MASTER

Inventory control in a multi-level distribution system with stationary and non-stationary demand

application on a distribution system in optic market

Vончken, M.A.

Award date:
2017

Eindhoven, March 2017

Inventory control in a multi-level distribution system with stationary and non-stationary demand

Application on a distribution system in optic market

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In partial fulfillment of the requirement for the degree

Master of Science

In Operations Management and Logistics

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Series Master Theses Operations Management and Logistics

Subject Heading: Two-echelon supply chain, divergent system, replenishment policy, stationary demand, non-stationary demand, simulation

Preface

This master thesis is the result of my graduation project executed in partial fulfillment of the requirements for the degree of Master of Science in Operations Management & Logistics and is conducted at GV's department of transformation in Schiphol in the Netherland.

Firstly, I would like to thank Pieter Aarts, my supervisor at the company, for his support and contribution to my project. I greatly appreciate his effort and time for supporting me. I really enjoyed our endless discussions. Also, I would like to thank Pierre Mille for giving me the opportunity for being part of such a challenging company and assignment. Furthermore, I would like to thank my colleagues at the Transformation department for their knowledge, experience and the fun times we shared. Being able to experience such changing company on first hand is of great value for my experience.

Secondly, I would like to thank my first supervisor from the TU/e, Karel van Donselaar, for the support. His critical feedback and tricky questions were highly enriching for both myself as a person and for my thesis. Further, I would like to thank my second supervisor, Ton de Kok, for sharing his knowledge and feedback during our meetings.

Finally, I would give my thank to my family and friends. Their support have been a tower of strength throughout my life and studies. They encouraged me to push forward and helped me face each challenge on the road. I thank my fellow colleagues in Eindhoven for all the experiences and fun we had. I will cherish these memories for the rest of my life.

Martin Voncken

Eindhoven, March 2017

Management summary

This master thesis is the result of a case study at *GV* and serves as a partial fulfillment of the requirements for a master degree in Operations Management and Logistics at the University of Technology in Eindhoven, the Netherlands. The study is commissioned by and executed in the transformations department of GV at Schiphol in the Netherlands.

GV is a major retailer on the international market for optic goods. Located in Schiphol, the international organization owns a world-wide distribution system of distribution centers (DC's), stores and operating companies. Country-specific operating companies (OpCo's) manage a wide range of local retail banners and associated stores where optical services and products are offered. Their product portfolio ranges from contact lenses to prescription glasses.

Currently, *GV* is in a transformation process. In order to become more efficient in customer services and bring more global compliance, the optic retailer aims to reshape their supply network to an integrated supply chain. By rolling out a worldwide ERP-system and shifting stock ownership from the local OpCo's to a central supply chain company (GVSC), GV's objective is to harmonize its business processes and create a more efficient supply chain. This involves some major chances. Previously, the stock at local warehouses (LWH's) were controlled by the OpCo's and communication regarding inventory mainly concerned replenishment orders. The decentralized supply chain has left the OpCo's to organize and control the LWH's and stores in their own manner. This has led to a disparity of local inventory control methods and a lack of transparency in the supply chain. The lack of transparency results in high stock levels, imbalance of stock across the supply chain and higher obsolescence risk.

As the GVSC takes ownership of the system stock, GV wants to professionalize their distribution system by implementing an appropriate and uniform inventory control methodology. The centralized supply chain requires a planning model for each stock point within the system.

The **main research question** is formulated as followed:

Which inventory control models optimize the stock points of Exclusive Brand frames in the GVSC-owned supply chain such that the customer service level is maintained?

This thesis focusses on the inventory planning of GVSC-owned stock in the distribution system, i.e. the replenishment and allocation of stock at the CWH and LWH'S. Rather than the current state, this thesis looks at the to be-state in which GVSC takes full ownership of the DC's in the four largest countries. Therefore, a divergent two-echelon inventory system, consisting of a CWH and four LWH's, is examined.

This project aims to **qualitatively** and **quantitatively evaluate** the distribution system of GV and design the optimal inventory planning model which optimizes stock availability and minimizes stock levels. On strategic level, the design of the distribution system is derived from the framework of de Leeuw (1999). Thereby, each design decision is evaluated based on the system's environment and characteristics. This is followed by the control of inventory systems on tactical level. The replenishment and allocation rules per stock point are described and evaluated on behavior under stationary and non-stationary demand.

In order to evaluate the performance of the replenishment policies, a discrete event-simulation constructed for a two-echelon system with four identical LWH's. During the simulations, the safety norms are determined via a two point simulation-based optimization in which the stock levels were minimized while satisfying a predetermined customer service level (fillrate).

Analysis of the distribution system

On strategic level, the network design decisions are divided over the *type of reorder planning, status information, central stock function* and *coordination of allocation process*. The decisions are evaluated on internal and external demand, system ownership, IT capabilities and process characteristics. On tactical level, the characteristics of the inventory systems and control policies are described in more detail by focusing on the behavior these logics.

The design of the distribution system corresponds to a two-stage distribution system with a central stock function. The central warehouse (CWH) and local warehouses (LWH's) are under centralized control by a single supply chain company (GVSC). Within the system, information is shared among business units regarding forecasts, stock levels and point of sales-data. Both the customer sales (independent demand) and intercompany demand (dependent demand) are subject to marketing events and production constraints. This results in periodic spikes in goods flows and suggesting the presence of a pattern in both demand types.

The inventory systems (stock points) within the distribution system are defined as (R, Q) systems. In other words, the systems are subject to periodic review and fixed lot sizing. As for the control of an inventory system, the distinction is made between stock replenishment and stock allocation. The latter is filled in by a generalized runout allocation rule that prioritizes the downstream locations with the largest gap between the desired and actual inventory position when there is insufficient stock at the CWH. As for the former, the selection of the appropriate replenishments logic depends on the usage of time phasing and the type of status information. Four different policies were modelled and simulated in order to provide an understanding and evaluate the suitability of these control policies in the scoped distribution system.

	Reactive replenishment logic	Proactive replenishment logic
Local status info	*Reorder Point (local)*	*Distribution Requirement Planning*
Integral status info	*Reorder Point (integral)*	*Line Requirement Planning*

Table 1 Types of replenishment logics

Firstly, status information concerns the sharing of goods information and provides a local (installation stock norms) or system wide-overview (echelon stock norms) of the supply chain for the replenishment policies. The case-specific simulations show that the integrated systems have a lower average amount of stock in comparison to the local-orientated systems whilst maintaining equal customer service levels. With the information such as point of sales-data, forecasts and stock levels being shared across the system, the transparency enables the system to synchronize and maintain a customer service level target with a significantly lower stock availability at the CWH. Also, the demand for upper stages is not obscured by case pack sizes or safety stocks, because the final customer demand is passed through to every layer within the system.

Secondly, the selection of replenishment policy also depends on time-orientation. For a proactive policy, the replenishments are forecast-driven. As for a reactive policy, the replenishment rules are based on historical data. As the good flows within the system are influenced by local promotional activities, supply restrictions and marketing-events, the system environment is subject to a dynamic and non-stationary demand. Moreover, the long lead time of the supplier delays the response time to change significantly. As is seen in the simulations, the proactive replenishment policies foresee the changes and respond appropriately. However, this depends heavily on the forecast accuracy. In short, the use of a system wide-orientated, forecast-driven replenishment policy is most appropriate; Line Requirement Planning.

The brief periods of stability in combination with the long lead time created a dynamic environment that leads to high risk of mismatching the potential market demand to the actual supply. Hence, the need for the synchronization of demand from downstream locations with distribution plans and the centralization of system coordination. However, this requires a considerable amount of trust and openness among the business units, relevant and timely information sharing and joint decision making.

Recommendations

In compliance with the research objective, the thesis aims to define the inventory control of the distribution system of *GV*, i.e. stock replenishment and stock allocation policies. For stock replenishment, the echelon-based and proactive Line Requirement Planning (LRP). With the centralized coordination and shared information, a preemptive allocation rule such as the generalized runout time allocation rule is suggested for stock allocation.

Secondly, the results suggest the use of product-specific case pack sizes and performance indicators. Selecting a case pack size corresponding to the average consumption rate reduces both average system stock and the risk on stock imbalance. As for the performance indicator, the optimized stock norms differentiate between product types. Due to the difference in demand average and uncertainty, it is reasoned to use more product-specific indicators instead of the current generic EB-coverage.

Future research

The findings of this study provide the company with better insights for design of a distribution system and the inventory control. The paper follows a number of steps in order to select the appropriate inventory policies and this could be used for other product groups.

As the thesis provides optimal values for the case-specific distribution system, we recommend to further investigate the parameter setting of the replenishment policies. On the contrary to a simplified model with identical LWH’s, reality is far more complex. It is also recommended to research an accurate and reliable forecasting tool for time-phased replenishment planning.

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1. Introduction

This chapter provides the introduction and context of the study. Subsequently, the approach and structure of the project is addressed in order to provide a clear understanding of the depth and reach of this thesis.

1.1 Problem introduction

Global operating companies have progressively started moving towards integrated supply chains. Due to the increasing competiveness in the global markets and technological advances, global companies face major challenges in structuring and optimizing their wide spread business units. As global corporations experience an increase of external threats, the demand for standardization and harmonization within global processes unfolds.

The growth in size and services has made *GV* to recognize the crucial role of the supply chain in its daily operations. By centralizing the key business activities and streamlining the information flows across its retail network, *GV* aims to harmonize its diversified supply chain management. This centralization of supply chain activities and responsibilities provides *GV* an ideal opportunity to restructure their supply chain from system wide-perspective.

The objective of this master thesis is to provide a bridge between the scientific literature and the business environment of *GV* and recommend applicable inventory control models for their distribution system.

1.2 Company Background

Founded on January 2011 by the merger of two well-known optic retailers, GV has grown to become a major retailer on the global market for optic goods. The corporations employs a workforce of more than 27.000 FTE over 6100 stores situated in 44 countries. This network of optical retail stores realized a revenue of € 3.205 million with € 231 million profit in 2015.

As an optical retailer, *GV* offers a variety of optical services and products. Their product portfolio ranges from contact lenses, contact lenses solutions, sunglasses, prescription glasses to associated accessories (i.e. cases). The prescription eyeglasses including frames and lenses form the biggest margin of their product sales. Furthermore, their assortment holds both internationally known licensed branded and *GV*-exclusive house brands. Within *GV*, these are so-called *Non-Exclusive Brands* (NEB's) and *Exclusive Brands* (EB's).

Currently, GV sells in 44 different countries. Within these countries, country-specific operating companies or known as *OpCo's* manage a wide range of local retail banners and associated stores. These OpCo's are responsible for the stores (the *Point of Sales* of GV), providing service to the customers and organize local marketing events. Moreover, *GV* holds a supportive role for the local OpCo's via product management, development of IT systems, product procurement and distribution; making sure that the OpCo's mainly focus on providing the best service to the customers.

In order to keep the daily operations of *GV* up and running, a far reaching supply chain has to be managed. This network consists of a central warehouse (CWH), local warehouses (LWH's) and stores. Within this network of DC's and stores, a multitude of different replenishment strategies are being used, e.g. VMI, cross-docking and direct shipping. The control and structure of these distribution systems varies per product-group and OpCo.

1.3 Project motivation

GV is currently in a transition. Formerly, GV operated as a financial holding covering multiple OpCo's. With their focus mainly on financial figures, GV limited their interventions to financial, corporate and merging & acquisition activities. However, GV has decided to transcend its role as a holding and expand its reaches to operational level. Their goal is to provide a worldwide integrated system which harmonizes all the fragmented procurement and supply chain-related activities from the OpCo's in order to become more efficient in customer services, bring global compliance and exploit economies of scale.

In prologue to the creation of an integrated supply chain, GV implemented a global purchasing platform for the OpCo's, reduced the number of suppliers and harmonized their product portfolio. This enabled GV to strengthen its market position and use product consolidation to a fuller extent. Successively, the global IT and transformation department initiated the development of a global ERP-system and the redesign of the supply chain structure in order to support the envisioned supply chain. Via these initiatives, the ownership and responsibilities of the distribution centers (DC's) are being shifted from the OpCo's towards a central supply chain department. The centralization of purchasing and supply chain-operations manifested in the GV Supply Chain Company (GVSC).

Nowadays, this supply chain center performs the procurement activities for most of the OpCo's and operates the DC's in the UK and Benelux. This number is expected to rise in short term as France and Germany are currently being prepared to join in the next two years. Ambitiously, GVSC aims to centralize all upstream activities and harmonize its fragmented supply chain.

1.4 Project approach

The project is classifiable as a business problem solving project. These type of projects aim to improve the performance of business units, departments or companies. The objective of business problem solving projects are of operational nature, e.g. improvement of effectiveness and efficiency of business processes. In case of this current project, the objective is to redesign and optimize the distribution system of *GV*.

The classic problem-solving regulative cycle by van Strien *(1986)* is recommended for business-problem-solving projects. Firstly, the cycle defines the problem into clear problem definition. Via quantitative and qualitative methods, information is gathered and analyzed, e.g. data analysis and unstructured interview. Thereupon, the design of the solution with the associated change plans is build and evaluated.

During the steps *analysis & diagnosis*, *plan of action* and *intervention*, the model by Mitroff et al. (1974) provides a specific methodological path for quantitative model-based research. The problem definition is reconstructed to a conceptual model which is derived from accepted scientific standards. This conceptual model is converted into a mathematical model for quantitative research via formal mathematical terms based on the conceptual model. A descriptive quantitative model, such as the commonly used simulations, will provide insights into the cause and effects of the model performance. The results of this model will give

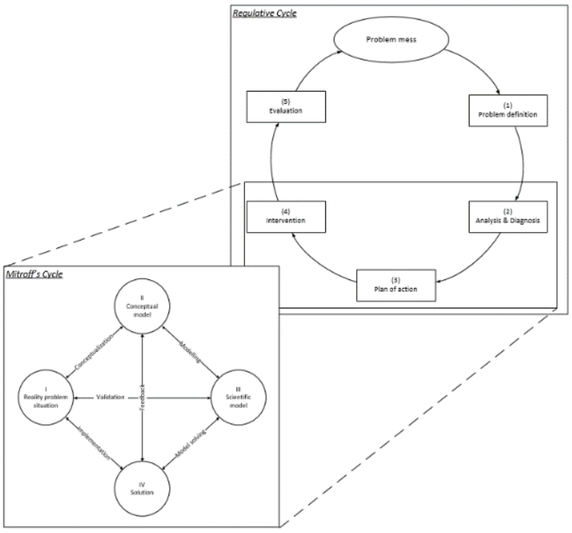

Figure 1 Regulative cycle and Mitroff cycle

feedback on the conceptual model. As for the scientific model has to be validated with the reality problem situation. This process is conducted iteratively.

This research focusses mainly on defining and analyzing the problem. Thereafter, modelling the conceptual and scientific model and providing the recommendations based on the found solutions to these models. In regards to the rigor of this thesis, the acquired models are guaranteed via academic literature and research methodologies. As for relevance, the solutions of this thesis are to be translated to managerial insights and relevant applications.

1.5 Report outline

The structure of this thesis is based on the previous research methodologies. Chapter 2 focusses on the problem situation and comprises of the problem description, the problem scope and research questions. Chapter 3 provides an overview of the relevant literature for the analysis and diagnosis. Chapter 4 follows with the conceptual model defined by the scientific literature and analyses. Chapter 5 proceeds by translating these concepts into mathematical terms and setting-up the design of experiments in research design. Chapter 6 presents the results of the research experiments. The plan of action for the implementation of the solution is given via conclusions and recommendations in chapter 7. The phases “intervention” and “evaluation” are left out of this paper.

