunities as well as in the robustness of the outcomes. We use gamma distributions and adapting sigmas in the underlying calculations (see Section 4.2). We also elaborate on some important side learnings of our research, which have interesting influences on both operational parameter setting and overall supply chain performance. The chapter starts with a section on data cleaning. In correspondence to most reality based data sets, data cleaning is necessary to obtain usable estimations of the demand distributions. This process bears an important influence on the reliability and the scientific value of our research. We provide addition background information on the analyses and the data cleaning process in Appendixes VI, VII, and VIII.

6.1 Data cleaning process

The model uses an estimation of the demand distribution based on the forecast error, to which we further refer as sigma. This is in line with the ISP-policy, which uses demand forecasts in its inventory position calculations. In Section 3.4, the underlying formulas for both a normal and a gamma distributed variant were described. A good estimation is essential for reliable model outcomes, as it has the major impact on safety stock levels. This section is oriented on the data sets that we use to obtain these estimations. Disposing them of erratic and obscure values is consequently essential to this as well.

We perform our analyses over the rolling forecast period from October 2007 up till March 2009. For our estimations of the forecast errors, we use the historical data available on the monthly demand forecasts and billed quantities of the preceding two years. We translate calculated standard deviations in correlation variants to fit the steady-state, rolling horizon characteristic of the model. We submit the data to a set of criteria established by the project team. These criteria are:

- *At least 1/3 of the periods with a forecast has also real sales*
- *The correlation variant is smaller than 2.5*
- *At least 5 out of the 24 periods have a forecast present*

It is the opinion of the project team that not meeting these criteria implies that the underlying data is polluted, incorrect, or incomplete. Consequently, the quality of the estimation of the standard deviation and the correlation variant becomes doubtful and by this unusable. We classify these combinations equal to products with a limited demand history. According to Silver et al. [1998], in these cases the correlation variant of more established items of the same inventory population often provides a reasonable fit. Therefore, we decide to replace the correlation variant of the combinations that do not meet the criteria, with the average of the combinations of the same product group that do meet them. Table 4 displays a summarized overview of the results of this process. In Appendix VI, we present more detailed overviews on product group level.

product / RDC-combinations		
	#	%
Total	1363	
Pass criteria	835	61%
Fail criteria	528	39%

Reason for failure		
	#	%
< 1/3 FC has RS	372	27%
C.V. > 2.5	195	14%
< 5 periods FC	322	24%

Average C.V.	
0,52	
No FC & no RS	
94	7%

Table 4: summarized results of data cleaning process

We find the results of the data cleaning process surprising. We presumed that at least a part of the combinations would not meet the criteria, as is the case with most reality based data sets. We did however not expect that this would enclose on average almost forty percent. We conducted more in-depth analyses on these results, which provided us with additional and interesting insights. We briefly describe several of these insights in the following list:

- Numerous combinations have limited or no historical demand forecast present. This would have a devastating effect on the forecast driven ISP-policy. At the start of our research, the concerning portfolios were however still using reorder point based policies with standard deviations on the demand distribution instead of on the forecast error.
- There are strong mutual relationships between the three criteria. Combinations fail on average on 1.6 criteria simultaneously. Correlation variants that are larger than 2.5, do not meet 2.2 of these criteria on average. This supports our assumption that high correlation variants are often a result of limited data or lumpy demand.
- The Halogen portfolio has both a higher fail rate on the criteria and a higher average correlation variant than the TL / CFL-ni portfolio; respectively 42% vs. 37% and 0.60 vs. 0.47. This seems to correspond with the faster evolving and more unpredictable nature of the consumer market. The lowest correlation variant and fail rate on a product group level are related to the professional market; respectively 0.37 and 26%.
- Almost seven percent of the combinations have neither historical demand forecast nor real sales over the past two years. They might be marked as inactive and clutter the overall picture. Without these combinations, the total fail rate declines from 39% to 34%.

We link the cleaned data set to the demand forecast for the upcoming 18 months. The results are depicted in Table 5. A large set of combinations that are present in the historical data are not present in that of the upcoming 18 months. The majority of these did not meet the criteria as well. This is mainly due to the improved forecast activities and product maintenance, resulting from the growing awareness on their impact on the upcoming ISP-policy. Around a quarter of the used correlation variants are now based on the average of that of the related product group; 4% due to new combinations and 22% due to rejected own ones. This will have some impact on the reliability of the outcomes of the model and the conclusions.

product / RDC-combinations					
With MTP	1071		+ history	993	93%
+ existing 12nc	1030	96%	+ own C.V.	794	74%

Table 5: input data & used Correlation Variants

6.2 Analyses on current situation

This section describes the analyses that we performed on the current situation of both sets of product portfolios. The outcomes of the calculations on the weekly stock, service, and capacity utilization levels are the starting point. It is based on the demand forecast for the upcoming 18 months that was available in October 2007. We used the data on the year 2008 for further in-depth analyses. This selection encloses a complete fiscal year and prevents a disproportional influence of seasonality. The section focuses mainly on the conducted highest level analyses and the resulting conclusions. We refer to Appendix VII for the analyses and underlying data at the product group or production facility level. In this section, we answer research question 4a.

6.2.1 Supply group TL/CFL-ni

At the start of the project, business unit management selected several product groups from this supply group to be included in the analyses. This selection was based on their representative value and capacity dedication at the three related production facilities (see Section 1.4). We show a summarized result of the calculations in Table 6. It is based on the weekly estimations over the year. The table states outcomes in weeks of supply instead of percentage of the Moving Annual Total (see Section 2.4). Although the latter is more commonly known and used within the organization, the former is more in line with the ISP- philosophy.

Estimated stock level for 2008
(in weeks of supply)

	Minimum	Average	Maximum
Total Stock level	2,7	3,0	3,7
Pipeline Stock	1,8	2,1	2,5
Goods in Transit	0,5	0,6	0,7
Physical Stock	2,1	2,4	2,9
Safety Stock	1,0	1,2	1,7
Anticipation Stock	0,0	0,0	0,0

**Without capacity restrictions*

	Minimum	Average	Maximum
Total Stock level	3,2	3,8	4,6
Pipeline Stock	1,4	2,1	2,6
Goods in Transit	0,3	0,6	0,8
Physical Stock	2,7	3,2	4,1
Safety Stock	1,0	1,2	1,7
Anticipation Stock	0,2	0,8	2,0

**With capacity restrictions*

Table 6: consolidated estimated stock levels for 2008

Without capacity restrictions

We conclude that, for the year 2008, realistic weekly tactical stock targets for the portfolio as a whole lie between 2.7 and 3.7 weeks of supply with an average of 3.0 weeks. The underlying weekly variation can be solely ascribed to the changes in demand forecast and their impact on other characteristics. After all, demand forecast is the only changing variable. Its relative small spread is in line with the demand stability and limited seasonality effects of this portfolio. An average 1.2 weeks are required as safety stock to obtain the service level of 95%. The remaining 1.2 weeks of physical stock is needed for cycle and minimum order related purposes. When comparing the three facilities (see Appendix VII), we see that Chalon and Pila have equal average total stock levels of 3.1 weeks. Chalon needs much less safety stock, while simultaneously needing more cycle and minimum quantity stock, and has slightly more goods in transit. It also has the smallest spread in weeks of supply on safety stock, while having the largest on all the other stock types. For Pila on the other hand, this all is exactly the opposite. Roosendaal outperforms the other facilities on all stock types and needs on average 0.4 weeks less total stock. Its spread is equal or close to equal to that of the smallest of the others. Overall we can state that Roosendaal has both the best performance and overall stability. Chalon needs to cope with the largest fluctuations in demand forecast, while also being the best capable to it. Pila seems to be the most sensitive to demand uncertainty. With this facility already performing equal to Chalon, while having the lowest variation in demand forecast of all, we mark it as the most risk full one regarding this portfolio and related characteristics. Strangely, both Chalon and Pila have an almost identical average correlation variant on the forecast error of 0.47 (see Appendix VI). This implies that the much larger sensitivity of Pila is caused by a less evident correlation of other characteristics. The average correlation variant of Roosendaal is the lowest with 0.40. The combined spread of all facilities is equal to or smaller than that of the smallest local spread. The facilities are leveling out each other well.

With capacity restrictions

On average an extra 0.8 weeks of supply is needed to cope with the capacity restrictions (see Table 6). The creation of the necessary anticipation stock elevates the overall average service level to 96.5%. Recall that the service level requirement must be met on a weekly level. If this requirement is set on a yearly level, the total average stock levels can be lowered. Related levels lie between that of the outcome with and without the capacity restrictions. There are large differences between the facilities in built up and height of the anticipation stock. Chalon and Pila need on average only 0.3 weeks with a maximum of less than 2.3 weeks, while Roosendaal needs on average 3.0 weeks with a maximum of 4.8 weeks. Figure 6 shows the estimated stock levels of the product groups linked to the production facility Chalon over the rolling horizon of 2008. Amongst others, it shows an anticipation stock built up from week 22 up till week 31. This stock is necessary to cope with a production stop from week 31 until week 33 and a small capacity shortage from weeks 34 until week 36. The table also shows a corresponding rise in service level in the weeks that anticipation stock is available.

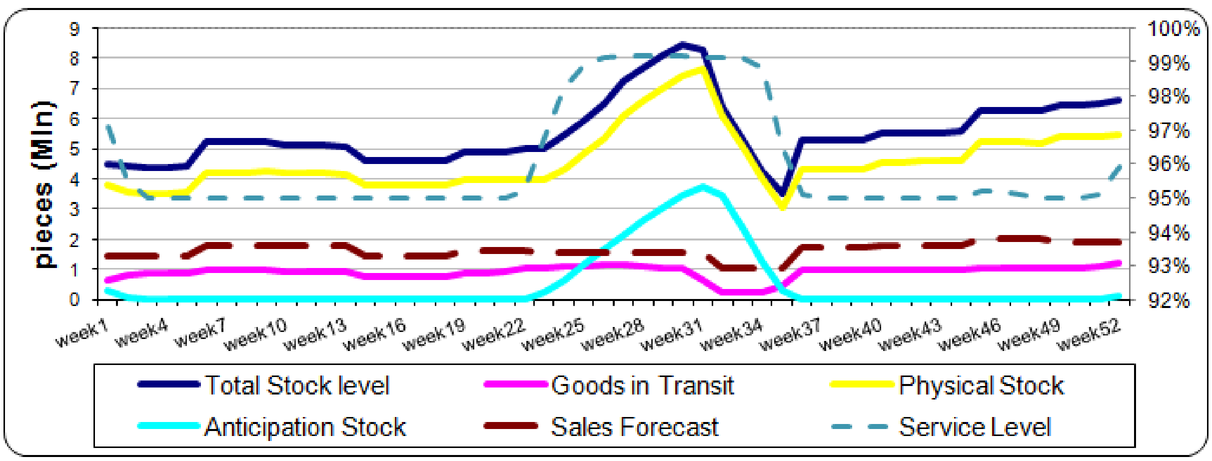


Figure 6: estimated stock levels of CAG 041020 & 041120; prod. facility Chalon in year 2008

We learn from further analyses that the total forecasted demand on Roosendaal lies at a slightly higher level than there is capacity available. This implies that there is a continuing need for anticipation stock which slowly diminishes to the end of the forecast horizon. Pila mainly requires anticipation stock to cover reallocation of equipment in the first quarter of year. Furthermore, it has a large capacity surplus with the exception of periods with regular production stops. Chalon has sufficient capacity to meet forecasted demand and only needs extra stock to cope with such stops as well. In total, there is almost enough capacity available to fully neutralize the reallocation problem of Pila and the regular capacity tightness of Roosendaal. Smartly redirecting capacity to other facilities provides a lower overall total stock level. In reality however, a large risk for declining service levels is likely to remain at Roosendaal due to its structural scarcity of own capacity.

Entitlement

Business unit management has an own strategy for setting stock targets. For each product group, they define the number of yearly stock turns it must achieve. For basic groups this is set to 20 stock turns and for more specialized groups to 15. They translate it to monthly stock levels by using forecasted demand over the interval +/- 3 months. In Table 7, the derived stock turns are compared to outcomes of our model. We conclude that for Chalon and Pila these entitlement levels are set higher than is realistically achievable according to our model. For Roosendaal they are set too low when sufficient capacity can be redirected to it. This supports the presumption of business unit management that such top-down way of target setting is, although very appealing, at a high risk of missing the link with reality.

		Capacity restrictions		
Production facility	Product group	without	with	Entitlement
Chalon	041020 & 041120	17,0	15,4	18,0
Pila	41090	16,7	15,5	19,8
Roosendaal	041010 & 041110	19,6	9,5	15,7

Table 7: estimated versus entitlement stock turns 2008

6.2.2 Supply group Halogen

The product groups that business unit management selected from this supply group were also chosen for their representative value. They are not bound to any restrictions on supply capacity as the supply is fully outsourced to external parties. The summarized result of our calculations is depicted in Table 8 and identical to and under the same motivation as with that of the other supply group. Recall that the analyses are based on the currently used supply flow. In this flow, products go from the Sourcing Agency through the Sourcing DC to the network of RDCs.

Estimated stock level for 2008

(in weeks of supply)

CAG 002040	Minimum	Average	Maximum	*CAG 004440*	Minimum	Average	Maximum
Total Stock level	10,4	12,7	14,3	Total Stock level	10,6	14,2	18,7
Pipeline Stock	10,9	12,4	14,2	Pipeline Stock	9,9	12,8	15,7
Goods in Transit	6,2	7,6	8,9	Goods in Transit	5,7	7,8	10,2
Physical Stock	4,2	5,1	6,4	Physical Stock	4,5	6,4	8,8
Safety Stock	3,5	4,3	5,7	Safety Stock	4,0	5,8	8,1

Table 8: consolidated estimated stock levels for 2008

Based on Table 8, we draw the conclusion that, for the year 2008, realistic weekly stock targets are on average 12.7 and 14.2 weeks of supply at the consolidated level. Over half of this stock is ‘lost’ as goods in transit of which on average only 0.7 week is related to the transportation to RDCs. At any given moment, more than 80% of the physical stock is required for safety stock purposes. This is needed to obtain an operational service level of 97% at a weekly basis. Cycle and minimum quantity stock are relatively low due to a review period of just one week and the possibility of large demand consolidation at the Sourcing DC-level. Despite this consolidation benefit, the safety stock levels are high. We ascribe this to long lead times in combination with large forecast errors.

