Doctoral Dissertation

Thomas Thron

The impact of enhanced coordination and scheduling of production and distribution in the light of various levels of collaboration within retail supply chains of SME manufacturers

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Kent Business School,
University of Kent,
Canterbury,
United Kingdom,

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Abstract

Investigating potential efficiency advances within supply chain management has experienced a great amount of recognition during recent years both in industry and academia. Within this context, a wide variety of investigations regarding the impact of increased demand visibility has already shown its positive effects on supply chain performance. However, most collaborative SCM research has mainly focused on situations in which manufacturers engage with all their downstream partners in a homogeneous collaboration pattern. In view of extensive entry cost, lack of trust or non-availability of suitable IT-systems or skill-sets this however provides only limited support to actual problems of many, particularly smaller companies. In a real-life business environment companies commonly operate within supply chains that are characterised by a wide variety of distribution policies and stages of collaboration. Each relationship between any two members of such chains requires individual strategies and guiding principles which often results in conflicting interests. Thus, investigating such heterogeneous delivery frameworks, is necessary to reveal possible advantages and drawbacks within the process of emerging with a varying number of customers from a traditional reorder-point (ROP) focused towards a collaborative planning forecasting and replenishment (CPFR) centred supply chain.

Consequently, within this dissertation, discrete-event simulation is applied to investigate what impact increasing adoption of collaborative replenishment between manufacturer and several major customers has on each market participant. To support decision making amongst particularly smaller companies, the investigation evolves around the distinct supply chain frameworks of three German SME food manufacturers.

The main research objectives of the thesis are firstly developing an appropriate simulation framework that allows exploring a multitude of possible issues within a complex supply chain context, and secondly to utilise the developed model in order to investigate the impact of enhanced coordination and scheduling of production and distribution in the light of various levels of collaboration.

To address these objectives, the thesis progresses by firstly introducing the main concepts that constitute the background of the research, followed by an outline of supply chain modelling in general and simulation modelling in particular as the investigation methods of choice. Later on, the underlying research methodology is described in more detail with a major focus on developing an appropriate simulation model that sufficiently allows investigating the wide range of issues and ideas that are proposed earlier on in the thesis.

Complementary to this, the dissertation discusses the process of collecting, pre-processing, decomposing and exploiting raw sales data. Within this context, innovative forecasting approaches are introduced and evaluated for their suitability for implementation in simulation models.

Within the major investigation part addressing the core elements of the second research objective, the thesis extends the work of Smaros et *al.* (2003) and Waller et *al.* (1999) by initially investigating what impact a limited collaboration framework involving only part of the customer base has on global supply chain performance. Following this, a CPFR system is split up into individual collaboration modules in order to analyse how important and how necessary each of these modules is when altering distribution frameworks. This is done to answer questions like "How much collaboration is really necessary or really reasonable?" or "What function of a collaboration framework is most beneficial for individual customers?". Finally, the effects of some customers engaging in collaboration on others that do not adjust their replenishment system is also explored. Within this context the investigation clarifies who would benefit the most from an early adoption of collaboration and to what extent the remaining non-collaborating customers are disadvantaged by not participating.

Following this, a number of complementary issues are discussed such as various prioritization strategies that evolve around the delivery process between manufacturers and several customers that are engaged at different stages of collaboration. Further investigations show the extent to which demand overstating reorder behaviour can be accommodated for in an altering, more collaborative supply chain. This is done in order to obtain recommendations regarding what ordering behaviour to encourage or condemn in the light of varying levels of demand transparency.

Finally, the previously obtained insights are expanded by investigating the impact of increased demand transparency and collaboration within supply chain environments with perishable goods. This will broaden the scope of applicability of the research.