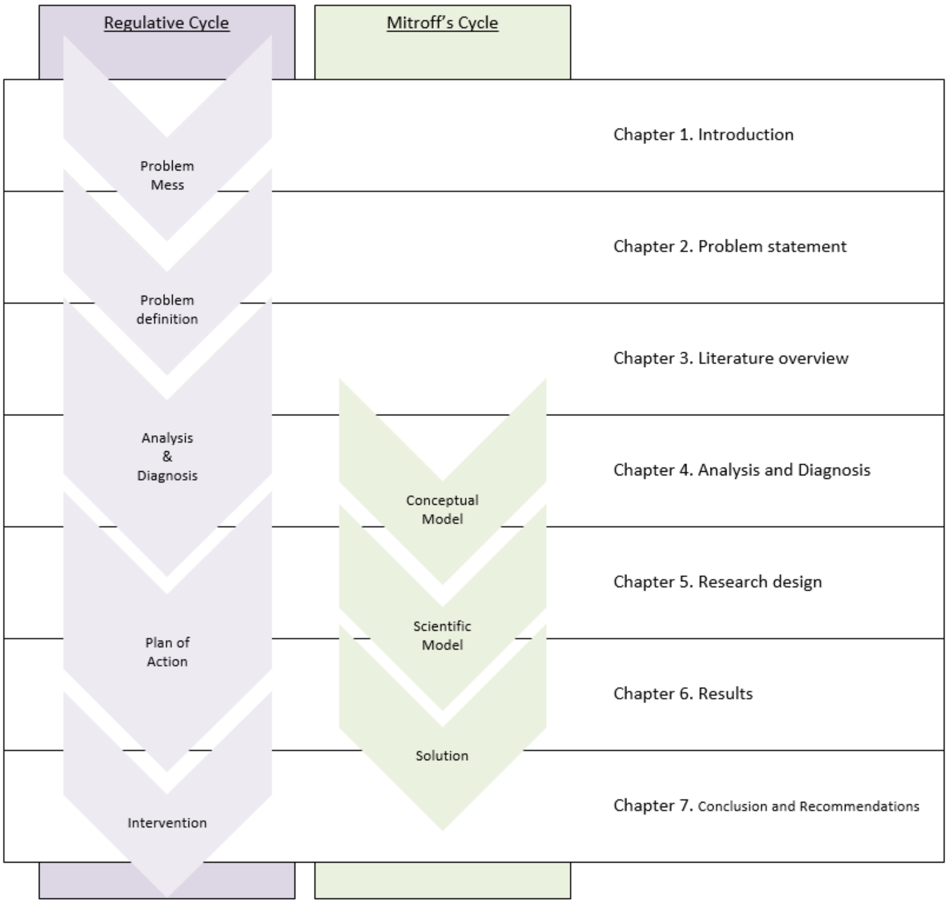

Figure 2 Report outline

2. Problem statement

This chapter presents the first step of the regulative cycle; the problem definition. Firstly, the problem description is described. The second section of this chapter elaborates on the scope of the research. Lastly, the research questions are formulated.

2.1 Problem definition

Currently, *GV* is in a transformational process. In order to become more efficient in customer services and bring more global compliance, the optic retailer aims to reshape their supply chain to a global integrated supply chain. Under the name of the "iSynergy"-project, GV is rolling out a worldwide ERP-system and shifts stock ownership to the central supply chain company (GVSC). The goal is to provide a worldwide integrated system which embraces and centralizes all fragmented procurement and supply chain-related activities within distribution system.

As part of the iSynery-project, *GV* has been mapping their global distribution system on stock levels and business processes. The initiative unveiled a disparity in inventory control methods across the various GV entities. Due to the previously decentralized supply chain, the OpCo's independently organized and controlled the LWH's and stores in their own manner. This has led to a disparity of local inventory control methods and a lack of transparency in the supply chain. The control methods vary over a range of simple Excel-based calculations to complex planning tools. In most cases, the systems rely on simplified methodologies which are based on employees' expert experience.

As a response to the lack of transparency, information is being collected from all DC's and stores concerning the size and distribution of stock across the supply chain. Expressed in "Days Sales of Inventory" (DSI), the current stock is converted to the length of a time period in which the inventory is turned into sales. Based on visibility reports of the G4-countries (Benelux, Germany, France, UK), the amount of stock for Exclusive Brand-frames in their supply chain exceeds a year of sales (appendix IV). Though the company is subject to low-volume, high-mix operations and a high desired service level in an environment with long lead times, these stock levels are considered to be high in comparison to the actual lead time.

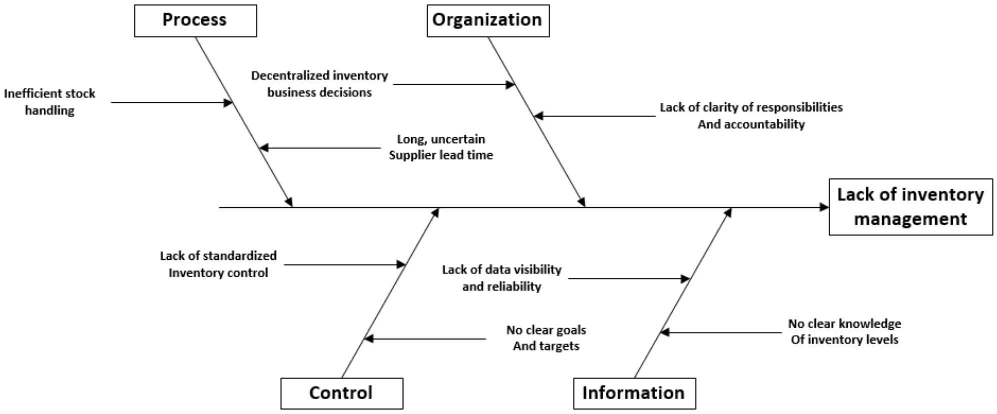

Figure 3 Cause-and-effect diagram

This project aims to **qualitatively** and **quantitatively evaluate** the distribution system of GV and **suggest improvements** for the current inventory control management methodology.

The problem can be stated as follows:

The lack of global alignment and decentralized inventory management led to a disparity of inventory control methodologies and inefficient inventory handling

2.2 Problem scope

Defining the scope of the problem anchors the agreement between expectations of the principal and limitations of the project. By clearly defining the scope, the project aims to find a feasible and relevant solution within a prescribed timeframe and limited resources. The following limitations have been established in agreement with the principal.

This thesis focusses on the inventory planning of GVSC-owned stock in the distribution system, i.e. the replenishment and allocation of stock at the CWH and LWH'S. Rather than the current state, this thesis looks at the to be-state in which GVSC takes full ownership of the DC's. Optimization of transportation and storage handling are left out of the scope. Therefore, a divergent two-echelon inventory system, consisting of a CWH and four LWH, is examined.

As an optical retailer, GV*'s* key products are the eyeglasses (frame and lenses). The frames and lenses represent more than 55% of the total sales of 2016 in the UK and Benelux. Due to the emphasis on Exclusive Brands (EB's) by the management and the high amount of stock, the research focusses on the EB-frames. The research area is delineated to the G4-region. This region has the highest contribution in revenue and stores than any other region. Also, as being first to be integrated into the ERP-system, this region provides the most reliable and relevant data.

2.3 Research questions

As mentioned in the problem motivation and definition, the lack of a global inventory methodology and stock ownership has led to a disparity of inventory control methodologies and inefficient inventory handling. The transition to an integrated and centralized supply chain provides opportunities for GV to optimize and standardize their inventory management.

This thesis focusses on the inventory control model, i.e. inventory replenishment and allocation, of the GVSC owned stock points. Thus, the objective of the thesis is to determine the appropriate inventory replenishment models for each stock point in the GVSC-owned supply chain for the EB-frames. The appropriate inventory control implies a model that controls the inventory most efficient based on balancing inventory and the customer service levels. Due to the cost build up, the inventory model will primarily be evaluated from a customer service perspective rather than on a cost perspective. However, the stock levels are taken into account in the evaluation.

The **main research question** is formulated as followed:

Which inventory control model optimize the stock points of Exclusive Brand frames in the GVSC-owned supply chain such that the customer service level is maintained?

Before evaluating the replenishment models, the characteristics of the inventory systems are to be derived from the current GV supply chain. The development of a conceptual model requires the inventory system's characteristics. This model will be used for the successive evaluation of inventory replenishment models.

The following **sub research questions** are derived:

Which theories provide a framework for the design of a distribution system?

What distribution system design is applicable for the EB-frames supply chain of GV?

Which inventory control policies are recommended for the GVSC- owned supply chain of EB-frames?

3. Literature overview

This chapter gives a brief overview of relevant literature for this project. The first section provides insights in distribution systems and their designs. Subsequently, an elaboration on the control of inventory systems in a distribution system is given.

3.1 Distribution system

For this thesis, the supply chain of GV is at the center of attention. The supply chain is classified as a divergent multi-level system according to the basic forms of Hoekstra & Romme (1993). In other words, the goods flow from a single supplier to several DC's which diverges the products to multiple stores. Each stock point has a single predecessor and several successors.

Figure 4 shows a divergent system with two levels; a central warehouse and a several retailers. According to Nahmias (2004), "most major retail chains utilize a distribution center (DC) as an intermediate storage point between the manufacturer and retail stores". Axsater (2007) explains, inventory is stocked at the retailers for the purpose of maintaining a high service level at the local markets. Moreover, the implementation of a CWH provides a shorter and reliable lead time for the retailers. Also, the inventory at the CWH allows *risk pooling* and facilitates the distribution of stock amongst the retailers which might grow out of balance. The optimal design of a distribution system depends on the structure of the system, transportation times and demand uncertainty.

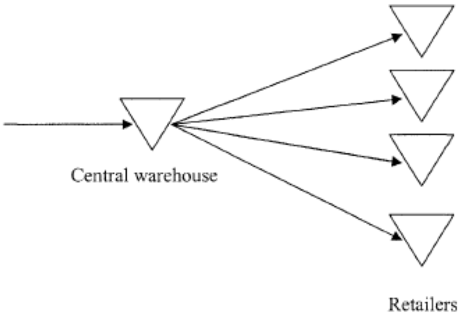

Figure 4 Two-echelon distribution system

3.1.1 Distribution system control

Due to the changing environment, it is necessary for organizations to be critical about the structure of their distribution system. For example, an organization is able to define a simple distribution system in a stable and predictable environment. However, businesses are forced to proactively review their systems when exposed to volatile and complex environments. In such cases, distribution systems have to be continuously redesigned in such way that their business objectives are met.

On strategic level, the design decisions of distribution systems are based on the internal and external environment. De Leeuw (1999) provides a framework for reviewing and designing distribution systems on strategic level. This framework breaks down the distribution systems control in four control decisions: *type of reorder planning, status information, central stock function* and *coordination of allocation process*. These control decisions are evaluated and selected on the basis of internal and external factors (product, market and process). The decisions are further explained on the following sections.

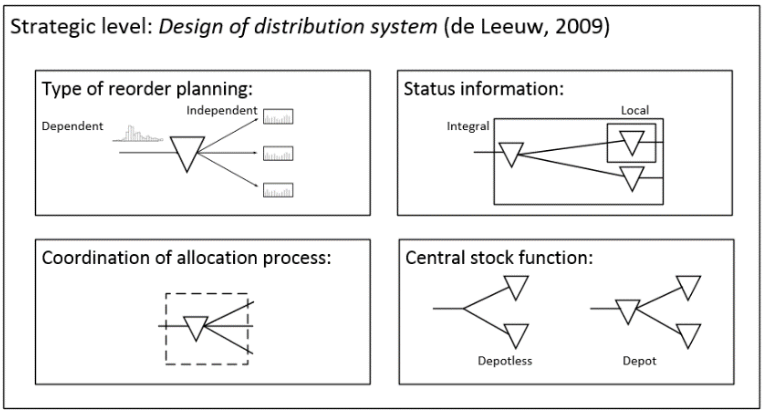

Figure 5 Design decisions for distribution system

I. *Type of reorder planning:*

The first distribution control decision focusses on dealing with internal and external demand of a distribution system. By identifying the presence of a strong and consistent pattern, this criterion aims to derive the degree of demand predictability and select an appropriate control mechanism. Therefore, enabling the system to anticipate on future demand. This decision covers the demand of the final customers (*independent demand*) and the stock requirements of DC's (*dependent demand*).

For *independent demand*, the demand is evaluated on the possibility of determining and incorporating a pattern within end-user's demand forecasting. This demand might be subject to stationary or non-stationary demand (e.g. seasonality, trend). One selects the appropriate forecasting technique based on these demand characteristics.

As for *dependent demand*, the requirements of downstream DC's are also evaluated on significant and consistent patterns. For example, large batch sizes or limited process capacities may result in periodic spikes which enables companies to forecast and anticipate the future requirements. Based on the presence of a pattern, two types of demand planning are distinguished: (1) *time-phased dependent demand* planning and (2) *non-time phased demand planning*.

(1) *Time-phased dependent demand planning* is used for internal demand with the presence of a strong pattern. This planning calculates the future replenishment dates for satisfying the forthcoming demand spikes. This *proactive* replenishment logic is "an attempt to predict the moment at which an order is generated by the lower echelon" (de Leeuw, 1999).
(2) Though, *non-time phased dependent demand planning* discards the use of forecasting due to the unpredictability of demand or the lack of pattern. This *reactive* replenishment logic rather awaits real-time demand until a certain threshold or *reorder point* is reached and reacts by placing a replenishment order at its predecessor.

To sum up, the distribution control decision classifies four different categories:

	Demand with pattern	Demand without pattern
Independent demand	*Forecasting technique with pattern*	*Forecasting technique without pattern*
Dependent demand	*Time phased dependent demand planning*	*Non-time phased dependent demand planning*

Table 2 Types of reorder planning

II. *Status information*:

Status information concerns information about goods, e.g. products demand and stock levels in the distribution system. This information can either provide a local or a system-wide overview of the supply chain and is mainly used for calculating the replenishment orders.

(1) The *local status information* means that ordering decisions at each installations are based on exclusively the inventory position at that installation. The local stock levels are referred as *installation stock* and only provide a limited view of the system.
(2) The system-wide overview or formally known as *integral status information* shares the demand of the end-users and stock levels over all stages in the system. The integral stock levels are also known as *echelon stock* and provide transparency of the whole system.

When applying integral stock norms, the use of echelon stock norms is closely related to stock balance. The higher echelons may cover the imbalance at lower stages in the system. Besides, an enlarged information base is needed to share all stock levels and independent demand across the supply chain. This has to be supported by the IT capabilities and the organization. On the contrary to local status information, only local information is necessary and is easily implemented. However, as Axsäter (2007) denotes, "installation stock policies experience delayed information through the supply chain and can yield very large demand variation, while the final demand is stable".

III. Coordination of allocation process:

The third distribution control decision focusses on the degree of control in regards to the allocation process. Depending on the ownership and the frequency of stock allocation, the criterion differentiates the control of distribution systems as centralized and decentralized.

(1) Decentralized control concerns local coordinated allocation. Each planner of a DC decides on their own authority the allocated quantity supported by the local information. This control is generally classified as *Pull.*
(2) As for c*entralized control*, one unique decision maker (central authority) decides the allocation of stock system-wide. The central control of a system resembles *Push* coordination.

Decentralized control and local status information leads to poor coordination, delay of information and information distortion between the supplier and receiver. This results in high demand variations at upstream stages. The phenomenon is often denoted as the *Bullwhip effect* (Axsäter, 2007). The use of a centralized control reduces significantly the Bullwhip Effect (Lee *et al.*, 1999). However, centralized control is inherently difficult to apply in practice and often lacks support by local business units due to the lack of power. The implementing of a centralized control requires willingness and the means to enforce cooperation from all stakeholders. Nevertheless, central control provides a higher customer service level with a minimal amount of system stock and reduces the risk of imbalance.