When comparing both product groups, we conclude that the difference in spread is more than noticeable. The spread of the second group is on the overall level twice that of the first. An explanation is mainly found in the combination of three aspects: a higher correlation variant on forecast error (0.70 vs. 0.52), a smaller product to product/RDC ratio (1:2.0 vs. 1:2.5), and a higher correlation variant of the standard deviation of the demand forecast to its mean (0.21 vs. 0.12). Translated this means that the second group must deal with higher demand uncertainty, has less postponement possibilities, and has a more fluctuating pattern of demand forecast (seasonality). The minimum quantity burden is however smaller for the second group (0.1 vs. 0.3 weeks), due to a higher average demand while having equal related quantity restrictions.

Within the organization, it is commonly comprehended that sourcing supply from the Far East has large effects on the goods in transit levels. This analyses show that it also bears a sizeable effect on the necessary safety stock levels and can result in a very large spread in total stock levels. This pins down much more capital in a more unstable matter than is often anticipated on in reality.

6.3 Analyses on scenarios

In this section, we describe the analyses that we performed on several what-if scenarios. They provide insights in the robustness of and the opportunities and risks on both sets of product portfolios. We performed these analyses under the same conditions as those of the current situations. At times we zoom in to a specific facility or product group level to provide a more usable view. The scenarios were mainly oriented on the supply group Halogen, as improving their performance has currently more attention of business unit management. More in-depth analyses and supporting graphs can be found in Appendix VII. In this section, we answer research question 4b.

6.3.1 Supply flows Halogen

The supply group Halogen sources its products at external suppliers in China. Supply flows in the current situation through the Sourcing DC, which functions as "break bulk"-facility, to the network of RDCs. In this section, we analyze the implications of using the other two available supply flows: Packaging Center and Shortcut flow (see Section 2.2.2). These flows have different impacts on the goods in transit, safety, and minimum quantity stock levels, resulting from other consolidation possibilities and transport routes. Table 9 displays the outcomes for both selected product groups.

Estimated stock level for 2008

(in weeks of supply)

Product group 002040	Physical	GiT	Total	*Product group 004440*	Physical	GiT	Total
All Sourcing DC	5,1	***7,6***	***12,7***	All Sourcing DC	6,4	***7,8***	***14,2***
All Packaging center	4,5	***7,6***	12,1	All Packaging center	5,3	***7,8***	13,1
All Shortcut	**6,5**	6,1	12,6	All Shortcut	**6,9**	6,2	13,0
Sourcing DC, fast & SD --> SC	5,5	6,6	12,1	Sourcing DC, fast & SD --> SC	6,4	6,4	12,8
Sourcing DC, SD --> SC	5,0	7,4	12,4	Sourcing DC, SD --> SC	6,1	6,9	12,9
Packaging center, fast --> SC	4,8	6,8	11,6	Packaging center, fast --> SC	5,8	6,6	12,4

** fast --> fast mover, SD --> single destination, SC --> Shortcut*

Table 9: consolidated estimated stock levels per supply flow variant

Based on Table 9, we conclude that for both product groups the current situation of solely using the Sourcing DC results by far in the worst total stock levels. It is being outperformed by the Packaging Center flow, which has more consolidation possibilities while having almost equal transport times. And the Shortcut flow, which benefits of smaller transportation times outweigh its full lack of such options. The second product group gives a smaller spread in physical stock levels between the three supply flows. This implies that it is less sensitive to influences of consolidation. We find an explanation for this in the earlier described smaller impact of minimum quantity restrictions and its smaller product to product / RDC ratio. This is further strengthened by a much smaller semi-finished to finished product / RDC ratio (1:2.3 vs. 1:13.7), relevant to the Packaging Centers. We expect that an optimal tradeoff between transport time and consolidation possibilities is found in a combination of the three supply flows. We selected three other variants in which the Packaging Center or the Sourcing DC flow is combined with the Shortcut flow. All of them outperform the current flow quite well. Of this, using the Shortcut flow for fast moving products and the Packaging Center flow for the remainder leads to the largest possible gain in total stock level reduction (resp. with 1.1 and 1.8 weeks of supply).

6.3.2 Service level

In this section, we discuss the impact of different service level requirements on total stock levels. This provides more insights in the robustness of supply chain performances and the possible consequences of altering service level requirements. In essence, these only influence safety stock levels. Related sensitivity depends strongly on the possibility to postpone allocation and in a lesser extent on lead time duration. By this, we expect that the Packaging Center flow bears the most stable set of outcomes, followed by the Sourcing DC flow. The Shortcut flow, with no possibilities to postpone allocation, would be the most sensitive of all. Table 10 shows the outcomes for one Halogen product group and the TL/CFL-ni production facility Chalon. For the Halogen group, we selected the best performing variant per standard supply flow.

Estimated total stock level for 2008

(in weeks of supply)

Product group 002040	**GiT**	**90%**	**95%**	**97%**	**98%**
Sourcing DC, fast & SD --> SC	6,6	10,7	11,6	12,1	12,6
Packaging center, fast --> SC	***6,8***	10,6	11,2	11,6	11,9
All Shortcut	6,1	***11,1***	***12,0***	***12,6***	***13,2***

Product groups 041020 & 041120	**GiT**	**90%**	**95%**	**97%**	**98%**
Without capacity restrictions	0,6	2,7	3,1	3,3	3,5
With capacity restrictions	0,6	3,1	3,4	3,6	3,8

** fast --> fast mover, SD --> single destination, SC --> shortcut*

Table 10: estimated stock levels per service level requirement

Based on Table 10, we conclude that the Packaging Center flow, with fast moving products through the Shortcut flow, outperforms the two other variants on each level. Not surprisingly, it also has the smallest spread, due to its largest postponement possibilities. This implies that the higher the service level requirements are set, the more this variant outperforms all others. It even requires 0.8 weeks of supply less stock than the current Sourcing DC flow, while obtaining a 1% higher service level. Benefits of postponement get smaller when requirements are set to a lower level, as it leads to more equal safety stock levels between the variants. Goods in transit and minimum quantity stock levels start to weigh more heavily on overall performance. The Shortcut flow, with the least performance and highest spread, has the most to gain by such scenario. It might eventually outperform the other variants if requirements are set very low and the influences of minimum quantity restrictions are limited. The Sourcing DC flow, with fast moving and single destination products through the Shortcut flow, seems to be an acceptable second best option when service level requirements are set not to high.

For the product groups related to the production facility of Chalon, we conclude that changes in service level requirements have a limited influence on overall stock levels. A rise from the current 95% to a possible 98% needs only 0.4 weeks of supply (or 14%) more total stock. With a high correlation variant on forecast error (0.47) and a low product to product/ RDC-ratio (1:1.9), this must be mainly due to large influences of minimum quantity restrictions and small lead and review times. Not surprisingly, there are no differences regarding the capacity restrictions, as the related anticipation stock is placed on top of the other stock types.

6.3.3 Forecast accuracy

In this section, we discuss the impact of changes in forecast accuracy on the total stock levels. It gives insights in the sensitivity to and relative importance of the quality of the demand forecasts. Initial influences are found on safety stock levels only. The sensitivity depends on the size of the correlation variants on the forecast error, the lead time durations, and the possibilities to postpone allocation. Table 11 depicts the outcomes for the same set of product groups as in the previous section. The percentages relate to the changes made on the correlation variants between the forecast's error and its mean on the product/RDC-level.

Estimated total stock level for 2008

(in weeks of supply)

Product group 002040	**GiT**	**-60%**	**-40%**	**-20%**	**0%**	**20%**	**40%**	**60%**
All Sourcing DC	***7,6***	***9,9***	***10,7***	***11,7***	***12,8***	***13,9***	15,2	16,6
Sourcing DC, fast & SD --> SC	6,6	8,9	9,9	10,9	12,1	13,4	14,9	16,5
Packaging center, fast --> SC	6,8	9,0	9,8	10,6	11,6	12,7	13,8	15,1
All Shortcut	6,1	9,0	10,0	11,1	12,4	13,8	***15,3***	***17,0***

** fast --> fast mover, SD --> single destination, SC --> shortcut*

Product groups 041020 & 041120	**GiT**	**-25%**	**-10%**	**0%**	**10%**
Without capacity restrictions	0,6	2,7	2,9	3,1	3,3
With capacity restrictions	0,6	3,0	3,2	3,4	3,6

Table 11: estimated stock levels related to change in correlation variant on forecast error

When studying Table 11, the first thing that we notice is the large spread in total stock levels. We conclude that for this selection the supply chain performance is highly sensitive to changes in forecast accuracy. This is largely explained by the related high average correlation variants in combination with large lead times. A small improvement of the demand forecasting quality supports large reductions in the total stock levels. For the current situation, an improvement of 20% results in a 1.1 weeks of supply (or 9%) lower total stock target. The spread per supply flow variant seems to be in line with the possibilities to postpone allocation. The Packaging Center flow, with fast moving products through the Shortcut flow, outperforms the other variants also on this criterion and remains the most robust. Interestingly, the current situation is again largely inferior to the others. Its higher goods in transit levels keep out weighting its benefits from consolidation on minimum quantity restrictions and demand uncertainty. The Shortcut flow remains the most sensitive one, leading to inferior performance at lower forecast accuracy levels. For the product groups related to the production facility of Chalon, we notice a high sensitivity to the quality of demand forecasts as well. An improvement of 10% results in a possible reduction of 0.2 weeks of supply (or 7%) on the total stock level.

This analysis confirms the importance of reliable demand forecasts. Recall that these forecasts are in basic coming from the sales organizations, which are not accountable for stock levels. The quantitative foundation of this analysis can add more emphasis on the quality of their forecasting process and provide business unit management in more related leverage.

6.3.4 Transport times

The supply group Halogen sources its products at external suppliers in China. The related longer transport times to the European distribution network bears a negative impact on the stock levels. This impact is both on goods in transit and on safety stock levels, as demand uncertainty is spread over a longer period of time. Management considers reducing transport times by selecting train instead of sea carriers for these routes. In this section, we discuss their impact on the stock levels, which can support the related decision making. Table 12 depicts the outcomes for the same group that was elaborated on in the previous sections.

Estimated stock level for 2008

(in weeks of supply)

	By sea			By train			Reduction in
Product group 002040	**Physical**	**GiT**	**Total**	**Physical**	**GiT**	**Total**	**stock levels**
All Sourcing DC	5,1	***7,6***	***12,7***	4,6	***3,7***	8,3	4,4
Sourcing DC, fast & SD --> SC	5,5	6,6	12,1	5,0	3,5	8,5	3,6
Packaging center, fast --> SC	4,8	6,8	11,6	4,4	3,5	7,9	3,7
All Shortcut	***6,5***	6,1	12,6	***6,0***	3,3	***9,3***	***3,3***

** fast --> fast mover, SD --> single destination, SC --> shortcut*

Table 12: estimated stock levels related to reduced transport times (train vs. sea)

When studying the table above, it becomes clear that shipping supply from China by train instead of by sea has a strong positive influence on the total stock levels. It can on average lower the goods in transit levels by 3.3 weeks, while also reducing the physical stock levels by an additional 0.5 weeks. The extent of this gain differs largely between the variants regarding to the goods in transit levels. While the current variant can reduce it by 3.9 weeks, the Shortcut variant's gain only reaches up till 2.8 weeks. This deviation depends mainly on the geographic location of the facilities in relation to the two different transport routes. The current variant for example needs relative long transport times when being supplied by the west (sea), while needing the shortest times when being supplied by the east (train). The gain in physical stock levels is solely due to reductions in safety stock levels, which results from smaller exposures to demand uncertainty. With a maximum difference of 0.1 weeks between the variants, we call its mutual effect marginal. The variants with better possibilities to postpone allocation are slightly less sensitive to lead time reduction, as they can partly nullify this uncertainty.

The current situation has the most to gain when supply from China is being shipped by train instead of by sea. It leads to a reduction of its total stock level with more than 4.4 weeks of supply. This makes it the second best variant regarding this scenario. We mark this as quite interesting, as on the other scenarios it almost structurally performs inferior to the others. The Packaging Center flow, with fast moving products through the Shortcut flow, remains outperforming the other variants. With the reduced transport times, it only needs a total of 7.9 weeks of supply in comparison to the 11.6 weeks under normal circumstances. The Shortcut flow has the smallest gain of all, which is caused by its relative small reduction in transport times.

6.4 Side learnings

In this section, we describe two side learnings of our literature study that we perceive as having interesting and not neglect able influences on overall supply chain performance and operational parameter setting. In Section 6.4.1, we elaborate on the impact of using inappropriate estimators of the demand distribution and of using a fixed sigma in our non-steady state environment. In Section 6.4.2, we quantify the positive effects of the ability of the ISP-policy to partially postpone the allocation of replenishment orders.

6.4.1 Demand distribution & sigma

Within the organization, estimations of demand uncertainty were traditionally based on the standard deviation over lead time on the historical demand. The resulting sigmas were mostly calculated once per semester and, for reasons of convenience, assumed to be normally distributed. For the product groups and replenishment policy under study, this is far from an appropriate estimation and it leads to significant under- as well as overestimations of the safety stock levels necessary. We already elaborated on our motivation behind this statement in Sections 4.2.3, 4.2.4, and 6.1. We summarize it as follows:

- The ISP-policy is forecast driven by which the demand uncertainty needs to be estimated based on the differences between real and forecasted demand: the forecast error (see Section 4.2.3).
- A large part of the products under study have a ratio between the forecast error and the forecasted demand larger than 0.5 (see Section 7.1). Because of this, assuming a normal distribution underestimates the safety stock levels. A gamma distribution provides a more adequate approximation (see Section 4.2.3)
- Using a fixed sigma with a changing demand forecast leads to both under- as well as overestimation of safety stock levels at different moments in time. A constant ratio between the historical forecast error and forecasted demand is far more appropriate (see Section 4.2.4).

In Figure 7, we show the impact on safety stock level outcomes of using a gamma or a normal distributed forecast error in relation with a fixed or an adapting sigma.