Altogether, the study successfully advances academic research ahead of previous considerations and simultaneously results in diverse findings on how to improve typical shortcomings experienced by the participating companies. A number of best practice improvement designs are generated and recommended for implementation. The benefits of engaging in collaborative replenishment are emphasised in particular, even in cases of limited scale and scope. The various analyses suggest that manufacturer and customers can indeed substantially benefit from even a partial increase in demand visibility. This nevertheless comes at a cost since favouring some customers due to sharing a collaborative replenishment system, means that others often seem to experience more severe delivery delays and a drop in service-level. Such issues have not been explored sufficiently within the context of emerging collaborative replenishment structures but are certainly worthwhile considering very carefully before engaging in any collaborative partnership.

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1. Introduction

1.1 Introduction and Overview

The research findings presented in this doctoral thesis have a primary focus on Logistics and more particular on Supply Chain Management. A supply chain, in general, can be thought of as a network of entities or a linked set of resources and processes that begins with the sourcing of raw material and extends through to the delivery of end items to the final customer. It includes vendors, manufacturing facilities, logistics providers, internal distribution centres, distributors, wholesalers and all other entities that contribute to final customer acceptance. Within this framework, each entity provides some activity necessary to fulfil the transformation. Supply Chain Management therefore constitutes a set of approaches utilized to effectively integrate suppliers, manufacturers, warehouses and retailers, as to produce and distribute merchandise in the right quantities, to the right locations, and at the right times, in order to minimize system-wide cost while satisfying service level requirements (Simchi-Levi, 2000).

Within this framework it is particularly the coordination and scheduling of production and delivery in the light of certain levels of collaboration between the various echelons of a supply chain that constitute the focal points of attention. The main tool to support these investigations was chosen to be computer simulation in order to allow realistic modelling of real-life supply chain systems with a high degree of realism. This will allow us to obtain findings that are of value for research and practitioners.

The research is very much oriented on practical problems practitioners face within a business environment that demands a constant push for efficiency improvements to stay competitive and ensure the survival of a company. Thus not surprisingly the core issues of the research project evolved out of a close cooperation with three actual companies that revealed certain areas of concern and interest which fed back into the definition and development of the research itself. This process furthermore actually revealed an apparent gap within common supply chain research concerning the analysis of delivery systems with a *heterogeneous* collaboration structure among certain echelons of a supply chain particularly within the business framework of small or medium sized enterprises. Various issues arising from that problem area will thus get the most attention within the research proceedings together with further practically relevant considerations that arose within the investigation process of the particular subject area.

Within the previously mentioned subject of supply chain management it is particularly the change from an isolated "everybody on its own" policy towards intensive collaboration in between particularly horizontal supply chain participants (i.e. manufacturer and retailers) that dominated the subject-research within recent years. Within that field a wide variety of investigations regarding the impact of information sharing and thus increased demand visibility have already shown its positive effects on supply chain performance. However, most collaborative SCM research has mainly focused on the ideal situation of manufacturers engaging with all their downstream partners. In view of extensive entry cost, lack of trust or simply non-availability of data-systems this provides only limited support to actual problems of many companies. Thus, investigating heterogeneous delivery frameworks as mentioned before is very much necessary to reveal possible advantages and drawbacks within the process of emerging with a varying number of customers from a traditional isolated Re-Order-Point (ROP) towards a Collaborative Planning and joint Forecast driven Replenishment system (CPFR).

The main part of the research was thus largely concerned with using discrete-event simulation to realistically model supply chain scenarios and later on to investigate various common performance measures to show how increasing adoption of CPFR replenishment between manufacturer and several major customers will influence these figures for each market participant. As a result of that, conclusions are drawn regarding possible benefits as well as potential and actual threats from partially or uniquely moving towards a collaborative replenishment system.

The progression of the individual chapters is initiated by an introductory chapter outlining recent developments within supply chain management as the focal point of the research framework. Furthermore research targets and a more detailed thesis structure outline will be presented. Chapter 2 will discuss various methods of supply chain modelling with a focus on simulation modelling as the method of choice. Within Chapter 3 specific research problems are identified, described and a plan of solution is presented. The fourth chapter explains in detail the research methodology including advantages and disadvantages of the chosen techniques, introducing the model itself and its underlying data base. Within Chapters 5, 6, 7, 8 and 9 the research findings are presented to address various issues identified in Chapter 3. Chapter 10 finally summarizes the findings, concludes implications and gives an outline of possible future research extension.