IV. *Central stock function*

The fourth distribution control decision concerns the implementation of a CWH into the distribution system. The *central stock function* questions the need for storing products at a CWH, using it as a cross-docking point or abstain from using a CWH and perform direct shipments.

Nahmias (2004) enumerates a variety of reasons for the use of a CWH. First and foremost reason is the *risk pooling*. In most cases, the CWH is used as a pooling center in order to reduce variability by aggregating demand across different locations instead of an individual store. These DC's enable retailers to exploit e*conomies of scale in storage and movement of goods* by consolidating orders and shipping the products in large bulk to the DC's. Also, the distance between DC's and stores are much smaller than factories and stores. Therefore, the *replenishment response* is much faster. However, the response time of the system may actually be worse in a multi-level system when the CWH is out-of-stock and products have to be shipped from manufacturer to the point of sales. Another downside lies in the investment in building and maintaining storage facilities and accumulation of safety stocks for each stage in the system.

3.2 Inventory system

Inventory systems provide structure for maintaining and controlling goods at a stock point. Depending on the degree of information sharing and ownership, inventory systems represents a single DC or a whole system. The purpose of an inventory control system is to determine *when* and *how much* to order (Zipkin, 2000). This decisions should be based on the *inventory position*, consisting of the stock on hand plus outstanding orders minus the back orders.

3.2.1 System type

For defining an inventory control system, Nahmias (2004) denotes the two most common ordering policies as the (R, Q) policy and (s, S) policy. These two policies differentiate on two main characteristic: the type of inventory review and the type of order quantity.

According to Silver (1998), the types of *inventory review* are divided in continuous and periodic. De Kok (1996) describes them as followed: ‘Continuous reviewing is at hand when stock levels are constantly monitored and, immediately after this level drops below a reorder point, an order is placed to replenish the stock. As for periodical review, the stock level is inspected periodically. So orders are generated at the review moment only.’ In practice, the periodical reviewing is most commonly used due to information synchronization and the frequency of stock replenishments.

As for order quantity, this accounts for an arbitrary amount of inventory used order to raise the stock to a specific level. The size of an order can either be fixed or variable. In practice, companies restrict the replenishment order to case pack sizes in order to reduce handling or use a fixed amount that minimizes the total cost (economic order quantity). Also, the system can be subjected by a minimum ordering threshold. This minimal order quantity (MOQ) is a form of ordering constraint.

3.2.2 Inventory control

Controlling inventory concerns the questions such as ‘’how much to order’’ and ‘’to whom to distribute’’? De Leeuw (1999) divides controlling inventory into two types of control decisions: *Stock replenishment* represents the refill of an inventory system with stock, irrespective of the future location of the stock. *Stock allocation* depicts the placement of inventory over subsequent locations in the system.

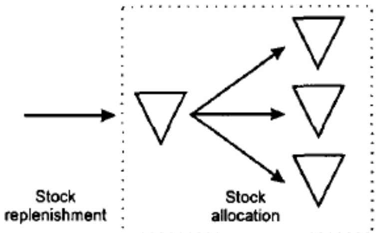

Figure 6 Inventory control

I. Stock replenishment

As described in the section *type of reorder planning*, replenishment logics are distinguished in *Time-phased* (proactive) and *Non-time phased* (reactive). The logics differ in the replenishment trigger and time perspective. Further explanation is given on the following page.

Proactive: According to de Leeuw (1999), this proactive replenishment logic is “an attempt to predict the moment which a new order is generated by the lower echelon”. Future demand requirements of downstream locations are projected in a schedule and divided over time buckets (days, weeks, months). This enables the company to foresee demand peaks (strong patterns) and incorporate production or storage constraints. Nevertheless, any type of uncertainty within or outside of the system leads to frequent rescheduling, otherwise known as *system nervousness*. An accurate and reliable forecasting is of the essence in order to reduce demand uncertainty. As for supply uncertainty, extra stock norms build in to reduce uncertainty via safety time.

Reactive: Discarding forecasting, this logic *reactively* responds to actual demand. Based on the inventory position, the inventory system places a replenishment order at its predecessor when a certain threshold or *reorder point* is reached. The reorder point often uses averaged historical data as input information and does not have mechanisms to anticipate changes in demand. This leads to a poor performance in business environments with high demand fluctuations.

For both replenishment logics, safety stock norms are incorporated in order to cope with demand and supply uncertainty. Vollmann (1992) distinguishes safety time and safety stock. Safety stock should be used for protection against uncertainty in quantities, such as the size of customer demand. On the other hand, safety time is suggested to deal with uncertainty in demand and production timing, such as product arrival. While safety stock is increased per product units, safety time is raised with time units.

Furthermore, the design decision *status information* plays also a role for stock replenishment. The calculation of replenishment orders depends on the available information. The replenishment is either based on local *installations stock* or system-wide *echelon stock*. This leads to various replenishment policies in literature. For instance, integral stock norms lead to Line Requirement planning (van Donselaar, 1992) for proactive planning logic and integral stock norms (van Donselaar, 1998) for reactive planning logic.

	Reactive replenishment logic	Proactive replenishment logic
Local status info	*Reorder Point (local)*	*Distribution Requirement Planning*
Integral status info	*Reorder Point (integral)*	*Line Requirement Planning*

Table 3 Replenishment logic types

II. Stock allocation

Clark & Scarf (1960) were first to describe the allocation problem in two-echelon distribution systems. In case of insufficient stock for supplying subsequent stock points, their Fair Share (FS) rationing policy aims to achieve an equal stock-out probability for all the end stock points without central stock function. The runout allocation rule of Jackson (1988) aims to by minimizing the cumulative stock out period of subsequent DC’s in a symmetric system. Fransoo (1993) emphasized the use of a sound runout rule by considering the behavior under certain demand levels inspired by the de Kok (1990). Extended research was conducted on a customer service approach where the main goal is to realize predetermined service levels in the final stock points. Diks, de Kok & Lagodimos (1996) discuss Fair Share (FS), Approximate Share (AS) and Consistent Approximate Share (CAS) rationing policies, which are used in push inventory systems. Priority Rationing (PR) is a policy used in Pull inventory systems. These policies concentrate on service levels such as the ready rate and fill rate.

Eppen & Schrage (1981) were the first to explicit refer to the phenomenon *imbalance*. “The phenomenon as not being able to achieve the targeted service levels at the end-stock points because the inventories deviate from the average inventory at the final stage.” The balance assumption implies that the quantities allocated by rationing are always sufficient to ensure equal stock-out probabilities for the retailers. Van der Heijden (1997) proposed the Balanced Stock (BS) rationing policy which tries to ration the system-wide shortage in a way do that the rationing fractions minimize average imbalance.

3.3 Summary

Distribution systems are classified as divergent multi-level inventory systems. In these type of systems, each stock point has a single predecessor and several successors. The use of distribution systems enables companies to use risk pooling and postpone shipments. However, a downside of this inventory system is the risk of stock imbalance. As for the control of a distribution system, there is a differentiation in a decentralized and centralized approach. While in a centralized approach, there is only one unique decision maker over the whole system, the decentralized approach suggests each stock point to make decisions on their own, local information. This decentralized approach may result in information distortion and upswings in replenishment orders. As for the inventory control, the distinction is made between stock replenishment and allocation. Stock replenishments represent the inventory refill of stock points and stock allocation depicts the placement of inventory over subsequent stock points. Both depend on the design and constraints of the system.

3.4 Contribution and relevance

This thesis evaluates the theory about distribution systems on a real-life, complex supply chain of a retail company. The selected literature contributes as guidance for the analysis and selection of inventory models. This research project can be considered as a case study on multi-echelon inventory management in a retail environment with respect to the potential inventory reductions by various inventory management policies. The research thesis provides additional insights in multi-level distribution systems subjected to non-stationary demand. According to de Kok & Fransoo (2002), a subject which is still “a white spot” in literature about stochastic models.

4. Analysis & Diagnosis

This chapter explores structure and surroundings of the distribution system and provides the reasoning for its design. Via quantitative and qualitative methods, information is gathered and analyzed in regards to distribution system of *GV* and is translated to a conceptual model.

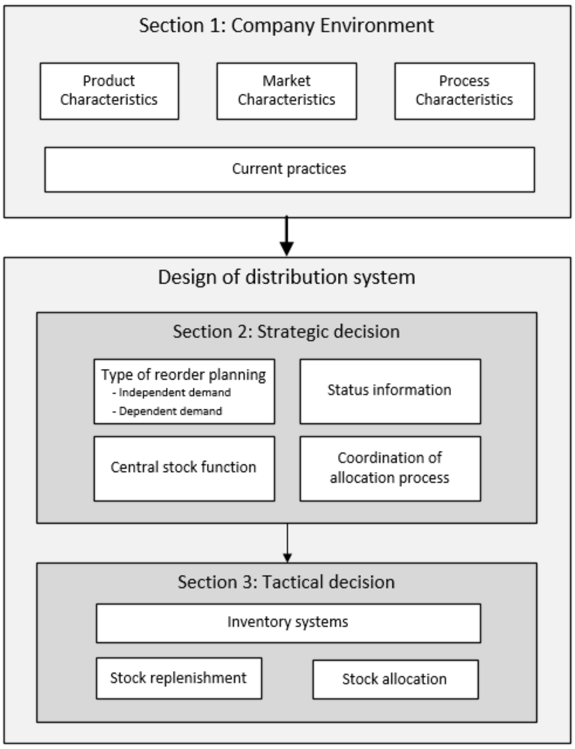

Figure 7 Overview analysis of distribution system

The first section describes the business environment by exploring the product, process and market characteristics. This illustrates the current practices within the system of *GV.*

The second section deals with the strategic and tactical decisions for designing the distribution system and assesses the relevant parameters. On strategic level, the framework of de Leeuw (1999) provides the basis for the analysis. As on the tactical level, the inventory systems and control are described in further details.

4.1 Environment

This section will provide background information about demand characteristics, product characteristics, process characteristics and distribution processes of *GV*.

4.1.1 Product characteristics

Nowadays, eyeglasses have become a prominent fashion item and often a key feature of an individual's personal appearance. The most fashion-driven part of the glasses, the frame, varies in various trend-related aspects; shape-, color- and material-level. Due to the fashion trends in the eyewear market, the present assortments are partially replaced in order to keep up with the new trends. Twice per year, a third of the assortment is replaced with new SKU's during the Go to Market-events. The frames of glasses are seen as fashionable goods with a product life cycle (PLC) of two to three years. However, the data is too limited to fully document the PLC.

4.1.2 Market characteristics

The global eyewear market is a competitive landscape. With many local players and a few international actors, the optic retail business is a highly competitive market which results in numerous promotions and price pressure. Within this landscape, GV positions itself as a mass merchandise retailer on international scale and distinguishes itself with affordable priced eye care.

As for the products, the eyeglasses are slow moving, low-cost products. From store perspective, on average three pieces of a SKU are sold per pin (shelf) on yearly basis. The daily demand at a LWH is 3 to 7 pieces for a single, average selling SKU. When evaluating the demand from Point of Sales-data, frames are subject to high variability and categorized by the classification of Syntesos (2005) as *erratic* and *lumpy* (Appendix IV).

4.1.3 Process characteristics

As a retailer, GV focuses on providing its products and services to the customers. GV's supply chain starts at outsourced manufacturing activities. Via various DC's, products are consolidated, stored and shipped towards local DC's or straight to the stores. GV manages the products from manufacturing till the moment that the products are sold at the point of sales.

The process goes as follows: Firstly, the EB-frames are ordered by GVSC at external suppliers. These are mainly positioned in Asia. After the Make To Forecast (MTF)-driven production and quality checks, the approved products are shipped in bulk quantities to nearby harbors for ocean freight. In case of major delays by the suppliers, air freight is used. However, this is only accounts for 22% of the total order lines in 2015-2016. The lead time from the start of production till the arrival at the CWH takes several months with a degree of uncertainty (Appendix VI).

Afterwards, the shipments arrive at the central warehouse (CWH). The CWH, situated in the Netherlands, receives daily to weekly shipments from their Asian supplier and replenishment orders are placed monthly. Subsequently, the frames are globally spread to the local warehouses (LWH's) in boxes of 10 to 50 pieces on weekly basis. The lead time of these shipments from the CWH to G4-LWH's take generally seven days. In most cases, the frames are assembled with the customer-specific lenses at the LWH. These lenses have to be cut, edged and fitted into the frame according to the customers' eye-specifications and frame-measurements. Therefore, this stock point is ATO-driven. As for the stores, the only instore products are showroom models. Nevertheless, there are stores which perform the customization activities and keep extra stock instore, but this study does not take those in to account in regards to the global strategy of GV to postpone customization.

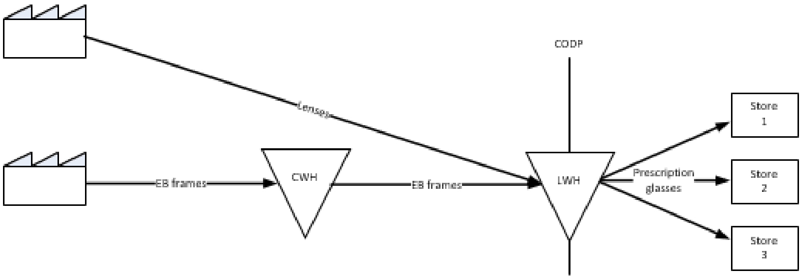

Figure 8 Distribution system of EB-frames

4.1.4 Inventory management

With such a vast and complex distribution system, the necessity for information and control manifested in the development of internal tools. These tools for inventory management are performance indicators and status reports.

As GV started consolidating replenishment orders of OpCo's, the *Rolling Order Forecast* (ROF) came to being. The OpCo's communicate their expected sales and replenishment orders over a forecast horizon of six months to GVSC on monthly basis. GVSC consolidates, reschedules and communicates these orders to their suppliers. This enables them to satisfy the imposed minimal order quantities and exploit economies of scale. Appendix II will provide further explanations in regards to the inventory management systems.

GV measures their inventory via the Days Sales of Inventory (DSI). This critical performance indicator indicates the length of a time period in which the current inventory is turned into sales. In other words, the amount of stock is divided by an average amount of sales per time unit. This indicator is used for two objectives; a performance measurement and a replenishment target.

In certain OpCo's, the coverage functions as a reorder point and is used to cover the upstream lead times and possible demand volatilities. Determining of the *future coverage* varies per OpCo and, in most cases, is based on expert experience of employees.

As performance measure, a monthly DSI-report depicts the amount of stock spread across the supply chain. The goal of this report is to create visibility of stock within the chain. Based on the forecasts and the current stock levels provided by the OpCo's, the system stock is translated into DSI's and compared to an *EB-coverage target*. The SKU's per OpCo are translated into months of sales by enumerating the corresponding stock on hand and stock in transit. Each point is compared to an arbitrary target area which is delineates by two coverage target (red lines). Keep in mind that these lines are mainly based on experience of employees.

4.2 Strategic decisions

On strategic level, the network design decisions are divided over the *type of reorder planning, status information, central stock function* and *coordination of allocation process*. These control decisions are further explained and applied to the supply chain of GV and EB-frames product group on the following pages.

4.2.1 Type of reorder planning

For one, the design of the distribution system is shaped by the demand characteristics. Both dependent and independent demand are evaluated on the presence of patterns for the selection of forecasting and replenishment logics. First, independent demand will be explored and followed by an evaluation of the dependent demand.