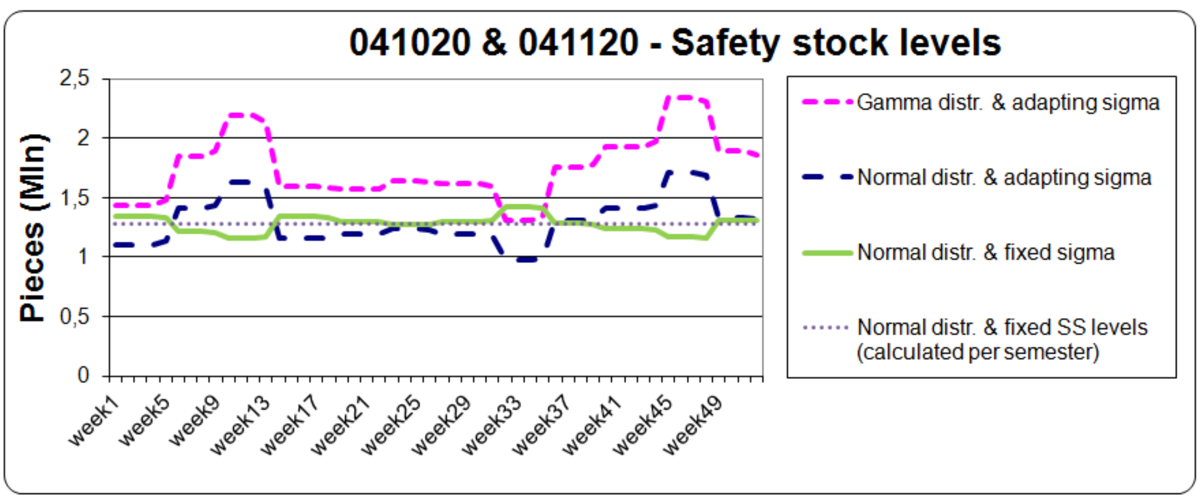


Figure 7: estimated safety stock levels for the Chalon facility over the year 2008

The option, based on gamma distributions and adapting sigmas, estimates by far the highest levels. It represents the best approximation for the selected product groups and replenishment policy. Consequently, we use this distribution for all the calculations of our research. The option, based on normal distributions and fixed safety stock levels calculated per semester, represents the traditional estimation of uncertainty used by the organization. It estimates an average 27% less safety stock to obtain the weekly operational service levels. At the highest point, it even estimates 45% less safety stock. We must draw the conclusion that the way in which the organization is estimating the influences of demand uncertainty leads to a large overall underestimation of the safety stock levels for at least the product groups under study. As these groups were selected for their representative value, we expect that the same is true for similar not included product groups. Setting safety stock levels in coherence with these estimations results in far lower than required overall service levels.

6.4.2 ISP & partial postponement

The upcoming ISP-policy has the standard ability to partially postpone the allocation of replenishment. At the higher echelon, purchase or production orders are generated based on the consolidated replenishment orders of the separate product / RDC-combinations. The real allocation to the lower echelon takes place just before shipping. This is based on the actual relative inventory position of the combinations. Management defines this feature as a key asset of the new replenishment policy and likes to gain more quantified insights in its benefits on overall supply chain performance. These insights can also support gaining further company-wide acceptance for the ISP-policy. Figure 8 displays the effects of partial postponed allocation for the selected product groups of the production facility in Chalon.

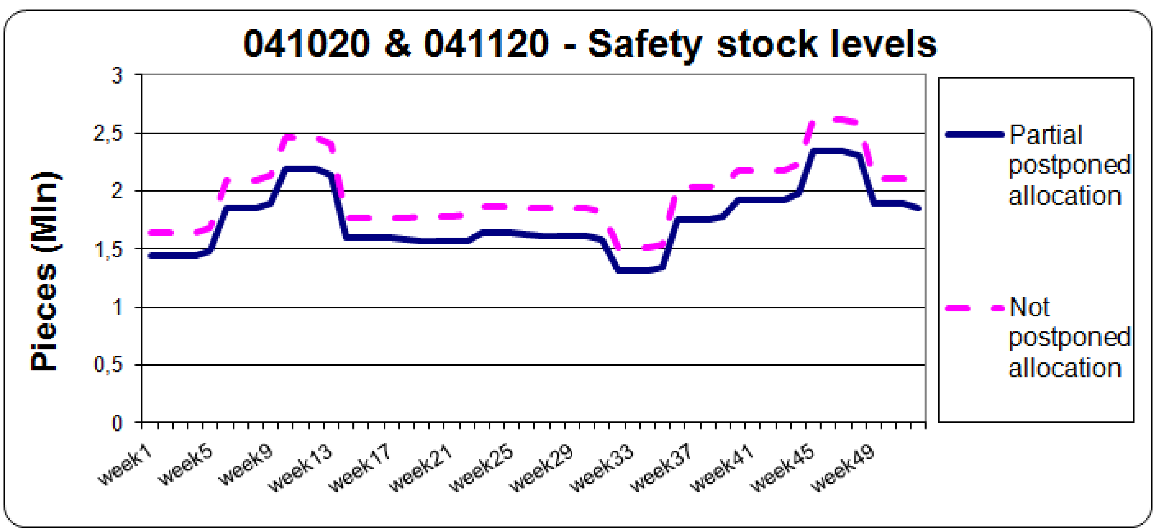


Figure 8: estimated safety stock levels for the Chalon facility over the year 2008

For the product groups depicted in Figure 8, the benefit of partial postponed allocation is on average 12%. The extent of this benefit depends mainly on the size of the forecast error, the product to product / RDC ratio, and the relative size of the higher echelon lead times. The reduction in safety stock levels for the complete set of product groups under study is on average 15%.

In this chapter, we described the performed analyses together with the conclusions that we derived from them. We started with a section on data cleaning, as data cleaning was necessary to obtain usable estimations of the demand distributions. Next, we conducted analyses on the current situation of both portfolios and several scenarios. We studied the outcomes of the calculations and compare them to the tactical stock targets that business unit management uses. The scenario analyses provided us with additional insights in further risks and opportunities as well as in the robustness of the outcomes. With this, the chapter answers research question 4 and we consequently realized the second part of our research goal. Additionally, we elaborated on some important side learnings of our research, which have interesting influences on both operational parameter setting and overall supply chain performance.

Chapter 7 Conclusions & Recommendations

In this chapter, we review the conclusions and recommendations of our research. We discuss the conclusions that we draw from the literature study, the realization of the software and model, and the conducted analyses on the current situation and the scenarios. We conclude the chapter with a set of final recommendations for business unit management.

7.1 General conclusions

This thesis started with the aim of management to gain deeper insights in the relationship between stock and service levels at the consolidated level. Management chooses related targets empirically based on historical achievements and the always-existing pressure to lower inventory costs. The first part of our research goal encloses the development of a model to estimate optimal tactical stock levels based on operational requirements and characteristics. Such bottom-up built method supports management in setting realistic tactical stock targets. This section describes the main conclusions we draw from the realization of this first part of our research goal:

- We developed a bottom-up built model to estimate optimal tactical stock levels based on a large set of operational characteristics and requirements. It provides weekly stock levels on a rolling horizon for the upcoming 18 months. The model is in line with the ISP replenishment policy, uses service level requirements and demand forecasts, takes supply capacity restrictions into consideration, and can deal with different supply flows simultaneously.

- The model is based on a two echelon divergent steady-state model of a periodic-review, order-up-to-level system with partially postponed allocation of stock and no central stock. It uses gamma distributed estimations of the forecast error as demand distribution. An adapting sigma is used to cope with changes in demand forecasts over time. We use a new heuristic approach to include minimum quantity restrictions and a deterministic one to include capacity restrictions on supply.

- The model provides outcomes that meet the required accuracy of our research. It is based on several assumptions on and relaxations of the environment, which have their impact on its accuracy and reliability. Extension possibilities are available to improve these and to provide additional insights in the performance of the supply chain.

- We developed software in Borland's Delphi 7 to perform all the necessary calculations. We perceive it as very suitable for gaining further insights in the characteristics and behavior of supply flows and product groups. It also provides a very usable platform for performing in-depth and scenario analyses.

- During the literature study, we learned that the organization is estimating demand uncertainty in an inappropriate way. This results in an almost structural underestimation of necessary safety stock levels. We elaborated on this observation and its overall effect on the performance of the supply chain in Section 6.4.

7.2 Analyses conclusions

In this section, we describe our main conclusions of the analyses that we conducted on both the current situation and several scenarios. The underlying outcomes are based on the model and the software that we developed during this research. The analyses all relate to the book year 2008, resulting from the demand forecast for the upcoming 18 months available in October 2007. We used the historical data on forecasted demand and billed quantities of the preceding two years for the estimation of the forecasts errors.

Data cleaning for forecast error

- The average correlation variant between the forecast error and its mean is high for the selected product groups of the supply groups Halogen and TL/CFL-ni (respectively 0.60 and 0.47). This has a substantial negative influence on the necessary safety stock levels. The assumption that the forecast errors are normally distributed becomes inappropriate and results in underestimating the effects of demand uncertainty. We selected a gamma distributed orientation as a better approximation, which we further used in the model and its calculations.

- The historical data on 26% of the product / RDC-combinations do not meet the data cleaning criteria for the estimation of forecast errors. Marked by the project team as unreliable, we replaced them with the average correlation variant of the approved combinations of the same product group.

Supply group TL/CFL-ni

- Between 2.7 and 3.7 weeks of supply, with an average of 3.0 weeks, is needed as total stock to obtain a weekly operational service level of 95% for the complete portfolio.

- An average extra 0.8 weeks of supply is needed to cope with the capacity restrictions of the production facilities. The availability of related anticipation stock elevates the overall average service level to 96.5%.

- The Roosendaal facility has the best performance and overall stability. Chalon needs to cope with the largest fluctuations in demand forecast, while also being the best capable to it. Pila is the most sensitive to demand uncertainty. In the long run, Chalon and Pila have sufficient capacity available to limit the need for anticipation stock. Roosendaal however requires an average extra 3.0 weeks of supply when no extra capacity is redirected to it.

- For the facilities in Chalon and Pila, business unit management chooses entitlement stock levels that are higher than realistically achievable: respectively 17.0 vs. 18.0 stock turns and 16.7 vs. 19.8 stock turns (when capacity restrictions are excluded). For the facility in Roosendaal, they are set too low when sufficient supply can be redirected to it: 19.6 vs. 15.7 stock turns.

- Forecast accuracy has a strong effect on necessary safety stock levels. A reduction of the relative correlation variants on forecast error of 10% reduces safety stock levels with an average 17%. Changes in service level requirements seem to have a limited influence. A rise from the current 95% to a possible 98% needs 0.4 weeks of supply (or 14%) more total stock for the facility in Chalon.

Supply group Halogen

- To obtain weekly operational service levels of 97%, an average 12.7 and 14.2 weeks of supply are respectively needed for the product groups 002040 and 004440 as total stock. Over half is consumed as goods in transit of which on average 0.7 week relates to the transport to the RDCs. More than 80% of the physical stock is required as safety stock.

- The weekly total stock levels fluctuate largely over the year, which is a result of the strong seasonal demand patterns. At the highest point, the second product group requires 18.7 weeks of supply as total stock. In comparison with the first product group, this group has the highest overall stock levels and spread. This is mainly caused by larger forecast errors, more fluctuating forecasts of demand (seasonality), and fewer possibilities to postpone allocation of stock.

- The current supply flow through the Sourcing DC performs inferior to all other evaluated flows. The best performing alternative, in which fast moving products flow directly to the RDCs and the remainder through the Packaging Centers, requires respectively 1.1 (-9%) and 1.8 (-13%) weeks of supply less total stock.

- Forecast accuracy has a strong effect on necessary safety stock levels. A reduction of the relative correlation variants on forecast error of 20% reduces safety stock levels with an average 26% for the Sourcing DC flow. Changes in service level requirements have a limited influence. A rise from the current 97% to a possible 98% needs on average 0.6 weeks of supply (or 5%) more total stock for the first product group.

- The supply flow through the Sourcing DC performs almost structurally inferior to the other variants regarding the scenarios on service level and forecast accuracy. Its advantages from extended consolidation options of demand uncertainty are out weighted by its disadvantages of longer transport times.

- The Packaging Center variant, with fast moving products flowing from the Sourcing Agency directly to the RDCs, outperforms all other variants regarding the scenarios on service level and forecast accuracy. It is by far the best performing and most robust variant analyzed. It combines the benefits of shorter lead times for the fast moving products, with those of extended consolidation options for the remaining products. With this variant, the overall service level can rise from 97% to 98%, while still reducing the total stock level with 0.8 (- 6%) weeks of supply in comparison to the current situation of the first product group.

- We mark the Sourcing DC variant, with fast moving and single destination products flowing from the Sourcing Agency directly to the RDCs, as the overall second best performing variant. It requires respectively 0.6 (-5%) and 1.1 (-10%) weeks of supply less total stock then the current situation and has a moderate robustness regarding the analyzed scenarios.

- Shipping supply from China by train instead of by sea has a strong positive influence on total stock levels. It lowers the goods in transit levels by 3.9 weeks, while also reducing the physical stock levels by an additional 0.5 weeks for the current situation of the first product group. This brings the total stock level to an average 8.3 (-35%) weeks of supply. It brings the Packaging Center variant to an average 7.9 weeks of supply, which is a reduction of 38% in comparison to the current situation of the first product group.

7.3 Recommendations

In this closing section, we describe our concluding recommendations to the supply chain management of business unit Professional Lamps Europe. Based on the literature study, derived model, and conducted analyses, they apply initially to the included product groups of the supply groups TL/CFL-ni and Halogen. As these were selected for their representative value, the outcomes also bear relevance to similar product groups of these portfolios.

1] Consider the development of a professional tool based on the developed model and software. With sufficient ICT-resources, it can become perfectly suitable for target / parameter setting and in-depth / scenario analyses on both the operation and managerial level. Step-by-step extension also increases its accuracy, makes it more applicable for other supply chain configurations, and supports in gaining further supply chain insights.

2] Stop using tactical stock targets solely based on large time intervals. They considerably under- and overestimate realistic stock targets at different moments in time. This leads to disturbing messages and corrective activities throughout the supply chain.

3] Review supply chain performance over the year 2008 based on the tactical stock levels calculated in this research. Reviewing it on the weekly and average year level provides realistic insights in the actual and structural performance of whole product groups.

4] Consider to strongly increase the efforts and available resources for improving forecast accuracy. Currently, at least 80% of the targeted physical stock levels of the Halogen portfolio are on average required to neutralize the effects of demand uncertainty on service level performance.

5] Consider redirecting the flow of the fast moving products of the Halogen portfolio from the Sourcing Agency directly to the RDCs and the remainder through the Packaging Centers. This leads to an average reduction of 11% in total stock levels compared to the current supply flow. Only redirecting the flow of the fast moving and single destination products directly to the RDCs leads to an average total reduction of 8%.

6] Consider shipping supply from China by train instead of by sea. We expect that this leads to an average reduction in total stock levels of 35% for the current situation of the Halogen portfolio and in a 38% reduction for the discussed Packaging Center variant.

7] Switch as soon as possible to a more appropriate estimation of the demand uncertainty, as the current one results in an average 27% underestimation of necessary safety stock levels. While using the ISP-policy and being subjected to low forecast accuracies, let these estimations at least be based on gamma distributed forecast errors. Using a related weekly based correlation variant between the forecast error and the forecasted demand, results by far in the best approximation and consequently overall performance.