1.2 Supply chain, logistics and supply chain management

Numerous definitions of a supply chain have been proposed to date. Christopher (1998) defines it as "a network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of material and information from suppliers to end users". Johansson (2002) describes it as "a system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via the feed-forward flow of materials and the feedback flow of information".

Altogether there are three main flows in the supply chain: material flow, information flow, and cash flow. The activities involved in the material flow are to deliver to the end-user via procurement of raw materials, manufacturing, distribution and customer service. All these activities must be managed using suitable information flows. Cash flow finally describes the monetary flow from the customer backwards.

Figure 1.1 shows the materials flow from the supplier further downstream, the bidirectional flow of information and the financial flow upstream from the customer.

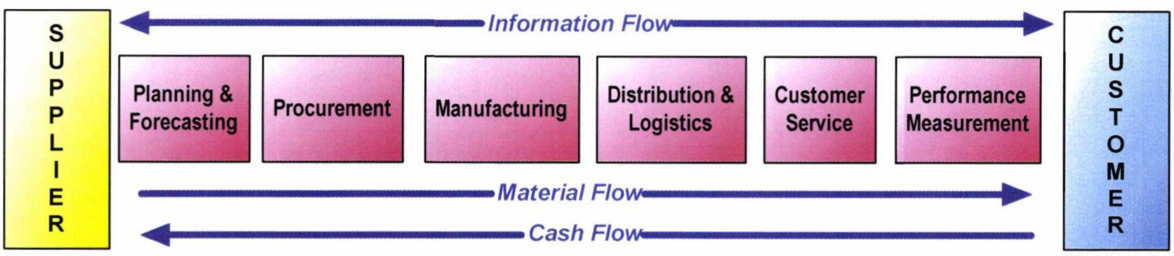


Figure 1.1: Flows in the supply chain (from Spekman et al., 1998)

Logistics within this framework of understanding can be thought of as the process of planning, implementing, and controlling the efficient, effective flow and storage of materials, finished goods, services, and related information from origin to the location where they are used or consumed (Fawcett and Clinton, 1997). Traditionally, logistics refers to activities that occur within the boundaries of a single organisation and supply chains refer to networks of companies that work together and coordinate their actions to deliver a product to market (Hugos, 2003).

Supply Chain Management as a framework concept is deeply interrelated with all kinds of logistical processes. The actual term "supply chain management" is thought to be introduced in the early 1980s by Oliver and Webber (1982) as part of a discussion of the potential benefits arising from integrating purchasing, manufacturing, sales and distribution. Houlihan (1987) refers to the above and uses the term to describe the management of materials across organisational borders. Ever since, numerous researchers have been working on further establishing and refining the theoretical and operational bases for supply chain management concepts. Major contributions within the field were made by Lee and Billington (1992), Ellram and Cooper (1993), Schary and Skjott-Larsen (1995), Fisher (1997), Lambert *et al.* (1998), Lee (2002) and Giannakis and Groom (2004). Overall, SCM goes beyond the scope of logistics in viewing the supply chain and the organisations in it as a single entity. Doing so it brings a systems approach to understanding and managing the different activities needed to coordinate the flow of products and services to best serve the ultimate customer. Designing a supply chain requires an enormous number of decisions: product development, choice of processing technologies, kind of resources, delivery strategies, procurement decisions, legal requirements, defining partnerships, just to name a few to highlight the complex nature of the problem. The most obvious problem that arises within such chains is a high level of complexity whilst still depending on decentralised decision making within most parts of the chain.

In the traditional supply chain, members are concerned with decisions that directly affect their bottom line. Manufacturing operations were designed to maximise throughput and lower costs with little consideration for the impact on inventory levels and distribution capabilities at preceding or following stages. The result was that there never existed any single integrated plan for the entire chain. Independent and often conflicting plans were made by each of the supply chain members to achieve their individual goals.