Independent demand

The independent demand is derived from the Point of Sales (POS)-data of the OpCo's. These POS-data of the EB-frames provides the opportunity to analyze the independent demand on both SKU-level and aggregated level for the demand characteristics and possible patterns.

On SKU level, the POS-data unveils numerous peaks in the SKU's demand. Figure 9 shows corresponding demand spikes in duration and frequency across a range of SKU's. While the intensity differs, the finite duration and frequency of these peaks resembles the promotion activities or known as "special events" within GV. The OpCo-organized promotions have a duration of weeks to months and take shape as "two for the price of one" or discounts for the lenses. Hence, encouraging the customers to buy products. These sales promotions are typical for this kind of market.

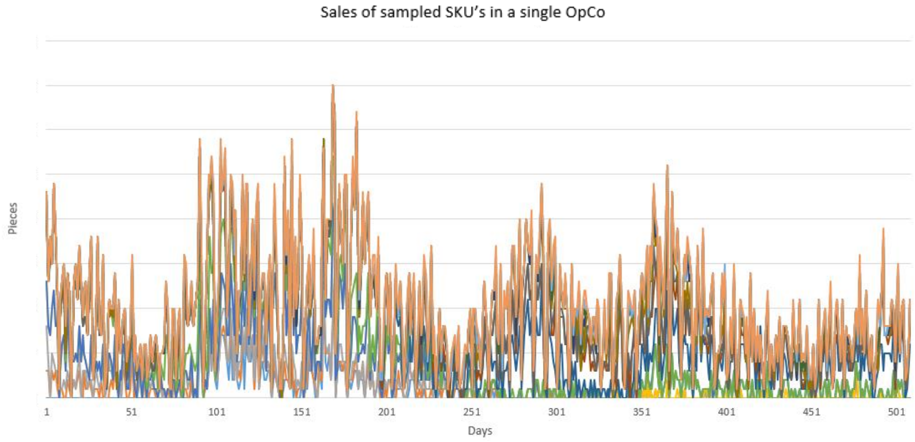

Figure 9 Independent demand of SKU's at a single OpCo

When looking on an aggregated level at the sales of frames (EB's & NEB's), the EB-frames experience an increase in overall sales at the expense of the NEB-frames. Figure 10 shows a relative growth in EB-sales. This is due to the implementation of an EB-target. The management intervention stimulated the sales of EB-frames at local stores. On store level, this triggers the retailers to allocate more EB-frames to a restricted number of in store-pins which results in a decrease of in store NEB's.

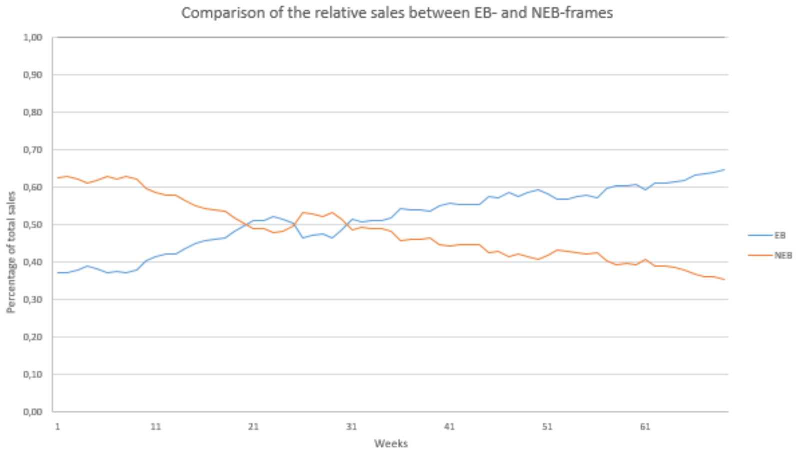

Figure 10 Overall EB's and NEB's weekly sales

Summarized, the data does show a clear interference in independent demand by marketing and management. 'Special events" have a significant impact on the sales. It concludes that the independent demand is subject to non-stationary, pattern demand. Nevertheless, the study for the appropriate forecasting technique is out of scope for the thesis.

Dependent demand

As for dependent demand, the replenishment order of the CWH and LWH's are evaluated on the presence of a demand pattern. For example, the large case pack sizes and the production or storage capacity may result in spikes in the flow of replenishment orders over time.

Figure 11 shows the visualization of the CWHs' inbound and outbound goods flow. Both flows are subject to a frequent number of peaks and wave motion. Through in-depth interviews, it became clear that these peaks were caused by marketing-events and production obstructions. GV organizes two Go to Market (GTM)-event each year which presents the new product assortment to their OpCo's and franchisers. In response, the OpCo's order simultaneously and create a large upswing in the goods flow in June and September. Secondly, the GTM-peak in December is amplified by a manufacturing closure. During Chinese New Year, the Far East production facilities are shut down and no stock arrives in February. This causes GV to push extra replenishment orders forward in order to overcome this constraint. After the GTM-related shipments arrive at the CWH, the goods flow towards the OpCo increases subsequently. This creates a wave-like pattern.

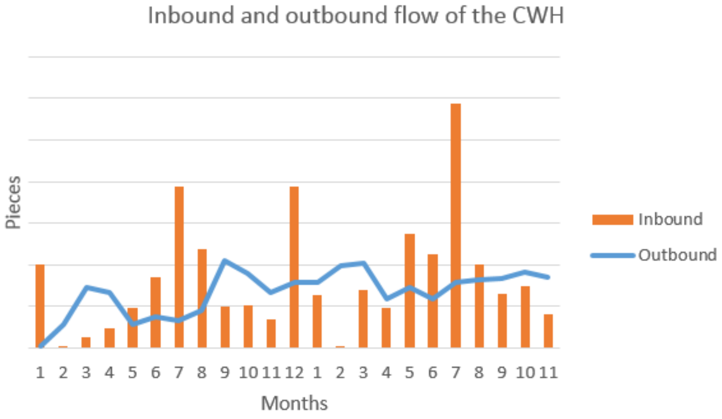

Figure 11 Inbound and outbound goods flow

In order to adequately control the distribution system and overcome these events, the system is recommended to foresee the required stock during those periods and advance replenishment order in order to cope with these constraints and smoothen the supply chain.

4.2.2 Status information

The second control decisions concerns degree of information sharing. The current IT capabilities and organization determine the use of installation (local) or echelon (integral) stock for controlling stock points.

As part of the iSynergy-initiative, incentives of data harmonization and integration are already in progress for improving the information sharing across the GV-entities. POS-data and stock level-data are being exchanged between business units via the ERP-system and Excel-based reports. Such visibility reports enables the company to oversee the inventory spread over the supply chain and, as a result of this transparency, the company is able to visualize possible overstocking within the system and prevents the placement of unnecessary replenishment orders. However, the current visibility is limited to monthly updates and there is still a lack of clarity at the users concerning the reporting procedures.

In regards to the research objective and the current progress in *GV*, the integral status information and echelon stock norms are both taken into account. Furthermore, the integral information provides the opportunity to use a preemptive rationing policy. This enables the company to balance out stock between downstream locations rationally and minimize stock imbalance.

4.2.3 Central stock function

The third control decision concerns the implementation of a central stock function (CWH), cross-docking center or perform direct-shipment to the customers. This depends on factors such as demand uncertainty, lead times duration and number of LWH's. These heavily influence the probability in stock outs, loss in sales and stock imbalances.

In the current situation, GV uses a central stock function for their EB-frames. Due to the large MOQ, the stock point in the Netherlands is used as consolidation center before separating and sending the products to their globally spread LWH's. Besides, the long distance and delivery uncertainty of the suppliers in the Far East is covered with inventory at the CWH and enables GV to resupply the LWH's in a reliable and shorter amount of time. The longer the lead time, the less responsive companies are to market change.

4.2.4 Coordination of the allocation process

The last distribution control decision focusses on the degree of ownership of replenishment decisions spread over the actors within the supply chain. "Who decides? Is there a central decision maker or is the ownership spread over various business units?"

The ownership of the GV's distribution system is divided over the following business units; the local OpCo's and the GV's supply chain company (GVSC). In compliance with the iSynergy-project, the ownership of the stores falls upon the OpCo's and the supply chain department is responsible for the DC's (CWH and LWH's). As the ownership is being shifted towards GVSC, the responsibility of order placement and allocation is assigned to a single decision maker. While the OpCo's are expected to submit their store requirements, GVSC is responsible for the availability of stock at the LWH and the CWH. This enables them to allocating the limited amount of stock to those who have priority and decrease the risk of imbalance. The figure below shows the delineation of ownership within GV,

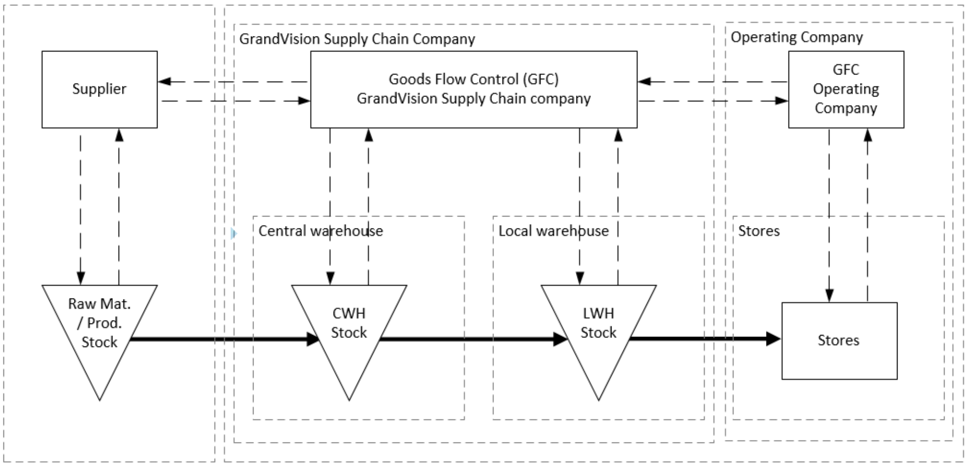

Figure 12 Goods flow and ownership of supply chain

The division of responsibilities in stock replenishment is shown in appendix VII via a cross-functional flowcharts. The charts shows similarities with the Collaborative Planning process of de Kok (2005). This is a periodically process that links the supply-chain-capacity agreements, production-planning activities and daily operational executions. The planning process of GV goes as follows in compliance with the Collaborative Planning:

1) *Gather data*: During this phase, all OpCo's review their promos and sales forecasts. Their requirements are proceeded as input to GVSC. The GVSC planners will collect the data for the netting off process.
2) *Decide*: The GVSC planners asses the data and provide stock decisions. These are evaluated during Sales & Operation Planning review meetings with the stakeholders.
3) *Escalate*: In case of disagreement or decisions fall outside of the planner's responsibilities, upper management is involved.
4) *Deploy*: The verified replenishment decisions are proceeded by GVSC to the suppliers and DC's.

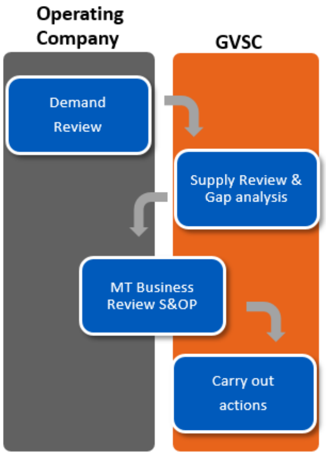

Figure 13 Planning Process GV

For this thesis, it is assumed that GVSC owns the stock in the CWH and LWH's in accordance with the iSynergy-initiative. The coordination of allocation is done centrally by the planners of the supply chain department.

4.3 Tactical decisions

On more detailed level, the tactical decisions focus on the control of inventory systems. First the inventory systems in the distribution system are defined. Afterwards, inventory control is divided into *stock replenishment* and *stock allocation*.

4.3.1 Inventory systems

The control of each inventory system is characterized by inventory review and replenishment quantities. These characteristics are applied to the stock points of *GV*.

Inventory reviews

As previous noted, there are two types of inventory review: continuous and periodic review. Continuous review refers to constantly checking stock levels and immediately placing a replenishment order when a threshold is reached. As for periodic review, the stock levels are checked only on review moments.

Currently, the OpCo's report their projected demands for a time horizon of half year on monthly basis. Based on those figures, GVSC places monthly replenishment order at the supplier. Afterwards, the LWH's are supplied ones a week by the CWH. This replenishment frequency might occur more often due to restricted inbound capacity. For the sake of the simplicity and in agreement with the company, it is assumed that the LWH is weekly reviewed and the CWH monthly. Hence, the CWH and LWH's are periodically reviewed.

Replenishment quantities

The second characteristics of inventory systems is *replenishment quantities*. The order quantity accounts for an arbitrary amount in order to raise the stock to a specific level. This amount can either be variable or fixed.

Based on in-depth interviews, the CWH and LWH's are subject to fixed order sizes. In case of the CWH, the suppliers demand a Minimal Order Quantity (MOQ) of 300 pieces. This is relevant for all EB-frames SKU's. As for the LWH, the CWH restricts the replenishment quantities for LWH's to full boxes in order to prevent extra handling and transport costs. The size of the case packs or boxes differ between 10 to 50 pieces, depending on the product group. This study assumes the average case pack of 30 pieces as generic case pack size.

Both the CWH and the LWH's are periodically reviewed. The CWH is restricted by a MOQ of 300 pieces. A periodic reviewed inventory system with a lot-size of 300 is most appropriate. The LWH's differ from the CWH by a restricted case pack sizes (Q) of 30 units.

4.3.2 Inventory control

The following section will elaborate on stock replenishment and stock allocation within *GV*.

Stock allocation

The first inventory control decision is *stock allocation*. Based on the scope, the allocation and the quantity size of replenishments are the matters of interest. When a situation with excessive demand occurs, which of the subsequent DC's get the priority or is it equally divided, do they get fixed or variable amount of stock and on what basis is this amount?

Currently, all inventory at the CWH is allocated to the OpCo's. In case of insufficient stock, no clear methodology is being used. However, seeing the importance of allocating stock in a distribution system and the transparency in the system, an allocation rule will be used. As recommended by de Leeuw (1997), the runout times allocation rule is easily implemented and aims to minimize the cumulative stock out period of subsequent DC's and reduces the risk of system imbalance. This is done by iteratively determining the runout period, based on the current inventory on hand before receiving any replenishment. The rule proposed by Jackson (1988) was later extended and generalized by Fransoo (1993).

Stock replenishment

The second inventory control decision is *stock replenishment*. As previously denoted, this concerns logic behind the refill of stock points. One questions "How much to order and when?"

The distribution decision *type of reorder planning* attends this matter by distinguishing reactive and proactive replenishment logics. These logics differ in time perspective; the proactive logic focusses on the future and the reactive logic responds to the past. The analysis of demand suggest the focus on the future. Due to a long lead time from the supplier and the patterns in demand, a time-phased replenishment planning is recommended. Also the type of *status information* is of influence. The use of installation stock or echelon stock has consequences for the replenishment logic.

However, the following chapters will provide more insights in the behavior and structure behind these logics. The logics will be modelled and simulated in order to create more understanding in selecting and applying these logics.

4.4 Diagnosis

By identifying the nature of the system and defining the characteristics, the previous sections illustrate the structure and surroundings of *GV*'s supply chain and construct a conceptual model. The structure and control of the distribution system is classified as followed:

Strategic level: Design of distribution system

On strategy level, the groundwork of distribution is constructed via the design decisions. Based on the internal and external demand, system ownership, IT capabilities and process characteristics, the design decisions come to being.