8] Enable / support further research in the feature of forecast consumption of the ISP-policy. We expect that describing its working mathematically and performing addition analyses leads to interesting new scientific material, a more accurate model, and improved quantified insights in the overall benefits of the ISP-policy.

Appendix

I. List of abbreviations

Packing Center	*PMPC*
Production facility	*IPLC*
Sourcing DC	*IBLC*
Sourcing Agency	*CSG*
Product group	*CAG*
Semi-finished product	*10nc*
Finished product	*12nc*
10nc	*Finished product that is not stamped and packed*
11nc	*Finished product that is stamped but not packed*
12nc	*Finished product that is packed and stamped*
SG	*Supply group*
MG	*Market group*
MAG	*Main Article Group; consists out of multiple Article Groups*
AG	*Article Group; consists out of multiple Committed Aggregation Groups*
CAG	*Committed Aggregation group; product group with committed production machinery / capacity*
CSG	*China Sourcing Group; department of Philips Lighting responsible for coordinating sourcing activities from China.*
IPLC	*International Production & Logistic Center / production facility*
PMPC	*Post Manufacturing & Packaging Center / production facility; converts 10nc's into 12nc's*
IBLC	*International Buying & Logistic Center / distribution center; receives the regular inbound supply flow of sourced products*
RDC	*Regional Distribution Center; is supplied by the IPLC, PMPC or IBLC*
DC	*Distribution Center; small (forward) DC linked to a specific RDC*
SAP	*Systems Applications Software; ERP-software*
SAP BW	*SAP Business Information Warehouse; business intelligence module*

II. Project charter (latest version)

Project Charter

Philips Business Unit: Professional Lamps Europe

Project Title: Tactical Stock Level Setting

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Business Case

BU-management wishes to gain a deeper insight in the relationship between stock levels and service level (Customer Requested Delivery Date) and become more supported in setting appropriate stock targets for finished goods.

Having a funded, bottom-up build, method to set tactical stock targets based on CRDD, will help to obtain the required service level, with minimal stock levels. It also supports BU-management in setting realistic medium term stock levels for Supply Groups as a whole.

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Opportunity Statement

Problems:
- Difficulty in setting stock targets due to (amongst others) WEEE impact; long lead-times BfR flow from China; acquisitions; reallocations; changes in replenishment policies, supply chain configuration and stock valuation
- Increasing complexity due to a growing product portfolio
- Increasing percentage of BfR-products in the product portfolio

Opportunities:
- Having a commonly accepted method to set realistic stock levels; a bottom-up build method will help gaining acceptance at operational level
- Having a method to experiment with changes in environment, (standard) operating procedures; forecasting accuracy; supply chain and production configuration

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Goal Statement

Develop a method to set realistic tactical stock levels based on required service level. Built up for dimensions at 12NC level, the method must support BU-management in setting medium term stock targets at CAG-level and higher. The method should also, but in a lesser extend, support IPLC-planners in setting / evaluating their stock replenishment parameters.

Deliverables:
1 Documentation on current practices at CAG-level and analyses on stock level, CRDD etc.
2 Method to set realistic tactical stock levels; tactical level is defined as medium term / CAG-level and higher
3 Implementation plan; advice on how Philips should go on with the project.
4 Improvement ideas and advice on parameter setting

Target:
A method to set realistic tactical stock levels

Constraints:
- Method must be able to deal with a changing environment and seasonality
- Method must be in line with the upcoming ISP and S&OP projects
- Method must be compatible with the SAP-environment; easy to maintain
- Method must be easy to understand and be supported by the IPLC-planners

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Project Scope

Organization in scope:
BU PLE SG TL/CFL-ni
BU CLE SG Halogen

Products in scope:
- All 12NC products of SG TL/CFL-ni belonging to the CAG's 041010 / 20 / 90 and 041110 / 20 / 90
- All IBLC 12NC products of SG Halogen belonging to the CAG's DICHROIC (2040) en TWISTLINE (4440)

In scope:
- Impact of forecasting accuracy, seasonality, equipment utilization strategies, events, supply chain configuration and operating procedures on the stock levels necessary to achieve the required service levels
- Plan for implementation

Out of scope:
- CMSU CRDD; distribution costs; components stock levels
- Changing supply chain configuration
- Implementation

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24-10-2007 14:11:00 Version: 1.6

Project Team

Name	Function	Role	% of time
Robin Boerrigter	Intern	Project leader	100%

Project Steering Group

Name	Function	Role
Hylke de Cock	VP SC BU PLE	Project Principal
Marco Bachrach	SC consultant SG TL/CFL-ni	Representative SG / knowledge carrier
Johan van der Werf	Jr. SC consultant BU CLE	Representative SG / knowledge carrier
Lonneke Driessen	Senior SC consultant / Black Belt	Coach
Johann Hurink	University of Twente	Representative University of Twente / Chairman graduation commision

Project Reference Groups

Name	Role
Antoon Martens	SC Manager BU CLE
John van den Anker	Logisitic Manager CFL-I and Hal
Jeroen van Weesep	SC manager SG TL/CFL-ni

Date: 24/10/2007 14:11:00
Document: Project charter TSLS 1.6

III. Initial project description

This appendix shows the initial description of the project, which was formulated by the principal and initiator of the project: Hylke de Cock. It has been drawn up prior to the approval of the project as a graduation assignment. To maintain its authenticity and prevent damage to its content, it is shown in the original language.

Voorlopige beschrijving opdracht:

Probleem:
In de loop van de afgelopen jaren is het voorraad niveau in de Business Unit Lampen (Europa) structureel toegenomen, terwijl de service graad (CRDD) niet is verbeterd. De druk op voorraden en kosten neemt toe, terwijl uit klantentevredenheidsonderzoeken (CSS, CVS) blijkt dat de onvrede over de service graad toeneemt.

Opdracht:

- *Het uitvoeren van een analyse van de huidige voorraad niveau en servicelevel (CRDD) in TL/CFLni;*
- *Het ontwikkelen van een methode om tot gefundeerde target setting van voorraden te komen, op basis van integrale optimalisatie;*
- *Het opstellen van een strategische doelstelling voor voorraden, vanuit integraal performance-denken;*
- *Het ontwikkelen van een proces om met deze target setting om te gaan gedurende het jaar, zodat targets bijgesteld kunnen worden op basis van actuele informatie door veranderende omstandigheden.*
- *Advisering over methode van implementeren binnen Supply Groep TL/CFLni en naar andere Supply Groepen binnen de Product Divisie Lighting.*

Scope:
Dit project zal onderdeel zijn van een groter programma. Het onderzoek zal zich beperken tot de Supply Groep TL/CFLni (4 fabrieken: Roosendaal, Chalon, Pila, terneuzen), te beginnen met Roosendaal. Parallel wordt een soortgelijk onderzoek uitgevoerd bij een Supply Groep die producten uit Azie betrekt (IBLC). Beide projecten worden door dezelfde Senior SC consultant gecoached.

Project organisatie:
Principal: Hylke de Cock (SC Manager BU Professional Lamps)
Coach: Lonneke Driessen (SC competence Center, Black Belt)
Stagiair: Robin Boerrigter
Universtiair begeleider: .. TBC

Timing:
20 weken

Standplaats:
Eindhoven

Randvoorwaarde/next steps:
Accordering onderzoeksopdracht met betrokkenen bij Philips (Marco Bachrach, Lonneke Driessen, Antoon Martens) en bij UT (Robin Boerrigter)

IV. Software description

This appendix contains a working description of the software that we developed to perform the calculations of our research. It provides additional knowledge needed to repeat the research and verify its calculations and outcomes. It also enables in using the software for calculations and analyses on other supply flows and products that fit the capabilities of the underlying mathematical model.

Software & settings

The software package consists out of the software itself (executable file) supported by three excel based templates. These templates are required for providing import data correctly to the software. Furthermore, the directory that contains the prototype must also contain two maps called "input" and "results". The software uses these for importing and exporting its data.

Required:	Prototype	→	*TSLScalc2.exe (517 kb)*
	Templates	→	*Import_Products.xls*
		→	*Import_LeadTimes.xls*
		→	*Import_SupplyCapacity.xls*
	Maps	→	*Input*
		→	*Results*

Working with the templates

The three templates are each oriented on different aspects of the model: product, lead time, and supply capacity characteristics. The essence behind each template is equal. Required data is to be placed in one (or two for product data) user friendly designed worksheet. This data is linked in a fixed format to another worksheet. When the data entry is complete, this latter worksheet must be saved as a CSV-file and be placed in the map "input".

Import_Product.xls

This excel file contains two worksheets in which all product data must be filled in: "master data 12nc" and "MTP". The first worksheet requires all static product data, which must be entered manually. Figure 9 shows a part of the first worksheet. The complete demand forecast can be copied directly into the second worksheet. Figure 10 shows a part of the second worksheet. The data is combined in a third worksheet that later becomes the necessary CSV-file. This worksheet must be saved under the name Import_Product.csv.

12nc (replenisment)	CAG	Drain	Source1	Source2	sigma	Service level	Review period	Carrier 1	Carrier 2	MOQ	Anticipation stock
928048002513	041020	AM01	CH01		119	0,95	2	1		5000	0

Figure 9: part of worksheet "master data 12nc"

		Fiscal year/period	010.2007	011.2007	012.2007	001.2008
			Final Fore	Final Fore	Final Fore	Final Fore
CAG	12NC - EOC for MTP	Plant	PCE	PCE	PCE	PCE
041020	**928048003328**	**AM01**	4.856	3.927	407	2.482

Figure 10: part of worksheet "MTP"

The route that a product follows through the supply chain is represented by the "drain-source1- source2"- link. The drain represents the lowest echelon, the source1 its supplier etcetera. In Figure 9, supply flows from the production facility in Chalon (CH01) to the RDC in Eindhoven (AM01). The 12nc combined with the drain becomes the unique product / RDC-combination. The forecast error and related correlation variant must be estimated externally. The sigma that is shown in Figure 9 equals the correlation variant on forecast error multiplied by the average forecasted demand over the upcoming 18 months. The carrier section links the supply flow of a product to specific lead times (represented in import_leadtimes.xls). Carrier 1 relates to the flow from source1 to the drain; carrier 2 to the flow from source2 to source1. The anticipation stock section is used to verify if such type of stock is allowed to be created on this product (1 equals yes).

Import_Leadtimes.xls

This excel file contains one worksheet in which all lead time data must be filled in. This data is required for every possible flow of the supply chain. Figure 11 shows the flow from the production facility in Roosendaal (RS01) to the RDC in Eindhoven (AM01). For carrier 1 it requires 1.5 weeks of production time, 0.2 weeks of transportation, and 0.4 weeks of waiting for shipment. For considering different carriers, lead time information on a second and third carrier must be filled in. It is linked to a specific product by the carrier sections in the Import_product.xls file. The lead time data is linked to a second worksheet that later becomes the necessary CSV-file. This worksheet must be saved under the name Import_LeadTimes.csv.

Supply group	Source	Destination	Lead Time (Carrier 1)			Lead Time (Carrier 2)		
			production	transport	additional	production	transport	additional
	RS01	AM01	1,5	0,2	0,4			

Figure 11: part of worksheet "Lead Time"

Import_SupplyCapacity.xls

This excel file contains one worksheet in which all supply capacity data must be filled in. This must be done on a weekly level for every production line of each production facility. In Figure 12 for example, the production facility in Roosendaal (RS01) has a net capacity of 974.000 pieces on production line 6001 in the first week. This week corresponds not to the first week of the year, but to the first week of the demand forecast (MTP). The data is linked to a second worksheet that later becomes the CSV-file. This worksheet must be saved under the name Import_SupplyCapacity.csv.

				40	41	42	43	44
Supply group	IPLC	HOR-line	Capacity	week 1	2	3	4	5
	RS01	6001	Netto	974000	974000	974000	974000	974000

Figure 12: part of worksheet "Supply capacity"

Working with the prototype

The executable consists out of an import, memo, and export section. The first section (see Figure 13) contains a button to start importing and calculating data, a checkbox to select if capacity restrictions must be included and several information fields. After activating the button, these information fields show the locations from which the data is imported. Recall that these are the CSV-files related to the excel templates, which need to be placed in the map "input" in the same directory as the executable itself.

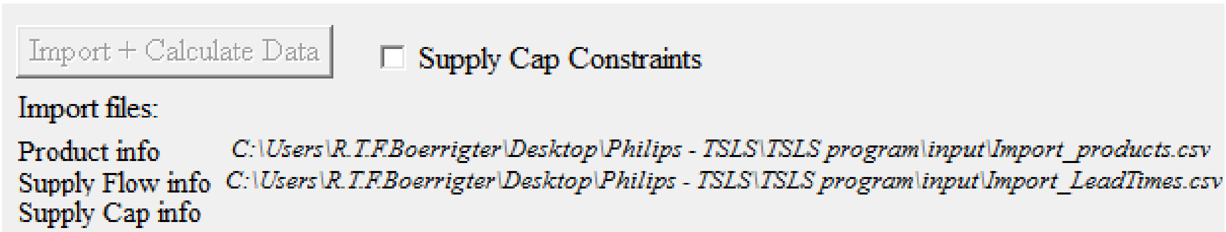


Figure 13: part of the model software – import section

After pushing the "Import + Calculate Data" button, the executable starts with importing the data. When this phase is complete, it continues with calculating the stock and service levels. The memo section (see Figure 14) displays some information on the progress of these calculations and the quality of the input data. The total calculation can take up to several minutes. A message appears in the memo section when the calculations are complete.

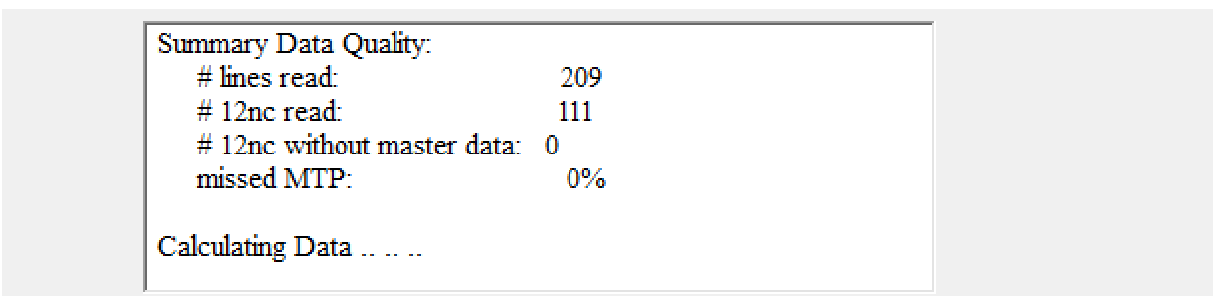


Figure 14: part of the model software – memo section

The export section (see Figure 15) contains a button to export data, a text field, several checkboxes, and information fields. Data is always exported on a weekly level for the upcoming 18 months for each stock type and service level. One can however specify to which level it must be consolidated before being exported. This is done by checking the different checkboxes. All data is standard summarized to the highest level. By selecting the "export all" checkbox, an overview of all stock and service levels of every product / RDC-combination will be exported as well. This information can be perfectly used for in-depth analyses and parameter setting at the operational level. By selecting one of the remaining checkboxes, the data can also be consolidated at a specific echelon. By selecting for example the "Drain" checkbox, the data would be consolidated at the lowest echelon: that of the RDCs. This way of consolidating data supports analyses at a more aggregate level. Data is exported at the summarized level and (when selected) at the product / RDC-combination level, and the echelon level separately. The information fields display the names and locations of each of these exported files. The first part of the file's name corresponds to the name filled in into the text field.