Supply Chain Management as a discipline tries to tackle such independencies whilst it emphasizes on integration. The primary focus is on manufacturing and logistics so that products can be delivered as required - on a timely and cost-effective basis. Collaborative efforts amongst supply chain members have therefore been key within any developments in SCM throughout the last decade. The underlying idea is that improving supply chain efficiency offers benefits to every single entity up to the final customer who profits from more attractive prices, improved quality and better service.

Figure 1.2 below summarises the main business processes within the supply chain and shows their integration in between various echelons.

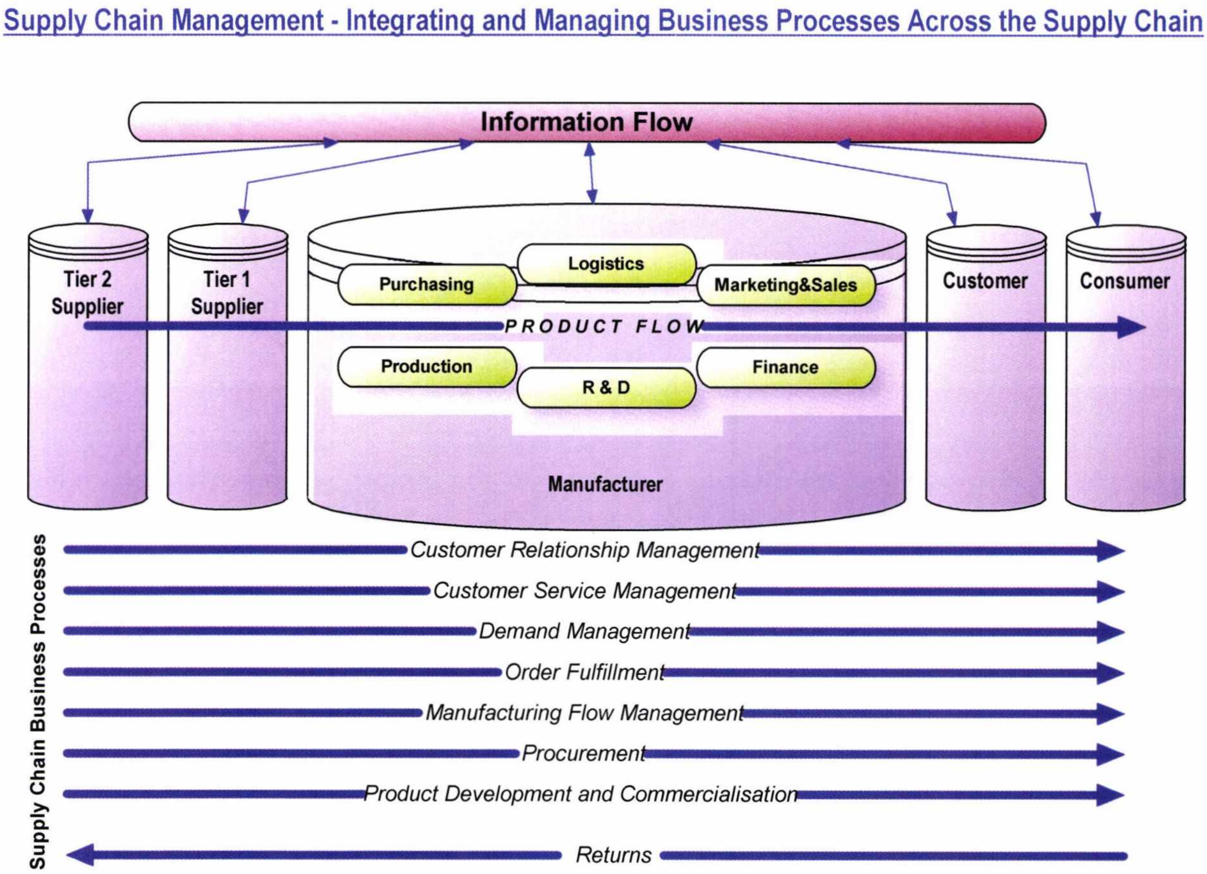


Figure 1.2: Key Supply Chain business processes (Lambert et al., 1998)

1.3 Contemporary trends within Supply Chain Management

After having introduced the underlying terminology, behaviour and basic control mechanisms of a supply chain we will now have a look at contemporary trends for SCM as a whole with a key focus on collaboration, supporting IT-systems and supply chain design innovations.