In compliance with the scope, the *GV*'s supply chain is classified as a two-echelon distribution system. This system consists of stockless retail stores, four LWH's and one DC as a central stock function. The external demand is generated by stockless, local retail stores. The ownership of the LWH's and CWH falls under centralized control of GVSC. This enables the system to share the information regarding the stock levels and PO-data between the business units. Therefore, enabling both installation and echelon stock for inventory control. The last design decision concerns the degree of pattern in demand. With the current GTM-events, long lead time and production limitations, a proactive replenishment logic is most appropriate.

Tactical level: Inventory system control

The tactical decisions consider further specifications regarding the stock points. These decisions illustrate the characteristics of the inventory system and inventory control policies.

Inventory systems are characterized by the type of inventory review and order quantity. The DC's within the system are defined as (R, Q) policies. In other words, the systems are periodic reviewed and lot sizing. For the CWH, the stock is monthly reviewed. Subsequently, the replenishments are forwarded to the suppliers in accord to the MOQ (case pack size). The LWH's are reviewed on weekly basis. The replenishment of the CWH is fixed to case pack sizes.

The control of inventory systems is divided in stock replenishment and stock allocation. The latter concerns division of insufficient stock among the subsequent stock points. Due to the lack of standardized method, the preemptive runout time allocation rule will be used. As for the former, the replenishments of the LWH's will be locally driven (installations stock). As for the CWH, both the local as system-driven information status is possible. Depending on the type of demand (stationary or non-stationary demand) and the type of status information, the appropriate replenishment logic is selected. These logics will be further modelled and simulated in the following chapters.

5. Research design

The previous chapter described the supply chain of GV in concepts. This section proceeds in translating these concepts into mathematical terms and relationships. This is followed by the set-up, the validation and the relevance of the quantitative simulation and the design of experiments.

5.1 Modelling the distribution system

In order to construct the model of the distribution system, *Hollier & Vrat* (1976) provide a framework for the design, operation and control of multi-echelon inventory systems. It classifies and separates various decision parameters into four categories: *Uncontrollable parameters, structural parameters, controllable decision variables* and *measures of system performance*.

5.1.1 Uncontrollable parameters

First of all, the environment of the modelled inventory system is described in the category *uncontrollable parameters*. These external factors influence and restrict the inventory model by e.g. the characteristics of demand, supply sources and replenishment time.

The model concerns a single item, single source system. This study assumes that the external supplier is unrestricted in production and supply capacity. The lead time of the supplier is subject to an independent stochastic process with a fitted normal distribution(appendix VI). As for the shipments between the CWH and LWH, a deterministic lead time is assumed.

Based on the previous chapter, the external demand of the final customers is stochastic. The type of demand distribution is chosen according to the product characteristics. For this thesis, the discretized Gamma distribution is chosen, because of its easily mathematically manipulation. Also, slow movers or low consumption goods, such as frames, are best represented by the Gamma distribution due to the asymmetric shape and non-negative probability. The shape and scale for the gamma distribution is derived in the following way (Silver, 1998):

$$Shape: \alpha = \left(\frac{\mu_{day}}{\sigma_{day}}\right)^2 \qquad Scale: \beta = \frac{\sigma_{day}^2}{\mu_{day}}$$

σ_i: Standard deviation of demand at location i
μ_i: Average demand at location i

As for the type of stochastic demand, this thesis will evaluate multiple scenarios. Because of the insufficient and obstructed demand data, the use of stylized demand is most appropriate to expose the inventory policies to specific changes in the external factors. The following demand types are selected based on the findings of the previous analysis.

1. *Stationary demand:*
   Random generated demand with known mean, variance and gamma distribution where the mean and standard deviation of demand stay unchanged.
2. *Non-stationary demand – stochastic trend:*
   Random generated demand with known mean, variance and gamma distribution. At a certain point, the mean will grow with a linear trend from a multiply factor of 1 to a factor of 2. Therefore, changing the conditions of the demand.

More information is given in section 5.4.3.

The second category focusses on the *measures of system performance*. The performance of the system should be thoroughly measured in order the evaluate various inventory models in the *GV*-specific distribution system

Within an inventory system, there is the *dilemma of inventory management* (Hopp & Spearman, 2009). This is the trade-off between the *high delivery capability* and *low stock levels*. A company aims to minimize stock levels in order to reduce inventory handling and storage costs. As a consequence, this may result in an increase of stock out-probability and, thus, a loss in customers and sales. Rather evaluating the inventory system from a cost perspective, the system will be evaluated on stock levels and occurrence of stock outs.

The occurrence of stock outs is measured by a customer service level. The most commonly used service level is the fill rate (Van Donselaar & Broekmeulen, 2014). This metric measures the quantity of shortages created in an arbitrary period in relation to the total demand of a period. The duration of a stock out is not accounted for. Still, this metric provides the most accurate degree of service.

Fill rate:

$$P_2 = 1 - \frac{E[BO]}{E[D(\tau+L,\tau+R+L)]}$$

$E[BO]$: Expected amount of backorders
$E[D(\tau + L, \tau + R + L)]$: Expected amount of demand during the review period

Typical for distribution system is the occurrence of imbalance. The degree of imbalance in the system is measured by the deviation of inventory on hand at the most downstream echelon. However, this deviation becomes less relevant when the LWH's vary in lead time and demand. For this study, the LWH's are assumed to be identical. The following formula determines the average imbalance of a system with identical LWH's (van Donselaar, 1999).

Degree of imbalance:

$$IOH_t^{imbalance} = \sum_{I\in i} \left| IOH_{i,t} - \frac{\sum_{I\epsilon i} IOH_{i,t}}{N} \right|$$

$IOH_{i,t}$: Inventory on hand at location i at time unit t
I: Collection of downstream locations (LWH's)
N: Number of downstream locations

5.1.2 Structural parameters

The category *structural parameters* illustrates the structure and control of the distribution system and stock points.

Based on the scope of the thesis and the design of the distribution network, this model is classified as a two-echelon arborescence inventory system. The CWH receives stock from an exogenous source and supplies the same products to four second-level depots which are experiencing external system demand. In case of insufficient stock, the stock orders will partially be fulfilled and the unmet demand will be backlogged. Previously, the system was decentralized by the separation of DC-ownerships over the various OpCo's and GV. With the envisioned integrated supply chain, the distribution system will be centralized under the management and ownership of GVSC.

On DC-level, the stock points are subject to a fixed periodic review. The CWH is reviewed on a monthly basis and the LWH on weekly. Also lot sizing has to be included in the system via the MOQ for the supplier shipments and the case packs between the CWH and LWH's. In short, the DC's are periodic lot-size-reorder point systems. Exposed to stochasticity and multi-periods, the control of stock points in the supply chain will be described in the following paragraph.

5.1.3 Controllable parameters

The last category concerns the *controllable parameters*. One uses these decisions variables within the model to control and measure their impact on the system with the previous stated performance indicators. These parameters focus on the tactical decisions in inventory control, consisting of stock replenishment and stock allocation.

Stock replenishment

The DC's are controlled by an underlying replenishment logic and the size of the safety stock. In order to get more understanding of the logics, the reactive and proactive replenishments are explained with the local and system-orientations. The types of replenishments are shown in the table below:

	Reactive replenishment logic	Proactive replenishment logic
Local status info	I. *Reorder Point (local)*	III. *Distribution Requirement Planning*
Integral status info	II. *Reorder Point (integral)*	IV. *Line Requirement Planning*

Table 4 Types of replenishment logics

Firstly, the *reactive replenishment*, i.e. the reorder point logic, ''reactively'' awaits the actual demand and responds when a certain threshold (reorder point) is reached by placing replenishment orders. The logic requires a predetermined mean and standard deviation based on historical data.

As previously described, there is a difference between local- and system wide-orientation of the system. This has consequences for the calculation of the replenishment orders. Hence, the reactive approach is divided in the following: local-orientated and integrated-orientation.

I. In the *local-orientated* two echelon system, replenishment order are places at two points in the system. Based on the inventory position of the stock point, the reactive approach compares the reorder point (ROP) with the inventory position (IP) of the stock point/DC.

Replenishment order LWH i at time t: $RO_{i,t} = \max\ (0, \left\lceil \frac{ROP_i - IP_{i,t}}{Q_i} \right\rceil) Q_i$

Replenishment order CWH at time t: $RO_{c,t} = \max\ (0, \left\lceil \frac{ROP_C - IP_{c,t}}{Q_c} \right\rceil) Q_c$

Reorder Point at location i : $ROP_i = (L_i + R_i)\ \mu_i + SS_i$

$IP_{i,t}$: Inventory position of location i at time unit t
Q_i : Case pack size at location i
L_i : Lead time of location i
R_i : Review Period of location i
SS_i : Safety stock of location i

II. As for the *system wide-orientated* system, the reactive approach disregards the CWH-level and focusses on the inventory position of the whole system. The system is based on echelon stock and compares the inventory in the chain directly to the end-demand. The two-echelon system consists of the LWH, the first echelon, and the second echelon which covers the whole system. The replenishment orders are placed according to these echelons.

Replenishment order System at time t: $RO_{c,t} = \max\ (0, \left\lceil \frac{ROP_{syst} - IP_{syst,t}}{Q_c} \right\rceil) Q_c$

Secondly, the *proactive approach* perceives and anticipates on future expected demand. The system forecasts its demand over a finite horizon (T) in order to anticipate changes in demand and pass their future required quantities to preceding stages. This enables the system to place replenishment orders just in time. The proactive logic is spilt in a local-orientated Distribution Requirement Planning (DRP) and echelon-based Line Requirement Planning (LRP).

The following formulae are based on the Time Phased Order Point-formula of Orlicky (1975) in a multi-stage environment. This technique determines the required stock based on the outstanding orders, current net stock and forecasted demand. The forecasting horizon on which the DC's react are equal to the cumulative lead time and review periods.

III. From a local-oriented perspective, the DRP is divided in two stages; the LWH and CWH. The LWH determines the replenishment orders on the initial stock ($X_{i,0}$), the actual independent demand ($d_{i,t}$), the demand forecasts ($f_{i,t}$) and scheduled receipts ($SR_{i,t}$). On the other hand, The CWH bases its actual demand on actual delivered LWH-replenishments ($RP_{i,t}$), the projected *gross requirement* or lower-stage required stock (GR_t) and scheduled receipts ($SR_{C,t}$). The formulae are as followed:

Replenishment order LWH at time t:

$$RO_{i,t} = max\left(0, \left\lceil \frac{\sum_{j=1}^{t} d_{i,j} + \sum_{j=1}^{PLT_i} f_{i,t+j} - \sum_{j=1}^{t+L_i-1} SR_{i,j} - X_{i,0}}{Q_i} \right\rceil \right) Q_i$$

Gross requirement CWH for period t: $GR_t = \sum_{i=1}^{I} \sum_{j=t}^{R_C-1} RO_{i,j}$

Net requirement CWH for period t:

$$RO_{c,t} = max\left(0, \left\lceil \frac{\sum_{j=1}^{t} \sum_{i=1}^{I} RP_{i,t} + \sum_{j=1}^{PLT_c} GR_{t+j} - \sum_{j=1}^{t+L_c-1} SR_{C,t} - X_{C,0}}{Q_C} \right\rceil \right) Q_C$$

Planned lead time of location i: $PLT_i = L_i + R_i + ST_i$

$d_{i,t}$: Actual demand of location i at time unit t
$f_{i,t}$: Forecasted quantity of location i at time unit t
$X_{i,0}$: Initial stock at location i
$RP_{i,t}$: Actual delivered LWH-replenishments
$SR_{j,t}$: Scheduled receipts for location i at time unit j

IV. Based on the echelon stock, the Line Requirement Planning (LRP) is an alternative approach of the DRP. Information on and requirements are separately proceeded in their basic form to upstream stages. The replenishment orders of the system are based on the total end-product demand, anticipated forecasts and outstanding replenishment, instead of gross requirements or LWH-replenishments (van Donselaar, 1992).

Replenishment order System at time t:

$$RO_{c,t} = max\left(0, \left\lceil \frac{\sum_{j=1}^{t} \sum_{i=1}^{I} d_{i,j} + \sum_{j=1}^{PLT_{syst}} \sum_{i=1}^{I} f_{i,t+j} - \sum_{j=1}^{t+L_c-1} SR_{C,t} - X_{C,0}}{Q_C} \right\rceil \right) Q_C$$

Planned lead time of system c: $PLT_{syst} = L_c + R_C + L_i + ST_{syst}$

In the preceding formulae, both reactive and proactive replenishments have safety norms built in the replenishment logics in order to cope with uncertainty. There are two ways: safety time in the planned lead time (PLT) and safety stock in the reorder point (ROP). The safety norms will be optimized via simulation-based optimization in order to determine the minimal stock level at a predetermined customer service level. This provides insights in how these logics copes with uncertainty in demand and lead time.

Stock allocation

The distribution of stock across the multiplicity of subsequent DC's comes at play. The question pops up: What type of rationing will be used for the allocation of inventory in case of insufficient stock? Based on the current practices and literature, the following rationing method will be used.

The preemptive stock allocation of two-echelon distribution system uses the initial stock levels of the identical LWH's. When the CWH runs out of stock before the replenishment arrives, the allocation rule acts as an optimization problem over the horizon until the next arrival of inventory at the CWH. The allocation rule selects the LWH with the largest difference between the desired and actual inventory position and allocates a single case pack. These steps are iterated till all LWH are satisfied. The allocation rule is used in a multi-period model with periodic review and assumes centralized coordination of allocation. In case of known average demand, the steps are given below:

Step 1: Select the LWH with the largest gap between the desired inventory position and the actual inventory position expressed in days, $GAP_{i,t}$

$$GAP_{i,t} = \frac{ROP_i - IP_{i,t}}{\mu_i}$$

Step 2: Allocate an available case pack to the selected LWH:

$$IP_{i,t} = IP_{i,t} + Q$$

Step 3: Return to step 1 until all LWH's are satisfied.

In case of the non-stationary demand scenario, a forecasting method is used in order to determine the average demand. The mean demand (μ_i) in the allocation rule is replaced by this forecasted average at that specific time.

Forecast

For a proactive replenishments, one needs to have an indication of the expected demand. While forecasting is not part of the thesis, a forecasting method will be used for the evaluation of the replenishment logics when subjected to non-stationary demand (section 5.3.4). In order to simplify the analysis, the simple moving average (MA)-method is used. The only parameter which has to be optimized is n (the number of periods for mean). After optimizing this parameter, a period of 21 days (n) is used. The formula for this forecast is given below (Nahmias, 2004):

Moving Average over n period: $MA_n = \frac{1}{n}\sum_{k=0}^{n-1} d_{n-k}$

The discrepancy between the actual demand and forecasted quantity is called the forecast error. For measuring the deviation of the forecasting, the mean absolute deviation (MAD) expresses the accuracy in the same units as the data. The formula is based on Nahmias (2004).

Forecast accuracy (MAD): $MAD = \frac{1}{N}\sum\left|d_{i,t} - f_{i,t}\right|$

5.2 Simulation

When conventional tools do not provide the opportunities the evaluation of complex systems, the construction of a case specific-simulation is recommendable. Hence, the decision is made to construct a simulation of an inventory system with stochastic demand, stochastic lead time and discrete time-units. The simulation enables the researcher to explore system behavior in a dynamic environment and provides the freedom of incorporating functionalities, building in case specific-formulas and providing a tool for the principal. However, the downside of using simulations is that it is time-consuming.

According to Law & Kelton (2000), “discrete-event simulations concern the modeling of a system which evolves over time by a representation in which the state variables change instantaneously at separate points in time, e.g. the system changes in *countable* number of points in time.” At each discrete time unit, the system changes/responds/acts to predetermined rules. By incorporating stochasticity and predetermined rules, this discrete-event simulation model aims to mimic the behavior of inventory systems.