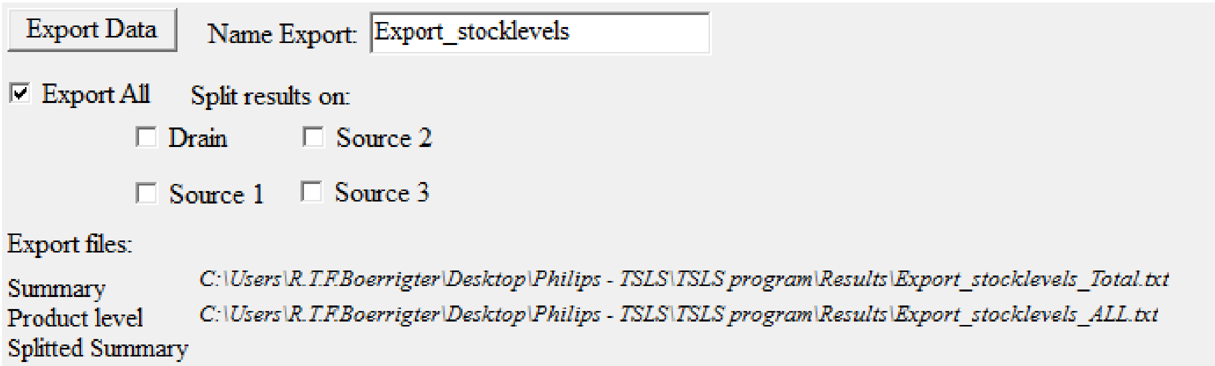


Figure 15: part of the prototype – export section

Changing source code

The software is currently programmed to perform its calculations based on gamma demand distributions, adapting sigmas, and partial postponed allocations. We concluded that this set up represents the best approximation of our research environment. To perform calculations based on a different set up, it is required to alter small dedicated parts of the source code. This requires the original source code and the software Borland's Delphi, version 7.0 or higher.

Switching distribution

The unit Basic_functions2 contains specific enclosed sets of functions for both normal and gamma distributed demand pattern. These sets are clearly marked within the source code. One can switch between these sets by simply (un)placing accolades around them.

Adapting vs. fixed sigma

The unit Import2 contains the procedure "CalcSeasSigma (var prod: Tproduct)". This procedure calculates the value of the sigma per week based on the imported sigma and the forecasted demand over the lead + review time. A small alteration at the end of this function makes switching between a fixed and adapting sigma possible:

Fixed → *Prod.Sigma[i]:= prod.S*

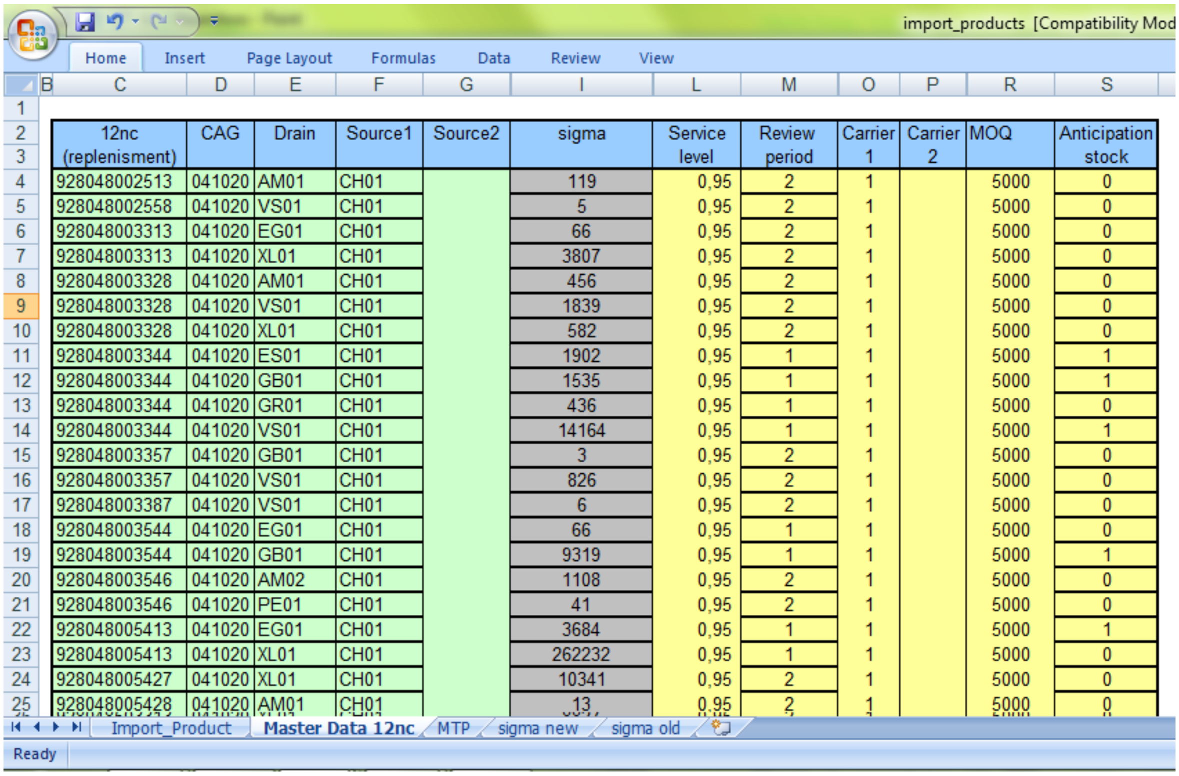
Adapting → *Prod.Sigma[i]:= prod.S * prod.fcw[i]/averagemean*

None or partial postponed allocation of stock

The unit Import2 contains the procedure "CalcPMPCSigma (var prod: Tproduct)". This procedure calculates the values necessary for partial postponed allocation under the balanced stock allocation rule. When the Prod.Pvalue[i] gets the value 0, all further calculations assume that no partial postponement is possible on this product. This is achieved by placing the code "Prod.Pvalue[i]:=0 end" behind the first line and placing the remaining code between accolades.

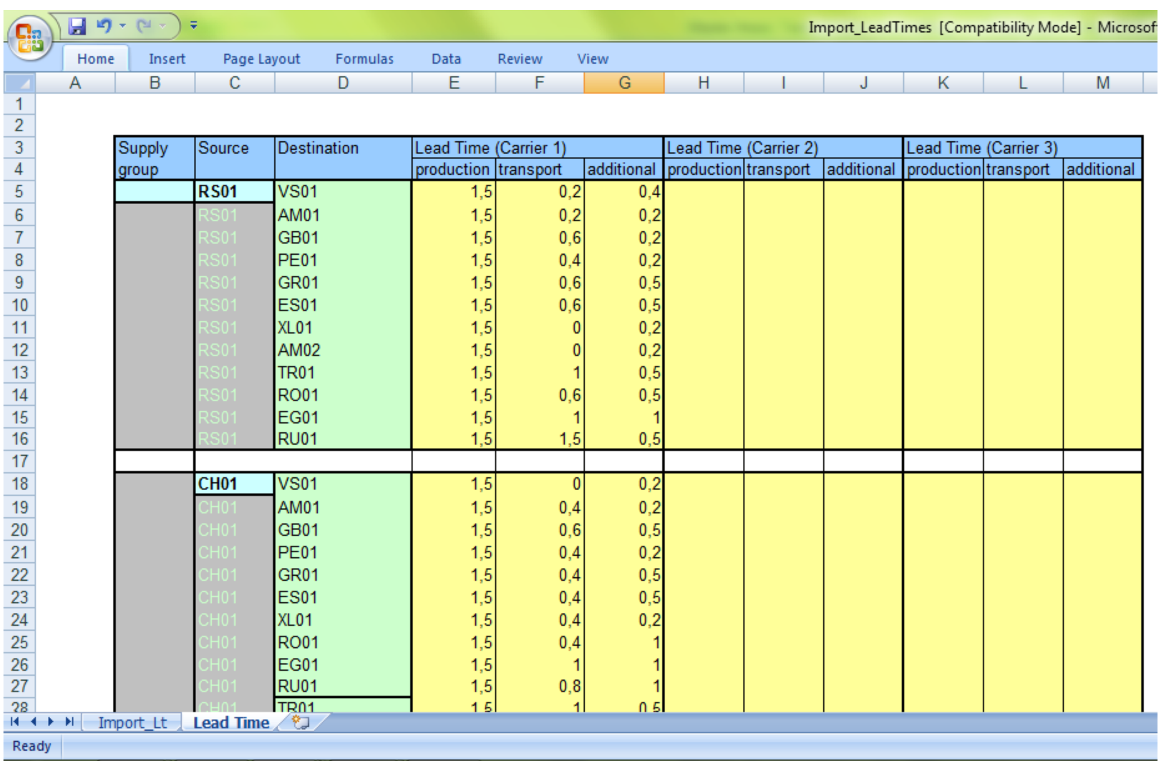
V. Screenshots of the software

Import Product template



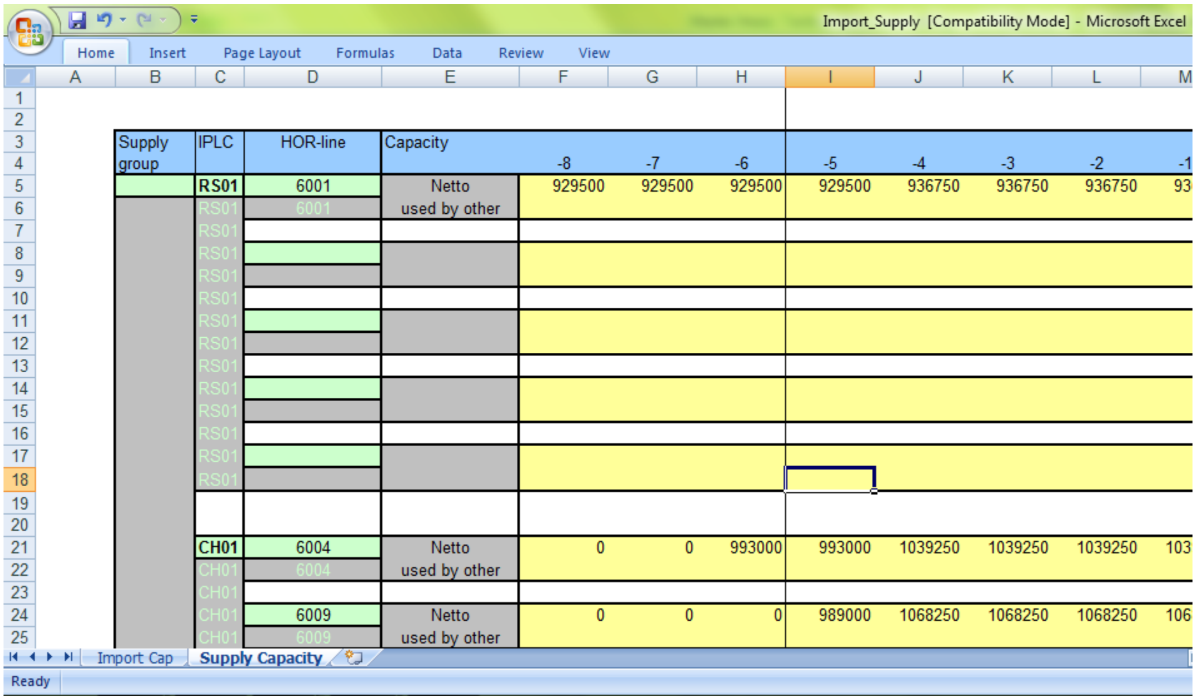
12nc (replenisment)	CAG	Drain	Source1	Source2	sigma	Service level	Review period	Carrier 1	Carrier 2	MOQ	Anticipation stock
928048002513	041020	AM01	CH01		119	0,95	2	1		5000	0
928048002558	041020	VS01	CH01		5	0,95	2	1		5000	0
928048003313	041020	EG01	CH01		66	0,95	2	1		5000	0
928048003313	041020	XL01	CH01		3807	0,95	2	1		5000	0
928048003328	041020	AM01	CH01		456	0,95	2	1		5000	0
928048003328	041020	VS01	CH01		1839	0,95	2	1		5000	0
928048003328	041020	XL01	CH01		582	0,95	2	1		5000	0
928048003344	041020	ES01	CH01		1902	0,95	1	1		5000	1
928048003344	041020	GB01	CH01		1535	0,95	1	1		5000	1
928048003344	041020	GR01	CH01		436	0,95	1	1		5000	0
928048003344	041020	VS01	CH01		14164	0,95	1	1		5000	1
928048003357	041020	GB01	CH01		3	0,95	2	1		5000	0
928048003357	041020	VS01	CH01		826	0,95	2	1		5000	0
928048003387	041020	VS01	CH01		6	0,95	2	1		5000	0
928048003544	041020	EG01	CH01		66	0,95	1	1		5000	0
928048003544	041020	GB01	CH01		9319	0,95	1	1		5000	1
928048003546	041020	AM02	CH01		1108	0,95	2	1		5000	0
928048003546	041020	PE01	CH01		41	0,95	2	1		5000	0
928048005413	041020	EG01	CH01		3684	0,95	1	1		5000	1
928048005413	041020	XL01	CH01		262232	0,95	1	1		5000	0
928048005427	041020	XL01	CH01		10341	0,95	2	1		5000	0
928048005428	041020	AM01	CH01		13	0,95	2	1		5000	0