1.3.1 The changing nature of competition

Within recent years, many industries worldwide are in the process of placing increased emphasis on integrating, optimising, and managing their entire supply chain from component sourcing, through production, inventory management and distribution to final consumer delivery. As part of this development over the last one or two decades, business environments are in a change process from mass-production to customer demand driven service fulfilment. Providing distinctive customer value has become one of the main business drivers for companies. Within this framework, a single company will face an uncertain future if it does not realise its role as part of an entire supply chain rather than an isolated entity. A clear trend in industry goes towards integrated supply chains where processes in between all echelons of a chain need to be more aligned and participants will cooperate and collaborate with each other to achieve common goals, hence gaining competitive advantages. Traditionally, performance, quality and price used to be key factors for competitive advantage, but service is increasingly becoming a differentiation factor. Companies find it more and more difficult to maintain profitability and competitive advantage simply with good quality products and technologies in the traditional ways

(Christopher, 1998). Companies have benefited from collaborative partnerships (Lummus and Vokurka, 1999) and risk-and-revenue sharing arrangements. Generating and maintaining distinctive customer value require the provision of a differentiated offering including short lead-times linked to high flexibility in the volume and variety of products and associated services. Such requirements and adoptions are common business for larger companies who have the financial budget and managerial culture to cope with changing business frameworks but are often overly demanding for smaller conservative companies which entirely rely upon using only their own resources. Within the business landscape as a whole, vertical integration as a means of alignment is no longer the solution because of a lack of flexibility that cannot accommodate the variety of individual requirements. Companies thus need to deliver increased value in new ways, as aligning their business frameworks and retaining vital business contracts (Lehtinen, 1999).

Christopher (1998) further argues that future competition in the marketplace comes to exist between supply chains, not between companies. This implies that an organisation can no longer act as an isolated and independent entity in competition, but a more integrated supply chain needs to provide competitive advantages in the market.

Traditionally, the operations of an individual company within a given supply chain are focused on its core activities to operate as efficiently as possible. This traditional understanding of business may nowadays not be able to create the desired value for end customers unless the entire up- and downstream supply chain is also effectively organised, coordinated and customer focused. Overall, there is a fundamental change in environment that takes away focus from the performance of individual companies but centres around competition in between entire supply chains. Within such business environments, no single company can ensure that its products will fulfil final customers' expectations in an optimal fashion because inefficiency, delays and sources of waste may be found elsewhere within their supply chain. Even though there are no obvious sources of inefficiency amongst individual supply chain echelons, a combination of seemingly optimal local solutions must not necessarily result in optimal performance of the system as a whole. The benchmark for excellent performance is set by the entire supply chain and inefficiencies caused by whatever reason affect the competitiveness of the supply chain as a whole and thus each individual echelon. Only an effectively integrated supply chain, consisting of companies working together as partners, can thus create excellent end customer value. As companies facing this new stage of competition, the winners will be those companies that manage to collaborate and work together with their partners in a supply chain committed to better, faster and closer relationships with their final customers (Christopher, 1998).

1.3.2 Collaboration

In today's rapidly changing market scenario, a company and their supply chain partners need to effectively synchronize supplies with evolving consumer demands. They also need to optimize inventory levels and lower working capitals. Whilst traditional business scheduling may at best be adequate for long-range forecasting and planning, it is much less effective in responding to daily changes in the dynamics of the demand and supply chain. This results in excessive inventory buffers and additional storage and handling costs across the supply chain.