The simulation consists of five inventory systems: one CWH/system and four LWH’s. Each of the DC’s in the system is subject to three events. According to Law & Kelton (2000), the following events are distinguished:

(1) *Order-arrival event*: The arrival of a previously placed order and an increase of the inventory level.
(2) *Demand-event*: The satisfaction of demand and decreasing the inventory on hand. If the demand is greater than the inventory on hand, the inventory is set to zero and the remaining amount is backordered.
(3) *Inventory-evaluation event*: When the inventory position is equal or below the reorder point, a replenishment order will be placed

Each of the replenishment orders originating from the LWHs’ inventory-evaluation phase forms the input for the demand-event of the CWH. This counts the other way around for the order-arrival of the LWH depends on the stock on hand of the CWH.

5.2.1 Simulation Parameters

The following simulation parameters are to be predefined: the warm-up period, the number of simulated days and initial stock at each stock point.

Firstly, the initial stock at the DC’s are set to zero stock. This is simplifies the registration of the inventory position and inventory on hand at each DC. However, this increases the warm up-period. The warm up-period is necessary for a simulation to reach a steady state where the initial conditions do not affect the outcome. Ones achieving the steady state, the stock levels in the system show a consistent pattern. Based on judgement by eye (Appendix VIII), a period of 300 days is chosen. The subsequent period of simulated days is equal to 360 time units or one year. For the simplification, the assumption is made that a week consists of 7 day and the LWH is exposed to independent demand every day in the week.

5.2.2 Validation

Before conducting the analysis, the simulation model has to be validated on the reliability and correctness. According to Law & Kelton (2000), “the validation is concerned with determining whether the conceptual simulation model is an accurate representation of the system under study.”

The simulation is specifically build for this case. There is no existing output data to compare the performance/output of the system. In order to test and validate the system, the system is will be exposed to a number of settings and the proceeding performance evaluated.

The inventory systems in the simulation model are evaluated in the following manners:

- By setting the actual demand to zero, the inventory systems achieve customer service levels of a 100% and no back orders are placed.
- Assuming that the CWH has unlimited amount of stock and always delivers, the customer service levels of the LWH in the 2-echelon system equal the service level in a 1-echelon system.
- Comparing the optimal values of the simulation model with those of the tool "DoBr" (van Donselaar & Broekmeulen, TU/e). The observations and explanation are given in Appendix IX.
- When all stochasticity and case pack sizes is left out, the deterministic DRP/LRP performs all its replenishments just in time without any residual.

5.3 Design of experiments

As noted in the previous section, the experiments will be conducted in discrete-event simulations with stochastic elements. The simulations aim to mimic operating behavior of an inventory system and evaluate the input variables by determining their impact on the system performance.

5.3.1 Input/output parameters

The objective is to minimize inventory in the system through tactical decisions-rules, while maintaining a predetermined customer service level quantified by the fill rate. These decision rules correspond to the predefined replenishments and allocation rules. Thus, the input variables for the simulations are the tactical decision-rules and the system output consists of the fill rate, average inventory in the system, system imbalances and the optimized stock levels.

5.3.2 Model

The distribution system will be represented by a simplified model. Due to time constraints, this simplified model reduces the amount of input parameters and enables the researcher to reduce the amount of simulations and time in order to determine the optima. The LWH's will be identical with a similar demand and equal lead time of 7 days. Based on the previous analysis (Appendix I & VI), the OpCo's have relatively equal demand percentages and lead times. Within this model two parameters will be optimized in order to satisfy the target fill rates. For the reactive approach, the ROP for the CWH and LWH. As for the proactive approach, the PLT will be optimized.

5.3.3 Procedure

To gain insights in the tactical decisions concerning inventory control, the replenishment policies will structurally subjected to the varying test conditions. Under the stochastic variables and per-set test conditions, the reactive ROP and proactive PLT are optimized. This provides an understanding of how the system copes with these circumstances.

The parameter optimization is done via simulation-based optimization. Due to the simplified model, two adjustable parameters are optimized in the simulation model: ROP/PLT of the LWH and the CWH/system. The two are interloped in order to find the optima for both parameters.

Initially, both parameters are set on a minimum value. With the help of DoBr, an indication is given of where this minimum might be. The simulation searches the optimal value for the LWH with the CWH is set on the minimum value and a predefined fill rate objective. When the simulation model has found the optimum, the parameter of the CWH is increased with one unit and starts with determining the next LWH optimum. The procedure is conducted iteratively and every value for the LWH is replicated for 2000 times in order to provide reliable values.

5.3.4 Test-environment

The parameters will be assessed under various environmental circumstances. Based on the system output, the rules are studied on their response to these type of environment. The test-environment is consist of varying product types, management interventions and distribution system.

Firstly, two product-types are selected for the thesis. Each type has their own product-specific demand characteristics. *Product A* is a best seller. The product-specific demand per LWH is subject to a mean of 4 pieces per day and a standard deviation of 4 pieces per day. Hence, the demand corresponds to a CV of 1 and is classified as *erratic* (Syntesos, 2005). *Product B* is a premium product with a lower and more sporadic demand. The product-specific demand is subject to a mean of 0.3 pieces per day and a standard deviation of 0.6 pieces per day. Hence, the demand corresponds to a CV of 2 and is classified as *lumpy* (Syntesos, 2005). See Appendix IV for more explanations.

Secondly, the influence of stationary and non-stationary demand are simulated. The demand analysis has shown that external sales are sensitive to management-driven interventions and promotions. In order to replicate an effect such as the EB-target, a temporal trend will be integrated in the simulated demand. The replenishment policies will be exposed to a stationary and non-stationary demand. The following assumptions are made upon the boundaries of the program and available time.

1. *Stationary demand*: The replenishment logics have to be judged on the equal grounds. However, the proactive logic requires a forecast in order to function. In this scenario, the forecast are set equal to the demand mean. This gives a MAD of 11.8. The reactive logic does not require any input values, besides the past demand. Both logics will be optimized via simulation-based simulation and judged on the average stock and imbalance in the system.
2. *Non-stationary demand*: The effects of the EB-target are recreated. In other words, the actual demand starts with a random generated demand with a mean multiplied with a factor of one. At a certain point, the demand growths linearly to a stable demand with a mean multiplied with a factor of two (the ceiling or the stylized ‘’EB-target’’). The replenishment logics use the optimized stock levels of the previous scenario under the same predetermined customer service levels. As for the proactive logic, two situation will be simulated. One will use a forecasting method (MA) and another possesses pre-knowledge of the growth in average demand. The forecasting method is the moving average-method with as n-value (number of periods) 21 days. Concerning the allocation rule, the forecasted or pre-known averages will be used as mean demand (μ_i) for determining the gap.

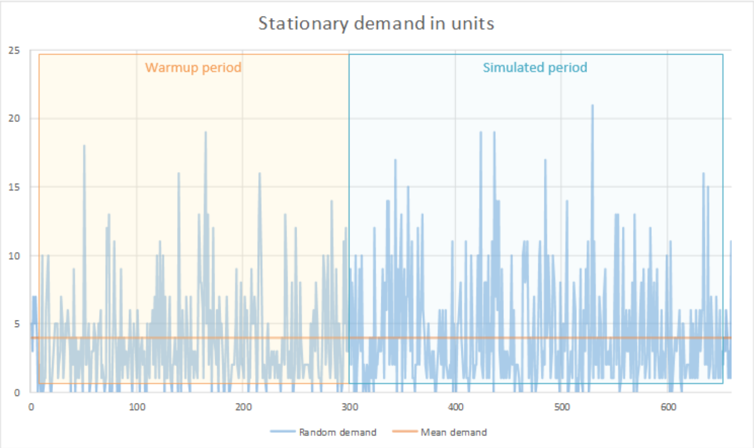

Figure 14 Stationary demand

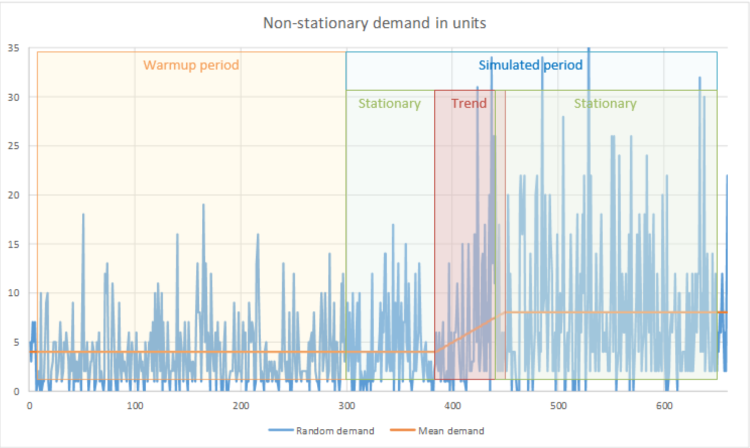

Figure 15 Non-stationary demand

6. Results

This chapter summarizes the results of the research design and provides further insights into the results. The results in this chapter serve as support for the subsequent recommendations.

As previously mentioned, this thesis distinguishes stock replenishment in four types. Each replenishment type depends on the type of status information (installation or echelon stock) and the application of time-phasing. The following results of the simulations provide support for the selection of the appropriate technique. Firstly, the use of status information, followed by the application demand-driven time-phasing and lastly some in-depth analysis on other relevant factors.

6.1 Status information

Regarding the control of the business units in the system, the DC's ought to be managed from a local- or system-orientated perspective, e.g. installation stock or echelon stock.

In the figure below, the tables on the right depict the performance of integrated systems and the left the local-orientated systems. For both the reactive as the proactive replenishment policies, the findings of the simulations show a lower average amount of stock in the integrated systems in comparison to the local-orientated systems whilst maintaining equal customer service levels.

Firstly, the simulations counter the idea that CWH have to guarantee a 100% stock availability. With appropriate stock norms at the LWH's and preemptive allocation rules, the fillrate of the CWH in an optimized system is significantly lower than the target customer service level. Noticeably, the customer service levels are overall lower for the integrated systems. This might be due to the transparency within the system. With no case pack sizes or safety norm obscuring the CWH's demand, the stock norms are more appropriately set.

Reorder Point - Stationary demand

Table A

Local-orientated: Product A						
Fillrate	ROP LWH	ROP CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	76	2371	0,982	0,990	43	2792
0,98	70	2311	0,976	0,981	43	2660
0,97	66	2281	0,970	0,971	43	2610
Local-orientated: Product B						
Fillrate	ROP LWH	ROP CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	6	121	0,984	0,992	26	344
0,98	5	121	0,984	0,985	26	341
0,97	4	121	0,984	0,974	26	338

Table B

System-orientated: Product A						
Fillrate	ROP LWH	ROP System	CL CWH	CL system	Imbalance	Av.Syst.St.
0,99	76	2741	0,982	0,990	43	2785
0,98	70	2651	0,973	0,980	43	2643
0,97	66	2607	0,967	0,970	43	2604
System-orientated: Product B						
Fillrate	ROP LWH	ROP System	CL CWH	CL system	Imbalance	Av.Syst.St.
0,99	6	204	0,973	0,990	26	329
0,98	5	187	0,952	0,980	26	314
0,97	4	185	0,955	0,970	26	313

DRP/LRP - Stationary demand

Table C

DRP: Product A					MAD = 11,8	
Fillrate	PLT LWH	PLT CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	36	140	0,998	0,990	138	3283
0,98	32	140	0,998	0,982	138	3330
0,97	30	140	0,998	0,974	138	3375
DRP: Product B					MAD = 1,8	
Fillrate	PLT LWH	PLT CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	26	140	0,998	0,990	33	402
0,98	16	140	0,998	0,980	33	393
0,97	10	140	0,998	0,974	33	385

Table D

LRP: Product A					MAD = 11,8	
Fillrate	PLT LWH	PLT System	CL CWH	CL system	Imbalance	Av.Syst.St.
0,99	19	168	0,976	0,991	44	2752
0,98	16	167	0,982	0,980	44	2733
0,97	15	165	0,979	0,970	44	2700
LRP: Product B					MAD = 1,8	
Fillrate	PLT LWH	PLT System	CL CWH	CL system	Imbalance	Av.Syst.St.
0,99	17	168	0,971	0,990	26	328
0,98	14	153	0,947	0,980	26	312
0,97	10	151	0,951	0,980	26	311

Table 5 Results stationary demand

6.2 Demand type

The replenishment policies are divided between time phased and non-time phased, i.e. proactive and reactive replenishment. In short, the proactive replenishment anticipates on future expected demand and the reactive logics assumes the historical data. These fundamental differences take shape when exposing them to stationary and non-stationary demand.

Stationary demand: For a system with a stable and stationary demand, the integrated replenishment logics achieve the best performance in maintaining the targeted fill rate with a low amount of average stock in the system. Both policies have a relative equal amount of average system stock. When rewriting the ROP into days of sales, the ROP of the integral ROP and the PLT of LRP uphold an almost similar PLT in days.

However, the LRP outperforms the reactive policy for product B and vice versa for product A with the reactive policy. This is due to the fact that the proactive logic uses safety time and the reactive policy uses safety stock. Depending on the average daily demand, the safety time might result in overstock or perform better safety stock. For example, one unit of safety time for product A equals an average daily demand of four products. If the demand uncertainty were to be equal to one product unit, incorporating a single unit of safety time may result in overstocking. This differs for products with a lower average demand.

Non-stationary: Assuming that management decides to enforce a sales-target for their house brands, the sales are expected to raise to a certain level. In such situation, it is naturally that the reactive policy is at a disadvantage. The reactive policy is unable to notice the increase in demand due to the fixed, predetermined input values. On the contrary to the reactive policies, the proactive policies rely on forecasts. Figure 16 shows how the proactive policies notices the increase via forecasting and take the change into account while the reactive policy experiences a dramatic downfall.

Nevertheless, the proactive policy with the moving average-method as forecasting tool shows a lag in response to the change. This might be due to the shortcomings of the forecasting tool and the long lead time. The MA-technique averages the demand over a period 21 days. This dampens the initial growth and reduces the appropriate response. By assuming that the system knows the average demand during the transition, the proactive replenishment logic is able to respond on time without any diminished effect. Hence show in the graph below, the proactive policy with pre-knowledge is able to respond without lag and upholds a stable pattern. This emphasizes the significance of a relevant forecast.

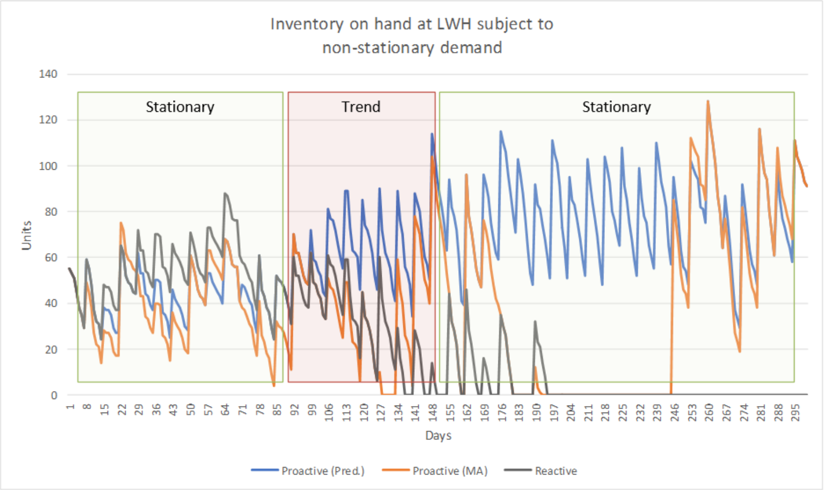

Figure 16 Inventory on hand at LWH subject to non-stationary demand

When looking at the performance indicators in the table 6, the reactive logic is not able to satisfy the predetermined customer levels. As for the proactive policies, the MA forecast-driven policies are also unable to achieve the fillrate target. However, the proactive logic with awareness of the growth is able to achieve the predetermined fil rate of 0.99. When comparing the DRP and LRP in this scenario, the LRP outperforms with a lower amount of average stock in the system and system imbalance.