Import Lead Time template

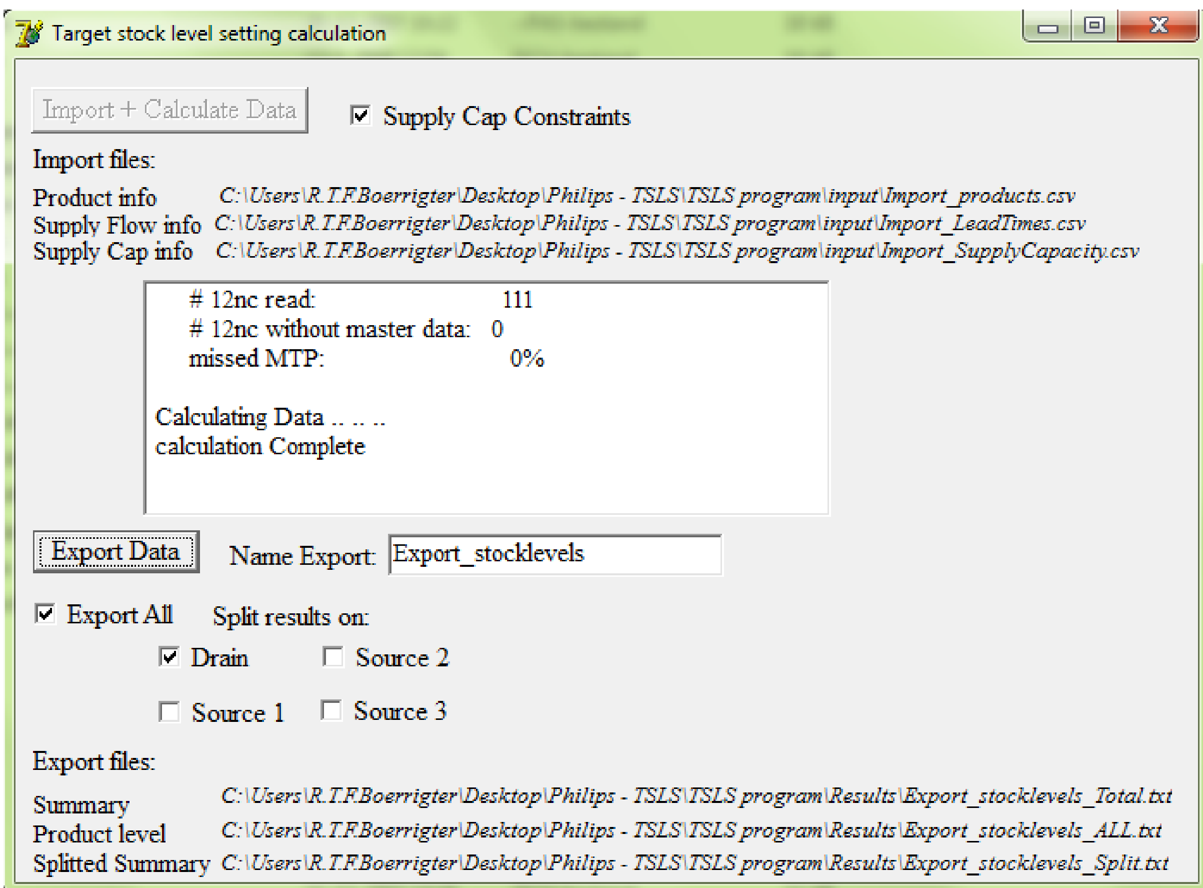


Supply group	Source	Destination	Lead Time (Carrier 1)			Lead Time (Carrier 2)			Lead Time (Carrier 3)		
			production	transport	additional	production	transport	additional	production	transport	additional
	RS01	VS01	1,5	0,2	0,4						
	RS01	AM01	1,5	0,2	0,2						
	RS01	GB01	1,5	0,6	0,2						
	RS01	PE01	1,5	0,4	0,2						
	RS01	GR01	1,5	0,6	0,5						
	RS01	ES01	1,5	0,6	0,5						
	RS01	XL01	1,5	0	0,2						
	RS01	AM02	1,5	0	0,2						
	RS01	TR01	1,5	1	0,5						
	RS01	RO01	1,5	0,6	0,5						
	RS01	EG01	1,5	1	1						
	RS01	RU01	1,5	1,5	0,5						
	CH01	VS01	1,5	0	0,2						
	CH01	AM01	1,5	0,4	0,2						
	CH01	GB01	1,5	0,6	0,5						
	CH01	PE01	1,5	0,4	0,2						
	CH01	GR01	1,5	0,4	0,5						
	CH01	ES01	1,5	0,4	0,5						
	CH01	XL01	1,5	0,4	0,2						
	CH01	RO01	1,5	0,4	1						
	CH01	EG01	1,5	1	1						
	CH01	RU01	1,5	0,8	1						
	CH01	TR01	1,5	1	0,5						

Import Supply Capacity template



Software / Executable



Export product level

Export_stocklevels_ALL - Microsoft Excel

	Product	StockType	Cag	Drain	Source1	Source2	Carrier1	Carrier2	Anti	week40	week41	week42	week43	week44	week45	week46
1							Results TSLS-calculation per product									
2																
544	928048503344	Sales Forecast	41020	ES01	CH01	0	1	0	1	4770	4770	4770	4770	4770	5569	5569
545	928048503344	Total Stock	41020	ES01	CH01	0	1	0	1	13799	13799	13799	13799	13799	16129	16129
546	928048503344	Service Level	41020	ES01	CH01	0	1	0	1	0,95	0,95	0,95	0,95	0,95	0,95	0,95
547	928048503344	Pipeline Stock	41020	ES01	CH01	0	1	0	1	11448	11448	11448	11768	12567	13366	13366
548	928048503344	GiT Total	41020	ES01	CH01	0	1	0	1	4293	4293	4293	4293	4293	5012	5012
549	928048503344	GiT 1	41020	ES01	CH01	0	1	0	1	4293	4293	4293	4293	4293	5012	5012
550	928048503344	GiT 2	41020	ES01	CH01	0	1	0	1	0	0	0	0	0	0	0
551	928048503344	GiT 3	41020	ES01	CH01	0	1	0	1	0	0	0	0	0	0	0
552	928048503344	PrevProd Stock	41020	ES01	CH01	0	1	0	1	0	0	0	0	0	0	0
553	928048503344	Physical Stock	41020	ES01	CH01	0	1	0	1	9506	9506	9506	9506	9506	11117	11117
554	928048503344	Cycle Stock	41020	ES01	CH01	0	1	0	1	2385	2385	2385	2385	2385	2785	2785
555	928048503344	Safety Stock	41020	ES01	CH01	0	1	0	1	6883	6883	6883	6883	6883	8054	8054
556	928048503344	BackLog	41020	ES01	CH01	0	1	0	1	238	238	238	238	238	278	278
557	928048503344	MOQ-stock	41020	ES01	CH01	0	1	0	1	0	0	0	0	0	0	0
558	928048503344	Anticipation Stock	41020	ES01	CH01	0	1	0	1	0	0	0	0	0	0	0
559	928048503344	Sales Forecast	41020	GB01	CH01	0	1	0	0	1376	1376	1376	1376	1376	2210	2210
560	928048503344	Total Stock	41020	GB01	CH01	0	1	0	0	5445	5445	5445	5445	5528	8745	8745
561	928048503344	Service Level	41020	GB01	CH01	0	1	0	0	0,95	0,95	0,95	0,95	0,95	0,95	0,95
562	928048503344	Pipeline Stock	41020	GB01	CH01	0	1	0	0	3578	3578	3578	4078	4912	5746	5746
563	928048503344	GiT Total	41020	GB01	CH01	0	1	0	0	1514	1514	1514	1514	1597	2431	2431
564	928048503344	GiT 1	41020	GB01	CH01	0	1	0	0	1514	1514	1514	1514	1597	2431	2431

Export_stocklevels_ALL

Export lowest echelon / RDC level

Export_stocklevels_Split - Microsoft Excel

2																
3	AM01															
4		week40	week41	week42	week43	week44	week45	week46	week47	week48	week49	week50	week51	week52	week1	week2	week3
5	Sales Forecast	124931	124931	124931	124931	124931	128655	128655	128655	128655	120773	120773	120773	120773	93012	93012	9301
6	Total Stock level	373072	373206	374052	374872	372962	378619	377819	379197	364522	353095	353019	355335	419619	269996	278213	27886
7	Service Level	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,961	0,961	0,95	0,9
8																	
9	Pipeline Stock	262356	262356	262389	263042	266765	270176	269967	267301	259419	253623	259592	306581	243171	155720	195328	19542
10	Goods in Transit	74958	74958	74958	74958	75145	77193	77193	77193	75941	72465	72465	72465	108280	32044	55809	5580
11	Physical Stock	298114	298248	299094	299914	297817	301426	300626	302004	288581	280630	280554	282870	311339	237954	222404	22305
12																	
13	PMPC WIP stock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14	Cycle Stock	67813	67813	67813	67813	68128	69987	69987	69987	67901	63961	63961	63961	64624	50745	50745	5074
15	Safety Stock	219527	219527	219527	219527	220831	223116	223116	223116	213198	200918	200918	200918	205900	157303	157303	15730
16	Back Log	6248	6249	6259	6268	6258	6432	6414	6418	6292	6089	6098	6118	4763	3661	4652	466
17	MOQ-stock	4528	4662	5507	6328	2600	1888	1087	2464	1152	9711	9637	11951	13084	9653	9705	1036
18	Anticipation Stock	0	0	0	0	0	0	0	0	0	0	0	0	23017	16591	0	
19																	
21	VS01																
22		week40	week41	week42	week43	week44	week45	week46	week47	week48	week49	week50	week51	week52	week1	week2	week3
23	Sales Forecast	830838	830838	830838	830838	830838	671662	671662	671662	671662	441407	441407	441407	441407	433693	433693	43369
24	Total Stock level	3585699	3586123	3584823	3583653	3566490	3258739	3252404	3247537	3174629	2488433	2484359	2499763	2490154	2048647	2022196	198003
25	Service Level	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,963	0,955	0,9
26																	
27	Pipeline Stock	1412418	1412418	1412418	1402745	1287170	1141822	1141822	1128994	962322	750387	750387	892038	831637	571993	737282	73728
28	Goods in Transit	166167	166167	166167	166167	163405	134329	134329	134329	130667	88281	88281	88281	128753	53679	86739	8673
29	Physical Stock	3419532	3419956	3418656	3417486	3403085	3124410	3118075	3113208	3043962	2400152	2396078	2411482	2361401	1994968	1935458	189329

Export_stocklevels_Split

VI. Results data cleaning

	Halogen & TL/CFL-ni		Halogen						TL/CFL-ni	
	Total		Total		CAG 002040		CAG 004440		Total	
	#	%	#	%	#	%	#	%	#	%
Total	1363		504		276		228		859	
Pass criteria	835	61%	293	58%	160	58%	133	58%	542	63%
Fail criteria	528	39%	211	42%	116	42%	95	42%	317	37%
With MTP	1071		428		233		195		643	
+ existing 12nc	1030	96%	413	96%	227	97%	186	95%	617	96%
+ history	993	93%	397	93%	221	95%	176	90%	596	93%
+ own C.V.	794	74%	296	69%	160	69%	136	70%	498	77%
Average C.V.	0,52		0,60		0,52		0,70		0,47	
Reason for failure										
	#	%	#	%	#	%	#	%	#	%
< 1/3 FC has RS	372	27%	138	27%	75	27%	63	28%	234	27%
C.V. > 2.5	195	14%	73	14%	38	14%	35	15%	122	14%
< 5 periods FC	322	24%	137	27%	77	28%	60	26%	185	22%
No FC & no RS	94	7%	39	8%	20	7%	19	8%	55	6%

TL/CFL-ni	IPLC Rossendaal				IPLC Chalon				IPLC Pila	
	CAG 041010		CAG 041110		CAG 041020		CAG 041120		CAG 041090	
	#	%	#	%	#	%	#	%	#	%
Total	191		316		119		172		61	
Pass criteria	113	59%	198	63%	76	64%	110	64%	45	74%
Fail criteria	78	41%	118	37%	43	36%	62	36%	16	26%
With MTP	122		261		80		129		51	
+ existing 12nc	121	99%	250	96%	69	86%	126	98%	51	100%
+ history	116	95%	237	91%	68	85%	126	98%	49	96%
+ own C.V.	98	80%	206	79%	57	71%	96	74%	41	80%
Average C.V.	0,62		0,37		0,43		0,54		0,47	
Reason for failure										
	#	%	#	%	#	%	#	%	#	%
< 1/3 FC has RS	60	31%	77	24%	31	26%	42	24%	24	39%
C.V. > 2.5	20	10%	52	16%	11	9%	21	12%	18	30%
< 5 periods FC	35	18%	80	25%	24	20%	24	14%	22	36%
No FC & no RS	13	7%	31	10%	5	4%	4	2%	2	3%

VII. Detailed analyses reports

Portfolio	*TL/CFL-ni*
Scenario	*Currrent situation*

Expected 2008
(weeks of supply)

All Production Facilities / ALL IPLC's
(All Product groups)

	Demand forecast	Minimum	Average	Maximum
	(x1000)	3.973	4.646	5.311
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,7	3,0	3,7
	Pipeline Stock	1,8	2,1	2,5
	Goods in Transit	0,5	0,6	0,7
	Physical Stock	2,1	2,4	2,9
	Safety Stock	1,0	1,2	1,7
capicity restrictions	Total Stock level	3,2	3,8	4,6
	Pipeline Stock	1,4	2,1	2,6
	Goods in Transit	0,3	0,6	0,8
	Physical Stock	2,7	3,2	4,1
	Safety Stock	1,0	1,2	1,7
	Anticipation Stock	0,2	0,8	2,0
	Requested Supply	0,9	1,0	1,1
	Available Supply	0,5	1,1	1,2
	Consumed Supply	0,5	1,0	1,2
	Entitlement stock	2,7	2,9	3,1

Production Facility Pila / IPLC PE01
(Product group 041090)

	Demand forecast	Minimum	Average	Maximum
	(x1000)	1727	2076	2303
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,5	3,1	3,6
	Pipeline Stock	1,8	2,2	2,5
	Goods in Transit	0,6	0,7	0,8
	Physical Stock	1,9	2,4	2,8
	Safety Stock	1,1	1,5	2,2
capicity restrictions	Total Stock level	2,5	3,4	4,8
	Pipeline Stock	1,3	2,1	2,8
	Goods in Transit	0,3	0,7	0,9
	Physical Stock	1,9	2,7	4,5
	Safety Stock	1,1	1,5	2,2
	Anticipation Stock	0,0	0,3	2,2
	Requested Supply	0,8	1,0	1,1
	Available Supply	0,0	1,1	1,4
	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,5	2,6	2,9

Production Facility Roosendaal / IPLC RS01
(Product groups 041010 & 041110)