Following simple cooperation between supply chain partners covering only long term business plans and strategic targets, supply chain coordination and collaboration have to form the basis for the next level of supply chain partnerships. This involves developing seamless links between business activities through advanced process connectivity and integration. True collaboration partnerships are based on trust, commitment and information sharing amongst the partners (Stack *et al.,* 2004). Even smaller companies need thus to understand that they have relations to many different partners, although playing a comparatively minor role in the entire supply chain. Nevertheless, their business decisions can have a significant impact on their own performance as well as that of the supply chain as a whole. Close, collaborative relationships with suppliers, distributors, manufacturers, transporters and end-customers are thus vital to a company's successful operations. Collaboration also fosters a joint understanding of potential risk, demand signals, market developments and customer expectations. Ultimately this leads to adaptive supply chains that are able to flexibly manage their capabilities and requirements in real time with highly increased speed of information and physical flow. According to Corbelt *et al.* (1999), the main benefits of such improvements evolve around increased market share, improved quality, shorter product development cycles and reduced inventory, cost and lead times.

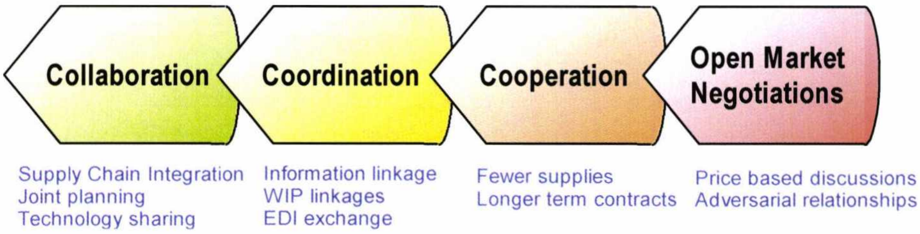


Figure 1.3: Key transition to collaboration in the supply chain (Spekman et al., 1998)

The increased degree of collaboration (Figure 1.3) in between companies and entire supply chains have led to a new concept of extended or virtual enterprises accumulating some or all partners within a supply chain in temporary or permanent conglomerate.

1.3.3 Extended and virtual enterprises

The context of the extended enterprise has been developed within recent years in order to reflect the increased level of collaboration between partners within a supply chain (VIVACE, 2004). The term aims to express both internal and external business relationships and associated services extended across multiple associated partners or divisions of a single corporation in one or more countries (Sukdeo, 2005). Commonly an extended enterprise is formed by integrating operations of independent companies into the operations of their partners. According to Browne *et al.* (1996) an extended enterprise exists if design, development, manufacturing and delivery of a product are collaboratively integrated processes between supply chain partners.

In contrast to the extended enterprise, the virtual enterprise is often defined as a temporary network of independent companies engaged in providing a product or service. The aim of temporary aggregation is commonly sharing of skills or core competencies and resources in order to better respond to business opportunities. Virtual enterprises allow companies to specialise and to be flexible within their business environment and to benefit through accumulated connections with suppliers, greater opportunities to create revenue from contracts beyond their business scope or scale, more efficient operations or reduced administrative costs. Sophisticated communication architectures are nevertheless essential within such partnerships. Figure 1.4 below shows a typical virtual enterprise with a co-ordinating agent that is specialised in matching the activities of several independent companies such as suppliers, subcontractors, manufacturers and distributors.