Reorder Point - Non-stationary demand

Table A

Local-orientated: Product A						
Target Fillrate	ROP LWH	ROP CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	76	2371	0,325	0,327	53	5252
Local-orientated: Product B						
Target Fillrate	ROP LWH	ROP CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	6	121	0,726	0,862	28	340

Table B

System-orientated: Product A						
Target Fillrate	ROP LWH	ROP System	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	76	2741	0,323	0,326	53	5257
System-orientated: Product B						
Target Fillrate	ROP LWH	ROP system	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	6	204	0,675	0,832	28	326

DRP/LRP - Non-stationary demand (Moving average forecast)

Table C

Local-orientated: Product A						
Target Fillrate	PLT LWH	PLT CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	36	140	0,962	0,639	378	6291
Local-orientated: Product B						
Target Fillrate	PLT LWH	PLT CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	26	140	0,984	0,923	64	588

Table D

System-orientated: Product A						
Target Fillrate	PLT LWH	PLT system	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	19	168	0,632	0,675	64	5267
System-orientated: Product B						
Target Fillrate	PLT LWH	PLT System	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	17	168	0,793	0,897	28	422

DRP/LRP - Non-stationary demand (Perfect pre-knowledge)

Table E

Local-orientated: Product A						
Target Fillrate	PLT LWH	PLT CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	36	140	0,998	0,989	138	5899
Local-orientated: Product B						
Target Fillrate	PLT LWH	PLT CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	26	140	0,999	0,997	34	602

Table F

System-orientated: Product A						
Target Fillrate	PLT LWH	PLT System	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	19	168	0,976	0,993	44	4933
System-orientated: Product B						
Target Fillrate	PLT LWH	PLT System	CL CWH	CL System	Imbalance	Av.Syst.St.
0,99	17	168	0,988	0,996	26	505

Table 6 Results non-stationary demand

6.3 Case pack sizes

For this study, a case pack size of 30 pieces is assumed. When comparing this case pack size to the average demand of the products, the case pack size covers 7.5 days of sales for product A and 100 days of sales for product B. One may question if this case pack size is appropriately set for this product B. Intuitively, a case pack size should cover the lead time, review period and uncertainty at LWH. Nevertheless, when looking at the PLT of Product B, the optimal PLT's of B are equal or lower than 14 days. This is remarkably low for a system where the review periods and lead times of the LWH sum up to 14 days.

A large case pack size may lead to an excessive amount of stock and system inflexibility. When reducing the case pack size, the system should is able to set a more appropriate stock level and create more flexibility. The influence of case pack sizes is explored in the following setting; case pack sizes of (1, 5, 10, 15, 30) for Product B under a customer service level of 98% and stationary demand. The results are shown in table 7.

System-orientated: Product B (CL = 98%)						
Case pack	PLT LWH	PLT CWH	CL CWH	CL System	Imbalance	Av.Syst.St.
30	17	145	0,917	0,980	26	305
15	20	133	0,945	0,981	14	293
10	20	133	0,962	0,980	10	293
5	24	132	0,970	0,980	7	292
1	27	138	0,985	0,980	6	299

Table 7 Results case pack simulations

As the results show, the reduction of the case pack size leads to a decrease of average stock in the system and stock imbalance between the downstream locations. However, as the PLT at the LWH are more accurately set, the stock availability at the CWH increases and putting a lot more strain on the performance of the CWH.

7. Conclusion & recommendations

This chapter summarizes the findings of this thesis and provides recommendations for GV. Afterwards, the limitations of the thesis and possible future research are illustrated.

7.1 Conclusions

The current study focusses on the design and control of the supply chain of GV in the G4-region for Exclusive Brands-frames. The supply chain in this thesis is defined as a multi-stage distribution system which consists of a single CWH and four LWH's. The system subjected to stochasticity in demand and supplier's lead time. As for the DC's within the system, the DC's are characterized by lot sizing and periodic reviews.

7.1.1 Design of the distribution system

For the design of the distribution system, the design decisions are divided over a strategic and a tactical level. The former concerns long term decisions with heavy impact investments. De Leeuw (1999) provides a framework of control decisions on strategic level. These decisions focus on the design of distribution systems. This framework breaks down the design of a distribution systems in four categories: *type of reorder planning, status information, central stock function* and *coordination of allocation process*. Based on the IT capabilities, product/market characteristics and ownership of responsibilities within the company, the design decisions of the distribution system for EB-frames in GV are as followed:

- Proactive reorder planning
- Echelon stock or Integral status information
- Central stock function
- Centralized coordination of allocation

7.1.2 Inventory control

De Leeuw (1999) distinguishes two inventory control decisions on tactical level. The tactical decisions are split in stock replenishment and stock allocation. For stock allocation, the easily implemented *runout allocation rule* specified in section 5.1.3 is used. Further in-depth research focusses on the comparison of reactive and proactive replenishment policies. Nonetheless, assumptions had to be made which compromise a fair comparison of the logic. Therefore, the current study mainly provides an understanding and suitability of the control policies in the distribution system of GV.

The outcomes of the simulations show that integral replenishment policies are able to maintain various fill rate targets with a lower amount of system stock than the local-orientated systems. This is due to the transparency in the system which enables the system to derive the demand for all upper stages. Therefore, the upstream demand is not obscured by case pack sizes or safety stocks. As for the safety norms, these are based on integral norms. In other words, the system uncertainty is dispersed over the business units and its impact mitigated.

This selection of replenishment logics depends on factors as the structure of the distribution system and the characteristics of the product demand. The distribution system of EB-frames is restricted by a long and uncertain lead time of Asian suppliers. As for the products, the frames are categorized as slow movers with an erratic/lumpy demand. Managerial and external factors influence both the dependent and independent demand. Hence, a replenishment logic is needed which has the ability to incorporate possible changes in demand over a long time horizon and possible constraints in the supply chain. It recommended to use a proactive replenishment logic.

Secondly, the simulations provide further insights in the control of stock points. In this study, the performance of stock points is measured via a customer service level (fill rate). This performance indicator measures the amount of shortage in relation to the total demand of that specific period. From a business perspective, one expects that the CWH should provide the highest service level in order to satisfy all LWH's demands. The simulations counter this intuition by satisfying the target fill rate of the system with a lower customer service level at CWH. With an appropriately set safety norm at the LWH and the use of a preemptive allocation rule, the system is able to maintain the fill rate-targets with a significantly lower fill rate as is noted by Van Donselaar (1998).

In practice, the implementation of inventory control policies may provide additional issues. On the contrary to the proactive replenishment, the reactive Reorder Point is easily determined via averaged historical data and has seldom to be recalculated due to stable demand. With reliable, historical data, the logic requires less coordination of information. Proactive replenishment, however, requires relatively complex software as well as extensive communication with other DC's in the system. Information, e.g. accurate forecasts and stock levels, have to be well coordinated from all downstream location. However, the uncertainty in forecasts or delivery times results in frequent rescheduling of orders. This requires more human effort and man-hours than the automatic Reorder Point.

As for the use of integral stock norms and preemptive stock allocation, the system requires system visibility, trust and openness amongst the business units and joint decision making. For the sake of system visibility, Point of sales-data and stock levels have to be exchanged over all stages within the distribution system. Furthermore, information systems over the whole supply chain have to be harmonized, periodic reporting implemented and a central ownership appointed in order to facilitate the necessary information. In practice, the willingness of the stakeholders and the IT system are frequently lacking which may lead to resistance.

7.2 Recommendations

The following recommendations concern specifically the distribution system of GV.

Performance indicator

The first recommendation concerns the performance indicator of GVSC; the EB-coverage. This CPI has been under continuous revision and still lacks a methodology. As well for the use of the indicator, the coverage is generically used for all EB-frames. However, the simulations show that the ''coverage'' varies between the types of product; as is seen by Product A and B. It is recommended to distinguish and specify the EB-frames in sub-categories based on demand characteristics. By differentiating products on consumption rate and volatility, more insight is obtained in the buildup of system stock and prevents from setting unreasonable targets.

Case pack alignment

The second recommendation is about lot sizing. This thesis assumes a generic case pack size of 30 units. During the simulations, it became clear that Product B exhibits a larger amount of imbalance than Product A. This might be caused by its substantial lower demand rate. Both products shared the same case pack size, but the consumption rates vary. In regards to the slow consumption and relatively high case pack, the risk of imbalance and average system stock increases. It is recommended to go in negotiation with suppliers for case pack sizes which are set in proportion to the product-specific demand rate.

Allocation rule

The third recommendation is regarding the centralization of control. With the shift of DC ownerships towards GVSC, new opportunities arise. At the moment, no clear policies or methodologies are used for allocating stock in case of insufficient stock at the CWH. With the stock visibility in the supply chain and the Point-of-Sales data, GVSC is able to preemptively allocate stock to the LWH's as the unique decision maker. By using a preemptive allocation rule such as the generalized runout allocation rule, the decision maker is able to reduce the risk of imbalance at downstream locations and to uphold the predetermined service levels of the LWH's.

Safety norms

The fourth recommendation relates to the use of safety norms. As noted on the introduction, no clear methodology is used for replenishments. Besides the subjective EB-coverage, no mathematical or statistical model is used for safety norms.

When applying proactive replenishment policies such as DRP, one should implement safety time. As for reactive policies, safety stocks are favored. For safety stocks, the paper of Donselaar (1990) provides insight in stock norm settings for reactive replenishment logics. As for the safety time in time-phased replenishment approaches, no heuristics are described in the literature. However, this research study provides an optimization tool for determining the appropriate safety norm.

7.3 Limitations

The imitation of the research is classified into three types: limitation to the scope of the project, research design and the data. These three types of limitations are explained in the following section.

The scope of the project is confined to G4-segment and the product group *EB-frames*. Nonetheless, this does not represent the whole of GV. The global presence of GV and its supply chain extents from South-America to East-Asia; covering 44 countries. As for the product range, their product portfolio also includes contact lenses, branded frames and sunglasses. Within the field of inventory management, this thesis only touches stock replenishment and allocation of inventory control for EB-frames. However, the selection and optimization of forecasting-methods stay untouched. Meaning that the current research is only a partial improvement of the GV supply chain. Also, the cost-elements are left out of the thesis. Therefore, the influences of the inventory control decisions are not evaluated from a cost-perspective.

In reality, supply chains are complex systems. It is naturally that the study has to take on assumptions and exclude certain conditions for its research design. However, these assumptions and simplifications limit the relevance and reliability of this thesis. As the optimized values are the results of the research design, these may be harmful in the real distribution system due to the simplifications. The following assumptions have been made: There are no capacity constraints for transport, production or warehousing in the system. On the contrary to reality, the selected LWH's of the G4-segment are assumed to be equal in lead time and demand. This external demand is modelled with a discretized gamma distribution. This results in a discrepancy between real life and simulated demand. Besides, the thesis only assumes stationary and non-stationary demand via a trend. However, the impact of promotions are excluded. The stationary and non-stationary demand generated in stylized models, due to insufficient and unreliable data. Also transshipments between LWH are left out of the distribution system.

Lastly, the data availability and reliability limits the relevance of the thesis. Firstly, this thesis made use of POS-data. The most accurate and reliable Point of sales-data dates back to July 2015 and only concerns the UK and the Benelux who were first to be integrated in the ERP-system. Therefore, this used data comprises of a limited amount of sales data from a selected few OpCo's. Other OpCo's report on monthly basis their sold quantities. Therefore, not usable for deriving daily sales. As for the documentation of replenishment of the supplier, the data had to be cleaned from negative values and invalid dates. This alteration of data harms the objectivity of the analysis.

7.4 Suggestions for future research

This section explores possible research opportunities followed from the recommendations and limitations of this thesis.

For future research, the first suggestion concerns the selection of an appropriate forecasting method for the EB-frames. Nowadays, GV uses a number of forecasting tools. However, these forecast are constructed on expert knowledge and lack in statistical and mathematical support. With the implementation of a time-phased replenishment planning, an accurate and reliable forecasting tool is needed. The forecast method in this research assumes a simple method, but further in-depth research should be done in this subject.

The second suggestion is in respect with the parameter setting of the replenishment policies. This research does not address the optimization of the appropriate planned lead times or reorder points on a priori basis. On the contrary to reality, a simplified model with identical LWH's is used. Nevertheless, it is also of interest to focus on the relationships of variability, service levels and other parameters within planning and control. It would be valuable to provide a detailed guide in parameter settings.

Lastly, further classification of SKU's would be recommended. This thesis focused on abstract products (A and B). By proceeding with further categorization of SKU's on demand size and pattern, the case pack sizes and safety norms can be adjusted to their specific consumption rate. This would enable the company to reduce the risk on imbalances and system inflexibilities.

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Appendix I. Company description

This appendix provides a more detailed elaboration on the presence, structure and products of GV.

Founded on January 2011 by the merging, GV came into being. This French-Dutch holding has grown over the years to a global leader in the optical retail sector by acquiring companies. Thus, it expanded itself far beyond the European borders.

GV is situated over 44 countries in Europe, Latin-America, Middle East and Asia. They employ worldwide a workforce of more than 27.000 FTE over 6100 stores. These stores operate under 34 well-known retails banners like Pearle, Eye Wish Opticiens, Générale d'Optique, GrandOptical and Vision Express. As an optical retailer, GV offers optical services and products, e.g. prescription glasses including frames and lenses, contact lenses and sunglasses through its portfolio of optical retail banners. This network of optical retail stores realized a revenue of € 3.205 million with € 231 million profit in 2015.

Global presence

Situated globally in 44 countries. GV divides its presence in three segments. The segments corresponds with the gradual growth which GV has been under going through the last decade. Gradually expanding its business operations across the globe from Europe to America and Asia. The following segments are distinguished *G4*, *Other Europe* and *America & Asia*.

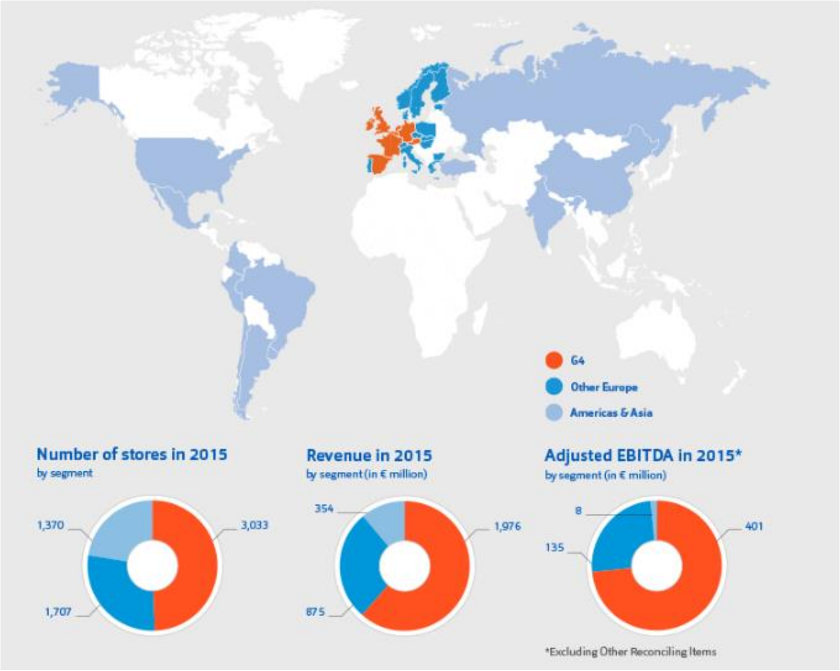


Figure 17 GV data

Based on the figure above, it is shown that the G4- segment is significantly larger in size of revenue and store numbers than any other segments. G4 stands for the four Operating Companies (OpCo) or business units operating in that area. The countries within this area are divided over these four OpCo's as followed:

I. Netherlands and Belgium
II. United Kingdom and Ireland
III. Germany and Austria
IV. France, Luxemburg, Monaco and Spain

Operational Companies and their markets

Operating companies (OpCo's) manage a wide range of local retail banners and associated stores across specific countries. These banners consist of acquired and GV-founded retail chains. These OpCo's are responsible for the promotion, price and space management, customer service and store replenishments. While the OpCo's are responsible for their country-specific stores, the companies report to GV. The figure below gives an impression of the hierarchy and distinction in terminology.