	Demand forecast	Minimum	Average	Maximum
	(x1000)	760	931	1091
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,1	2,7	3,3
	Pipeline Stock	1,7	2,1	2,4
	Goods in Transit	0,5	0,6	0,7
	Physical Stock	1,7	2,1	2,6
	Safety Stock	0,7	1,0	1,5
capicity restrictions	Total Stock level	3,8	5,5	6,6
	Pipeline Stock	0,5	2,0	2,1
	Goods in Transit	0,1	0,5	0,6
	Physical Stock	3,2	5,0	6,4
	Safety Stock	0,7	1,0	1,5
	Anticipation Stock	0,6	3,0	4,8
	Requested Supply	0,8	1,0	1,2
	Available Supply	0,0	0,9	1,1
	Consumed Supply	0,0	0,9	1,1
	Entitlement stock	3,1	3,4	3,7

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

	Demand forecast	Minimum	Average	Maximum
	(x1000)	1061	1639	2041
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,1	3,1	3,9
	Pipeline Stock	1,3	2,1	2,5
	Goods in Transit	0,4	0,6	0,7
	Physical Stock	1,7	2,5	3,3
	Safety Stock	0,8	1,1	1,4
capicity restrictions	Total Stock level	2,2	3,4	5,2
	Pipeline Stock	0,5	2,1	2,6
	Goods in Transit	0,1	0,6	0,7
	Physical Stock	1,9	2,8	4,7
	Safety Stock	0,8	1,1	1,4
	Anticipation Stock	0,0	0,3	2,3
	Requested Supply	0,7	1,0	1,2
	Available Supply	0,0	1,1	1,3
	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,7	2,9	3,3

Portfolio *TL/CFL-ni / CL01*
Scenario *Service level*

Expected 2008
(weeks of supply)

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Service level *90%*

	Demand forecast	Minimum	Average	Maximum
	(x1000)	1061	1639	2041
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	1,8	2,7	3,6
No capacity	Pipeline Stock	1,3	2,1	2,5
No capacity	Goods in Transit	0,4	0,6	0,7
No capacity	Physical Stock	1,4	2,1	2,9
No capacity	Safety Stock	0,5	0,7	0,9
capicity restrictions	Total Stock level	1,9	3,1	4,9
capicity restrictions	Pipeline Stock	0,5	2,1	2,6
capicity restrictions	Goods in Transit	0,1	0,6	0,7
capicity restrictions	Physical Stock	1,6	2,5	4,4
capicity restrictions	Safety Stock	0,6	0,7	1,0
capicity restrictions	Anticipation Stock	0,0	0,3	2,3
capicity restrictions	Requested Supply	0,7	1,0	1,2
capicity restrictions	Available Supply	0,0	1,1	1,3
capicity restrictions	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,7	2,9	3,3

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Service level *95%*

	Demand forecast	Minimum	Average	Maximum
	(x1000)	1061	1639	2041
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,1	3,1	3,9
No capacity	Pipeline Stock	1,3	2,1	2,5
No capacity	Goods in Transit	0,4	0,6	0,7
No capacity	Physical Stock	1,7	2,5	3,3
No capacity	Safety Stock	0,8	1,1	1,4
capicity restrictions	Total Stock level	2,2	3,4	5,2
capicity restrictions	Pipeline Stock	0,5	2,1	2,6
capicity restrictions	Goods in Transit	0,1	0,6	0,7
capicity restrictions	Physical Stock	1,9	2,8	4,7
capicity restrictions	Safety Stock	0,8	1,1	1,4
capicity restrictions	Anticipation Stock	0,0	0,3	2,3
capicity restrictions	Requested Supply	0,7	1,0	1,2
capicity restrictions	Available Supply	0,0	1,1	1,3
capicity restrictions	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,7	2,9	3,3

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Service level *97%*

	Demand forecast	Minimum	Average	Maximum
	(x1000)	1061	1639	2041
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,2	3,3	4,2
No capacity	Pipeline Stock	1,3	2,1	2,5
No capacity	Goods in Transit	0,4	0,6	0,7
No capacity	Physical Stock	1,8	2,7	3,5
No capacity	Safety Stock	1,0	1,3	1,7
capicity restrictions	Total Stock level	2,3	3,6	5,4
capicity restrictions	Pipeline Stock	0,5	2,1	2,6
capicity restrictions	Goods in Transit	0,1	0,6	0,7
capicity restrictions	Physical Stock	2,0	3,1	4,9
capicity restrictions	Safety Stock	1,0	1,3	1,7
capicity restrictions	Anticipation Stock	0,0	0,3	2,3
capicity restrictions	Requested Supply	0,7	1,0	1,2
capicity restrictions	Available Supply	0,0	1,1	1,3
capicity restrictions	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,7	2,9	3,3

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Service level *98%*

	Demand forecast	Minimum	Average	Maximum
	(x1000)	1061	1639	2041
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,3	3,5	4,4
No capacity	Pipeline Stock	1,3	2,1	2,5
No capacity	Goods in Transit	0,4	0,6	0,7
No capacity	Physical Stock	2,0	2,9	3,7
No capacity	Safety Stock	1,1	1,5	2,0
capicity restrictions	Total Stock level	2,5	3,8	5,5
capicity restrictions	Pipeline Stock	0,5	2,1	2,6
capicity restrictions	Goods in Transit	0,1	0,6	0,7
capicity restrictions	Physical Stock	2,2	3,2	5,0
capicity restrictions	Safety Stock	1,1	1,5	2,0
capicity restrictions	Anticipation Stock	0,0	0,3	2,3
capicity restrictions	Requested Supply	0,7	1,0	1,2
capicity restrictions	Available Supply	0,0	1,1	1,3
capicity restrictions	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,7	2,9	3,3

Portfolio	*TL/CFL-ni / CL01*
Scenario	*Forecast accuracy*

Expected 2008
(weeks of supply)

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Forecast accuracy *0.75 x Correlation Vector*

	Demand forecast	**Minimum**	**Average**	**Maximum**
	(x1000)	1061	1639	2041
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	1,7	2,7	3,5
No capacity	Pipeline Stock	1,3	2,1	2,5
No capacity	Goods in Transit	0,4	0,6	0,7
No capacity	Physical Stock	1,4	2,1	2,8
No capacity	Safety Stock	0,5	0,7	0,9
capicity restrictions	Total Stock level	1,8	3,0	4,8
capicity restrictions	Pipeline Stock	0,5	2,1	2,6
capicity restrictions	Goods in Transit	0,1	0,6	0,7
capicity restrictions	Physical Stock	1,6	2,4	4,3
capicity restrictions	Safety Stock	0,5	0,7	0,9
capicity restrictions	Anticipation Stock	0,0	0,3	2,3
capicity restrictions	Requested Supply	0,7	1,0	1,2
capicity restrictions	Available Supply	0,0	1,1	1,3
capicity restrictions	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,7	2,9	3,3

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Forecast accuracy *0.90 x Correlation Vector*

	Demand forecast	**Minimum**	**Average**	**Maximum**
	(x1000)	1061	1639	2041
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	1,9	2,9	3,8
No capacity	Pipeline Stock	1,3	2,1	2,5
No capacity	Goods in Transit	0,4	0,6	0,7
No capacity	Physical Stock	1,6	2,3	3,1
No capacity	Safety Stock	0,7	0,9	1,2
capicity restrictions	Total Stock level	2,0	3,2	5,0
capicity restrictions	Pipeline Stock	1,3	2,1	2,5
capicity restrictions	Goods in Transit	0,4	0,6	0,7
capicity restrictions	Physical Stock	1,6	2,3	3,1
capicity restrictions	Safety Stock	0,7	0,9	1,2
capicity restrictions	Anticipation Stock	0,0	0,3	2,3
capicity restrictions	Requested Supply	0,7	1,0	1,2
capicity restrictions	Available Supply	0,0	1,1	1,3
capicity restrictions	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,7	2,9	3,3

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Forecast accuracy *1.00 x Correlation Vector*

	Demand forecast	**Minimum**	**Average**	**Maximum**
	(x1000)	1061	1639	2041
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,1	3,1	3,9
No capacity	Pipeline Stock	1,3	2,1	2,5
No capacity	Goods in Transit	0,4	0,6	0,7
No capacity	Physical Stock	1,7	2,5	3,3
No capacity	Safety Stock	0,8	1,1	1,4
capicity restrictions	Total Stock level	2,2	3,4	5,2
capicity restrictions	Pipeline Stock	0,5	2,1	2,6
capicity restrictions	Goods in Transit	0,1	0,6	0,7
capicity restrictions	Physical Stock	1,9	2,8	4,7
capicity restrictions	Safety Stock	0,8	1,1	1,4
capicity restrictions	Anticipation Stock	0,0	0,3	2,3
capicity restrictions	Requested Supply	0,7	1,0	1,2
capicity restrictions	Available Supply	0,0	1,1	1,3
capicity restrictions	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,7	2,9	3,3

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Forecast accuracy *1.10 x Correlation Vector*

	Demand forecast	**Minimum**	**Average**	**Maximum**
	(x1000)	1061	1639	2041
	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,2	3,3	4,2
No capacity	Pipeline Stock	1,3	2,1	2,5
No capacity	Goods in Transit	0,4	0,6	0,7
No capacity	Physical Stock	1,8	2,7	3,5
No capacity	Safety Stock	0,9	1,3	1,7
capicity restrictions	Total Stock level	2,3	3,6	5,3
capicity restrictions	Pipeline Stock	0,5	2,1	2,6
capicity restrictions	Goods in Transit	0,1	0,6	0,7
capicity restrictions	Physical Stock	2,0	3,0	4,8
capicity restrictions	Safety Stock	0,9	1,3	1,7
capicity restrictions	Anticipation Stock	0,0	0,3	2,3
capicity restrictions	Requested Supply	0,7	1,0	1,2
capicity restrictions	Available Supply	0,0	1,1	1,3
capicity restrictions	Consumed Supply	0,0	1,0	1,3
	Entitlement stock	2,7	2,9	3,3

Portfolio	*TL/CFL-ni / CL01*
Scenario	*Other*

Expected 2008
(weeks of supply)

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Other *Normal distribution*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	1061	1639	2041

	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	1,9	2,8	3,6
	Pipeline Stock	1,3	2,1	2,5
	Goods in Transit	0,4	0,6	0,7
	Physical Stock	1,5	2,3	3,0
	Safety Stock	0,6	0,8	1,0
	Entitlement stock	2,7	2,9	3,3

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Other *Normal distribution + fixed sigma*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	1061	1639	2041

	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,1	2,8	3,6
	Pipeline Stock	1,3	2,1	2,5
	Goods in Transit	0,4	0,6	0,7
	Physical Stock	1,7	2,2	2,9
	Safety Stock	0,7	0,8	0,9
	Entitlement stock	2,7	2,9	3,3

Production Facility Chalon / IPLC CL01
(Product groups 041020 & 041120)

Other *No postponed allocation*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	1061	1639	2041

	Stocklevels	**Minimum**	**Average**	**Maximum**
No capacity	Total Stock level	2,2	3,2	4,1
	Pipeline Stock	1,3	2,1	2,5
	Goods in Transit	0,4	0,6	0,7
	Physical Stock	1,8	2,6	3,4
	Safety Stock	0,9	1,2	1,6
	Entitlement stock	2,7	2,9	3,3

Portfolio	***Halogen / Product group 002040***		**Expected 2008**
Scenario	***Supply flows***		**(weeks of supply)**

Supply flow *All Sourcing DC*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,4	12,7	14,3
Pipeline Stock	10,9	12,4	14,2
Goods in Transit	6,2	7,6	8,9
Physical Stock	4,2	5,1	6,4
Safety Stock	3,5	4,3	5,7

Supply flow *All Shortcut*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,6	12,6	14,4
Pipeline Stock	9,4	10,9	12,6
Goods in Transit	5,0	6,1	7,1
Physical Stock	5,6	6,5	7,8
Safety Stock	4,3	5,3	7,1

Supply flow *Sourcing DC, fast & SD --> SC*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,0	12,1	13,9
Pipeline Stock	9,9	11,4	13,1
Goods in Transit	5,4	6,6	7,7
Physical Stock	4,6	5,5	7,0
Safety Stock	3,8	4,8	6,3

Supply flow *Sourcing DC, SD --> SC*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,1	12,4	13,9
Pipeline Stock	10,7	12,1	14,0
Goods in Transit	5,9	7,4	8,6
Physical Stock	4,2	5,0	6,2
Safety Stock	3,4	4,2	5,6

Supply flow *All Packaging Centers*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	9,8	12,1	13,7
Pipeline Stock	10,9	12,4	14,2
Goods in Transit	6,2	7,6	8,9
Physical Stock	3,6	4,5	5,6
Safety Stock	2,3	3,0	3,8

Supply flow *Packaging Centers, fast --> SC*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	9,5	11,6	13,0
Pipeline Stock	10,2	11,6	13,3
Goods in Transit	5,7	6,8	8,0
Physical Stock	3,8	4,8	6,2
Safety Stock	3,0	3,7	4,9

Portfolio	*Halogen / Product group 004440*
Scenario	*Supply flows*

Expected 2008
(weeks of supply)

Supply flow *All Sourcing DC*

Demand forecast	Minimum	Average	Maximum
(x1000)	286	429	578

Stocklevels	Minimum	Average	Maximum
Total Stock level	10,6	14,2	18,7
Pipeline Stock	9,9	12,8	15,7
Goods in Transit	5,7	7,8	10,2
Physical Stock	4,5	6,4	8,8
Safety Stock	4,0	5,8	8,1

Supply flow *All Shortcut*

Demand forecast	Minimum	Average	Maximum
(x1000)	286	429	578

Stocklevels	Minimum	Average	Maximum
Total Stock level	9,5	13,0	17,0
Pipeline Stock	8,5	11,1	13,8
Goods in Transit	4,4	6,2	8,1
Physical Stock	5,1	6,9	9,1
Safety Stock	4,2	6,1	8,5

Supply flow *Sourcing DC, fast & SD --> SC*

Demand forecast	Minimum	Average	Maximum
(x1000)	286	429	578

Stocklevels	Minimum	Average	Maximum
Total Stock level	9,2	12,8	16,8
Pipeline Stock	8,6	11,3	14,0
Goods in Transit	4,6	6,4	8,3
Physical Stock	4,6	6,4	8,8
Safety Stock	4,0	5,8	8,2

Supply flow *Sourcing DC, SD --> SC*

Demand forecast	Minimum	Average	Maximum
(x1000)	286	429	578

Stocklevels	Minimum	Average	Maximum
Total Stock level	9,4	12,9	17,0
Pipeline Stock	9,0	11,8	14,5
Goods in Transit	4,9	6,9	9,0
Physical Stock	4,3	6,1	8,3
Safety Stock	3,7	5,5	7,6