Figure 18 GV hierarchy

Products and services

As an optical retailer, *GV* offers a variety of optical services and products. Their product portfolio ranges from contact lenses, contact lenses solutions, sunglasses, prescription glasses to associated accessories (i.e. cases). The prescription eyeglasses including frames and lenses form the biggest margin of their product sales. Furthermore, their assortment holds both internationally known licensed branded and *GV*-exclusive house brands. Within *GV*, these are so-called *Non-Exclusive Brands* (NEB's) and *Exclusive Brands* (EB's).

The table depicts the key product and services.

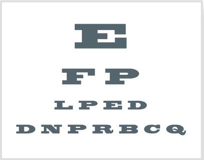
Key products and services			
Eye test		Prescription glasses (frames & lenses)	
Contact lenses and care products		Sunglasses (plain and with prescription lenses)	

Table 8 Key products and services

Appendix II. Current inventory management

This appendix elaborates on the current tooling used by GV on how the stock of EB-frames is currently handled.

Rolling Order Forecast

GV developed an internal inventory management tool called the Rolling Order Forecast (ROF). The system focusses on the consolidation of downstream replenishment orders and forwards these to the supplier.

Based on a bottom-up design, the system takes the experience of local salesmen as principal. Depending on the time horizon, the OpCo's pass their forecasted demand and purchase orders through the ROF to GV. While some of the OpCo's use mathematical models, others base their decisions on local expert experience. By consolidating the requirements of the OpCo's, the replenishment orders for the suppliers are combined in order to satisfy the minimum order quantity (MOQ) set by the manufacturers. This is an ad hoc and iterative process. Orders are continuously shifted by GV within the horizon in order to find the most optimal ordering.

On monthly basis, the OpCo's report their forecasted demand and purchased orders over a time horizon of eight months. These eight months are based on the length of the lead time and expert experience. The ROF is divided over three time bucket based on the activities and commitment between the GV and suppliers.

Appendix III. Current situation G4-countries MSI

CONFIDENTIAL

Appendix IV. Independent demand analysis

CONFIDENTIAL

Appendix V. Dependent demand analysis

CONFIDENTIAL

Appendix VI. Lead time analysis

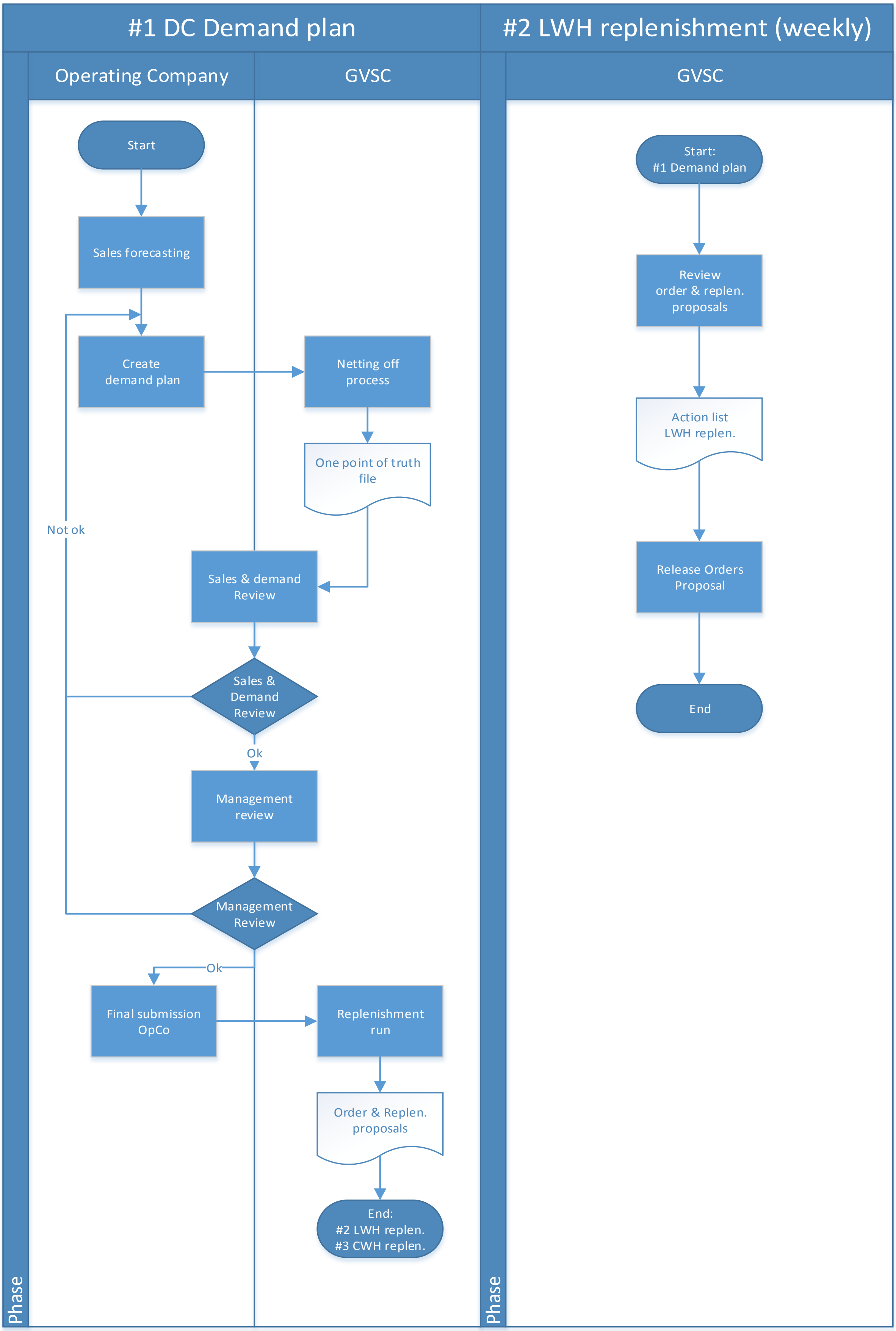
CONFIDENTIAL

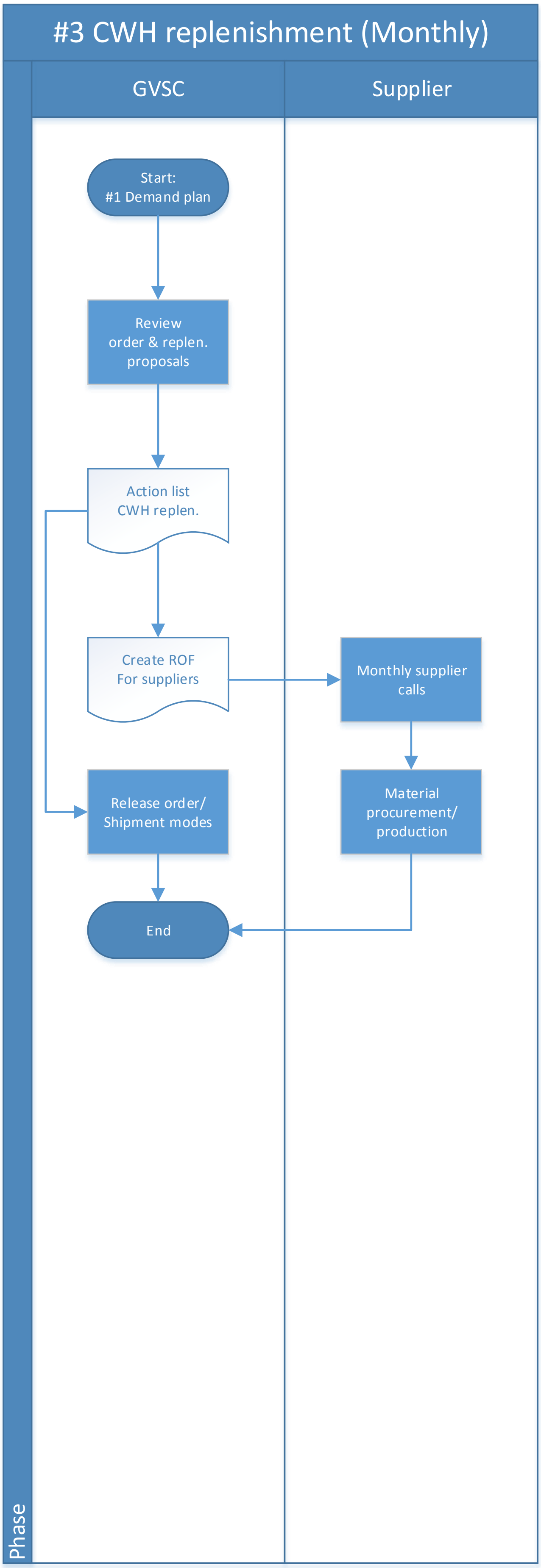
Appendix VII. Replenishment process

This appendix illustrates the division of responsibility and activities of the replenishment processes in GV among GVSC and OpCo’s.

In order to explain the separation of responsibilities and activities, a flowchart diagram with swimlanes is used. This visual representation of the business process distinguishes the different activities required in the process and determines the responsibilities among the business units. Hence, job sharing and dependencies are illustrated.

The charts on the following pages show the business processes of the GVSC’s supply chain operations. These processes cover the information flows among the GV’s business units (GVSC and OpCo’s) and the appropriate activities.


#1 DC Demand plan
#2 LWH replenishment (weekly)
Operating Company
GVSC
GVSC
Start
Sales forecasting
Create demand plan
Netting off process
One point of truth file
Not ok
Sales & demand Review
Sales & Demand Review
Ok
Management review
Management Review
Ok
Final submission OpCo
Replenishment run
Order & Replen. proposals
End: #2 LWH replen. #3 CWH replen.
Start: #1 Demand plan
Review order & replen. proposals
Action list LWH replen.
Release Orders Proposal
End
Phase
Phase


#3 CWH replenishment (Monthly)
GVSC
Supplier
Phase
Start:
#1 Demand plan
Review
order & replen.
proposals
Action list
CWH replen.
Create ROF
For suppliers
Monthly supplier
calls
Release order/
Shipment modes
Material
procurement/
production
End

Appendix VIII. Setting warmup period

This appendix provides the reasoning for the selection of the warmup period.

Firstly, it is necessary to analyse the stock points on their steady state in order to determine the most consistent simulation results. The implementation of a warmup period enables the system to cancel out the effects of the initial stock quantities. During the warmup period, the simulation simulates a number of time units unregistrated. When the steady state is reached, the various performance indicators start to document data. In order to determine an appropriate warmup period, the inventory position of the most downstream location is visualized in a graph and via judment by eye the appropriate period is selected.

For the simulations in the study, all stock points in the sytem are set to zero quantity in order to prevent calculation mistakes. As is seen in the figure below, it takes time for the system to recover from the intitial settings and establish a stable pattern. This periode corresponds to sum up of lead times and review period. Due to the long supplier lead time and zero intitial stock, the warmup period in question will set upon 250 days.

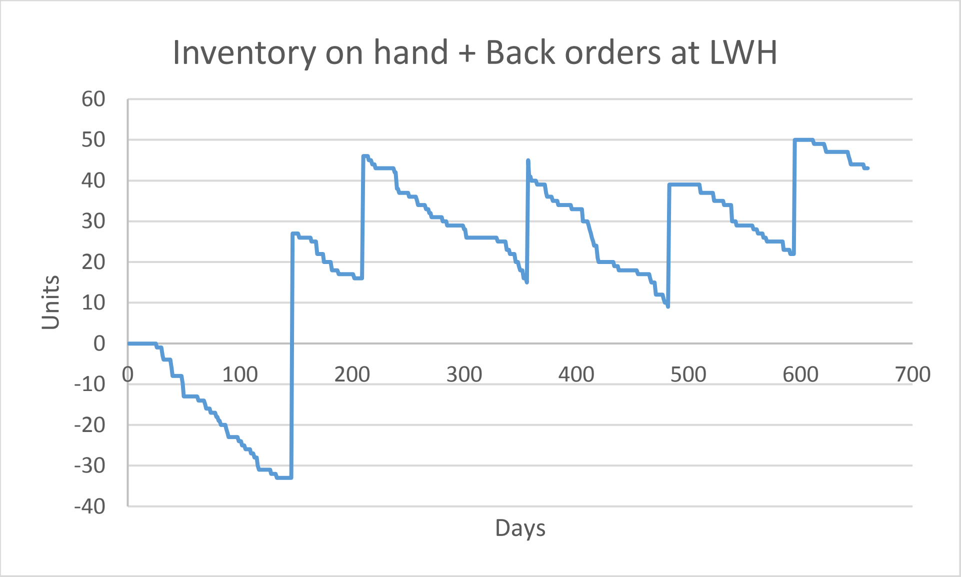


Figure 19 Simulation generated inventory position of LWH

Appendix IX. Simulation validation

This appendix provides an explanation of the DoBr-tool (van Donselaar & Broekmeulen, TU/e) and the comparison of the simulation with the DoBr results.

The VBA Excel-based tool is developed by van Donselaar & Broekmeulen (2014) and generates exact results for the (R, s, nQ)-policy. The tool enables the users to generate the reorder points for many situations with stationary demand. Function such as lost sales, back ordering and outdating are incorporated and are given over a wide range of performance indicators.

In regards to the study at GV, the DoBr has been adjusted to recreate the modelled distribution system. The adjusted DoBr-tool is able to recreate a single-echelon inventory system and a two-echelon distribution system with multiple LWH's, stochastic lead time and stationairy demand. As for the reorder points, the tool is able to determine the integral reorder point for the whole system and the local reorder point for the LWH.

The exact results of the DoBr-tool are compared to the optimized values of the simulation developed in R. With the same settings of the distribution system and product types(mean, standard deviation, fill rate, lead times, review period, number of LWH's), the following results are given:

Fillrate	Two-echelon disitrbution system							
	Product A				Product B			
	LWH		System		LWH		System	
	SB opt.	DoBr	SB opt.	DoBr	SB opt.	DoBr	SB opt.	DoBr
0,97	66	66	2607	2621	4	4	183	188
0,98	70	70	2651	2675	5	5	184	199
0,99	76	76	2741	2761	6	6	204	209

Figure 20 Comparison DoBr with simulation results

As the figure shows, the optimal results of both tools provide close the same results. While the DoBr-tool provides exact results, the simulation tool is subject to uncertainty in demand and supply. Moreover, the demand uncertainty is subject to discretized gamma distribution. The rounding of random-generated demand results in discrepancy.