Supply flow *All Packaging Centers*

Demand forecast	Minimum	Average	Maximum
(x1000)	286	429	578

Stocklevels	Minimum	Average	Maximum
Total Stock level	10,0	13,1	17,3
Pipeline Stock	9,9	12,8	15,7
Goods in Transit	5,7	7,8	10,0
Physical Stock	3,7	5,3	7,4
Safety Stock	2,6	3,7	5,4

Supply flow *Packaging Centers, fast --> SC*

Demand forecast	Minimum	Average	Maximum
(x1000)	286	429	578

Stocklevels	Minimum	Average	Maximum
Total Stock level	8,9	12,4	16,2
Pipeline Stock	8,8	11,6	14,3
Goods in Transit	4,8	6,6	8,5
Physical Stock	4,0	5,8	7,9
Safety Stock	3,4	4,9	6,8

Portfolio *Halogen / Product group 002040*
Scenario *Service level*

Expected 2008 (weeks of supply)

Supply flow	*Sourcing DC, fast & SD --> SC*		
Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414
Service level	90%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	8,8	10,7	12,1
Pipeline Stock	9,9	11,4	13,1
Goods in Transit	5,4	6,6	7,7
Physical Stock	3,4	4,1	5,2
Safety Stock	2,8	3,5	4,6
Service level	95%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	9,5	11,6	13,2
Pipeline Stock	9,9	11,4	13,1
Goods in Transit	5,4	6,6	7,7
Physical Stock	4,1	5,0	6,3
Safety Stock	3,4	4,2	5,6
Service level	97%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,0	12,1	13,9
Pipeline Stock	9,9	11,4	13,1
Goods in Transit	5,4	6,6	7,7
Physical Stock	4,6	5,5	7,0
Safety Stock	3,8	4,8	6,3
Service level	98%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,3	12,6	14,5
Pipeline Stock	9,9	11,4	13,1
Goods in Transit	5,4	6,6	7,7
Physical Stock	5,0	6,0	7,6
Safety Stock	4,2	5,2	6,9

Supply flow	*Packaging Centers, fast --> SC*		
Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414
Service level	90%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	8,7	10,6	11,8
Pipeline Stock	10,2	11,6	13,3
Goods in Transit	5,7	6,8	8,0
Physical Stock	3,0	3,8	4,8
Safety Stock	2,2	2,7	3,5
Service level	95%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	9,2	11,2	12,5
Pipeline Stock	10,2	11,6	13,3
Goods in Transit	5,7	6,8	8,0
Physical Stock	3,5	4,4	5,6
Safety Stock	2,6	3,3	4,3
Service level	97%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	9,5	11,6	13,0
Pipeline Stock	10,2	11,6	13,3
Goods in Transit	5,7	6,8	8,0
Physical Stock	3,8	4,8	6,2
Safety Stock	3,0	3,7	4,9
Service level	98%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	9,8	11,9	13,5
Pipeline Stock	10,2	11,6	13,3
Goods in Transit	5,7	6,8	8,0
Physical Stock	4,1	5,1	6,6
Safety Stock	3,2	4,0	5,3

Supply flow	*All Shortcut*		
Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414
Service level	90%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	9,2	11,1	12,6
Pipeline Stock	9,4	10,9	12,6
Goods in Transit	5,0	6,1	7,1
Physical Stock	4,2	4,9	6,0
Safety Stock	3,2	3,9	5,2
Service level	95%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,1	12,0	13,8
Pipeline Stock	9,4	10,9	12,6
Goods in Transit	5,0	6,1	7,1
Physical Stock	5,1	5,9	7,1
Safety Stock	3,8	4,7	6,3
Service level	97%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,6	12,6	14,4
Pipeline Stock	9,4	10,9	12,6
Goods in Transit	5,0	6,1	7,1
Physical Stock	5,6	6,5	7,8
Safety Stock	4,3	5,3	7,1
Service level	98%		
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	11,1	13,2	15,2
Pipeline Stock	9,4	10,9	12,6
Goods in Transit	5,0	6,1	7,1
Physical Stock	6,1	7,1	8,6
Safety Stock	4,7	5,8	7,7

Portfolio	*Halogen / Product group 002040*
Scenario	*Forecast accuracy (1)*

Expected 2008 (weeks of supply)

Supply flow *All Sourcing DC*

Demand forecast	Minimum	Average	Maximum
(x1000)	274	350	414

Forecast accuracy *0.40 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	8,1	9,9	11,2
Goods in Transit	6,2	7,6	8,9
Physical Stock	2,0	2,3	2,7

Forecast accuracy *0.60 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	8,8	10,7	12,1
Goods in Transit	6,2	7,6	8,9
Physical Stock	2,6	3,1	3,8

Forecast accuracy *0.80 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	9,6	11,7	13,1
Goods in Transit	6,2	7,6	8,9
Physical Stock	3,4	4,1	5,0

Forecast accuracy *1.00 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	10,4	12,8	14,3
Goods in Transit	6,2	7,6	8,9
Physical Stock	4,2	5,1	6,4

Forecast accuracy *1.20 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	11,4	13,9	15,8
Goods in Transit	6,2	7,6	8,9
Physical Stock	5,2	6,3	8,0

Forecast accuracy *1.40 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	12,4	15,2	17,5
Goods in Transit	6,2	7,6	8,9
Physical Stock	6,2	7,6	9,7

Forecast accuracy *1.60 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	13,5	16,6	19,4
Goods in Transit	6,2	7,6	8,9
Physical Stock	7,3	9,0	11,7

Supply flow *Sourcing DC, fast & SD --> SC*

Demand forecast	Minimum	Average	Maximum
(x1000)	274	350	414

Forecast accuracy *0.40 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	7,4	8,9	10,1
Goods in Transit	5,4	6,6	7,7
Physical Stock	2,0	2,4	2,8

Forecast accuracy *0.60 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	8,1	9,9	11,1
Goods in Transit	5,4	6,6	7,7
Physical Stock	2,8	3,3	4,0

Forecast accuracy *0.80 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	9,0	10,9	12,3
Goods in Transit	5,4	6,6	7,7
Physical Stock	3,6	4,3	5,4

Forecast accuracy *1.00 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	9,9	12,1	13,9
Goods in Transit	5,4	6,6	7,7
Physical Stock	4,6	5,5	7,0

Forecast accuracy *1.20 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	11,0	13,4	15,7
Goods in Transit	5,4	6,6	7,7
Physical Stock	5,6	6,9	8,8

Forecast accuracy *1.40 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	12,2	14,9	17,6
Goods in Transit	5,4	6,6	7,7
Physical Stock	6,8	8,3	10,7

Forecast accuracy *1.60 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	13,4	16,5	19,8
Goods in Transit	5,4	6,6	7,7
Physical Stock	8,1	9,9	12,9

Portfolio	*Halogen / Product group 002040*
Scenario	*Forecast accuracy (2)*

Expected 2008 (weeks of supply)

Supply flow *Packaging centers, fast --> SC*

Demand forecast	Minimum	Average	Maximum
(x1000)	274	350	414

Forecast accuracy *0.40 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	7,4	9,0	10,2
Goods in Transit	5,7	6,8	8,0
Physical Stock	1,8	2,2	2,7

Forecast accuracy *0.60 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	8,0	9,8	11,0
Goods in Transit	5,7	6,8	8,0
Physical Stock	2,4	2,9	3,7

Forecast accuracy *0.80 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	8,7	10,6	11,9
Goods in Transit	5,7	6,8	8,0
Physical Stock	3,1	3,8	4,9

Forecast accuracy *1.00 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	9,5	11,6	13,0
Goods in Transit	5,7	6,8	8,0
Physical Stock	3,9	4,8	6,2

Forecast accuracy *1.20 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	10,4	12,7	14,5
Goods in Transit	5,7	6,8	8,0
Physical Stock	4,7	5,8	7,6

Forecast accuracy *1.40 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	11,3	13,8	16,0
Goods in Transit	5,7	6,8	8,0
Physical Stock	5,6	7,0	9,2

Forecast accuracy *1.60 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	12,3	15,1	17,7
Goods in Transit	5,7	6,8	8,0
Physical Stock	6,6	8,2	10,9

Supply flow *All Shortcut*

Demand forecast	Minimum	Average	Maximum
(x1000)	274	350	414

Forecast accuracy *0.40 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	7,6	9,0	10,2
Goods in Transit	5,0	6,1	7,1
Physical Stock	2,6	2,9	3,3

Forecast accuracy *0.60 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	8,4	10,0	11,3
Goods in Transit	5,0	6,1	7,1
Physical Stock	3,4	3,9	4,6

Forecast accuracy *0.80 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	9,3	11,1	12,6
Goods in Transit	5,0	6,1	7,1
Physical Stock	4,3	5,0	6,0

Forecast accuracy *1.00 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	10,3	12,4	14,3
Goods in Transit	5,0	6,1	7,1
Physical Stock	5,3	6,3	7,7

Forecast accuracy *1.20 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	11,4	13,8	16,1
Goods in Transit	5,0	6,1	7,1
Physical Stock	6,5	7,7	9,5

Forecast accuracy *1.40 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	12,7	15,3	18,2
Goods in Transit	5,0	6,1	7,1
Physical Stock	7,7	9,2	11,6

Forecast accuracy *1.60 x Correlation Vector*

Stocklevels	Minimum	Average	Maximum
Total Stock level	14,1	17,0	20,4
Goods in Transit	5,0	6,1	7,1
Physical Stock	9,1	10,9	13,8

Portfolio	***Halogen / Product group 002040***		
Scenario	***Lead times / Transport by train***		

Expected 2008
(weeks of supply)

Supply flow *All Sourcing DC*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	6,8	8,3	10,0
Pipeline Stock	6,9	8,6	9,9
Goods in Transit	2,9	3,7	4,4
Physical Stock	3,8	4,6	5,7
Safety Stock	3,0	3,7	4,8

Supply flow *All Shortcut*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	7,8	9,3	11,2
Pipeline Stock	6,6	8,2	9,5
Goods in Transit	2,6	3,3	4,0
Physical Stock	5,2	6,0	7,2
Safety Stock	3,7	4,6	6,1

Supply flow *Sourcing DC, fast & SD --> SC*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	6,9	8,5	10,3
Pipeline Stock	6,8	8,3	9,7
Goods in Transit	2,7	3,5	4,1
Physical Stock	4,2	5,0	6,3
Safety Stock	3,3	4,1	5,5

Supply flow *Packaging centers, fast --> SC*

Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414

Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	6,4	7,9	9,5
Pipeline Stock	6,8	8,4	9,7
Goods in Transit	2,8	3,5	4,1
Physical Stock	3,6	4,4	5,7
Safety Stock	2,7	3,3	4,4

Portfolio	*Halogen / Product group 002040*
Scenario	*Other*

Expected 2008 (weeks of supply)

Supply flow	*All Shortcut*		
Other	*Normal distribution*		
Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,1	12,1	13,6
Pipeline Stock	9,4	10,9	12,6
Goods in Transit	5,0	6,1	7,1
Physical Stock	5,2	5,9	7,0
Safety Stock	3,4	4,3	5,6

Supply flow	*All Shortcut*		
Other	*Normal distribution + fixed sigma*		
Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	11,3	12,3	13,3
Pipeline Stock	9,4	10,9	12,6
Goods in Transit	5,0	6,1	7,1
Physical Stock	6,0	6,2	6,3
Safety Stock	4,2	4,5	4,7

Supply flow	*Sourcing DC, fast & SD --> SC*		
Other	*Normal distribution*		
Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	9,0	11,0	12,5
Pipeline Stock	9,9	11,4	13,1
Goods in Transit	5,4	6,6	7,7
Physical Stock	3,6	4,4	5,1
Safety Stock	2,6	3,4	4,1

Supply flow	*Sourcing DC, fast & SD --> SC*		
Other	*Normal distribution + fixed sigma*		
Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,1	11,2	12,4
Pipeline Stock	9,9	11,4	13,1
Goods in Transit	5,4	6,6	7,7
Physical Stock	4,5	4,6	4,8
Safety Stock	3,4	3,6	3,8

Supply flow	*Packaging, fast --> SC*		
Other	*Normal distribution*		
Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	9,1	11,1	12,4
Pipeline Stock	10,2	11,6	13,3
Goods in Transit	5,7	6,8	8,0
Physical Stock	3,4	4,3	5,4
Safety Stock	2,5	3,1	4,0

Supply flow	*Packaging centers, fast --> SC*		
Other	*Normal distribution + fixed sigma*		
Demand forecast	**Minimum**	**Average**	**Maximum**
(x1000)	274	350	414
Stocklevels	**Minimum**	**Average**	**Maximum**
Total Stock level	10,0	11,2	12,4
Pipeline Stock	10,2	11,6	13,3
Goods in Transit	5,7	6,8	8,0
Physical Stock	4,3	4,4	4,5
Safety Stock	3,0	3,2	3,4

VIII. Overview report / data used

This appendix contains an overview of the sources from which the input data to our research's calculations originate. This supports the reader with additional knowledge necessary to repeat the research and gives insights in the quality of the data.

Forecast errors / correlation variants

These are based on the billed quantity and final forecast data from the SAP BW report "Sales history report BQ / FF - flexible period"; period October 2005 - September 2007.

Demand forecasts

These are based on the final forecast data from the SAP BW report "Sales history report BQ / FF - flexible period"; period October 2007 - March 2009.

Supply flows

Within the TL/CFL-ni portfolio, each specific product group is linked to a dedicated production facility. The supply flows of the products of each included group are configured in accordance to this set up. The standard supply flow for the Halogen portfolio is from the Souring Agency to the Sourcing DC.

Service levels

The service level requirements were stated by Hylke de Cock, vice president of supply chain of the business unit Professional Lamps Europe. He states that the targeted weekly service level of each product of the TL/CFL-ni portfolio is 95% and that of the Halogen portfolio is 97%.

Review periods

The review periods of the TL/CFL-ni portfolio originates from the production wheels provided by Marco Bachrach, supply chain consultant SG TL/CFL-ni. It is supported by interviews we conducted with several logistics planners at the Roosendaal production facility. The review periods of the Halogen portfolio originate from an interview with Johan van der Werf, junior supply chain consultant business unit Consumer Lamps Europe. He states that the review period for all products belonging to this portfolio equals 1 week.

Minimum order quantities

These are based on the data from the SAP BW report "ZM60" and were verified by Marco Bachrach and Johan van der Werf.

Lead times

These originate from interviews and sparring sessions with both Marco Bachrach and Johan van der Werf.

Supply capacity restrictions

These are based on the available Goods Movement files of the TL/CFL-ni portfolio and interviews with Marco Bachrach.

Lead times shipment by train

The lead times for shipment from China by train instead of by sea were stated by Hylke de Cock. At that moment he himself was researching the effects of such supply flow.

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