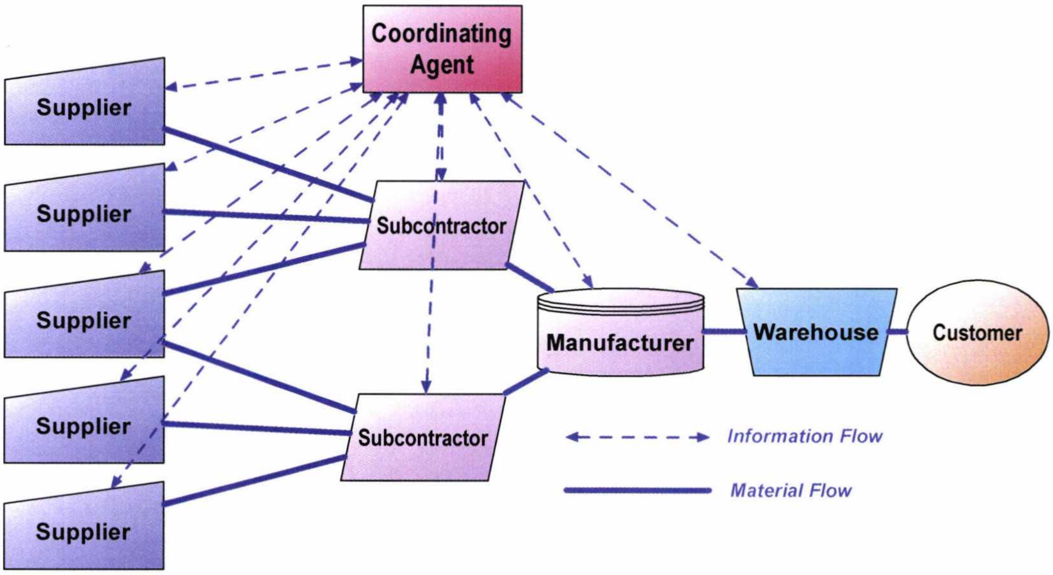


Figure 1.4: Example structure of a virtual enterprise (Jagdev and Browne, 1998)

1.3.4 IT-systems supporting Supply Chain Management

Due to the broadening scope of supply chain management which includes more and more functions within ever growing logistics networks, there is an urgent need for IT based support to prevail visibility and control. Consequently, software supporting the various functions of supply chain management covers a wide range of possible applications to support specific tasks within each of the five major supply chain steps - Plan, Source, Make, Deliver, Return (Hugos, 2003). Some large ERP (Enterprise Resource Planning) software vendors such as SAP or Oracle have combined numerous individual application modules under a single roof to provide an end to end integrated supply chain solution. However, no single generic package is right for every company. Common usage for supply chain management software evolves around tracking demand and supply, manufacturing status, distribution and logistics (i.e. location of items in the supply chain). Additionally, they provide a platform to enable companies to share data with supply chain partners.

Evolution of SCM software

The development of supply chain management software began in the early 1970s when availability of computer hard- and software allowed developing rather simple programmes for demand forecasting, planning and scheduling, plant location and plant layout.
Within this timeframe, the concept of Materials Requirement Planning (MRP) emerged. It based on detailed material lists that described hierarchically the order of raw materials, components and resources necessary to create a final product. These lists were later on captured in form of Bills of Materials (BOM). These initial MRP systems were over time extended to include scheduling and other associated functions to form Manufacturing Resource Planning systems (MRP II). An ever increasing scope of application and increased computerisation of data capturing and processing led to the definition of Enterprise Resource Systems (ERP) that are common nowadays. The purpose of an ERP system is mainly to carry out all necessary IT transactions occurring throughout common operation of a given company. This includes all relevant manufacturing, sales and accounting processes.

Altogether today's market is rather dominated by products from large ERP vendors like SAP's Advanced Planner and Optimizer (APO) which can perform many or all of the mentioned tasks. Nevertheless, because many individual supply chains have unique challenges, companies often decide to go with "best of breed" products that are designed specifically to excel in just one or a few applications instead.
Although SCM Software is still in a phase of development and it is not yet possible to define all standard elements of a system, there are commonly two major application segments: Supply Chain Planning and Execution support, and Logistics Management support. Supply Chain Planning and Execution support covers applications surrounding demand planning, production and distribution planning, production scheduling, procurement and inventory management and manufacturing execution. Logistics Management support on the other hand provides primarily assistance within warehouse and transportation management.

1.3.5 Supply Chain Innovation Concepts – examples from the grocery industry

Since the 1980s, the grocery industry as one of the main drivers of supply chain innovations developed numerous value innovation concepts for the supply chain that were later on adopted by other industries. Perhaps the two most significant innovations were *category management*, a relationship orientated technique to improve shelf-space productivity, and *efficient replenishment* that instead of waiting for an order empowers the supplier to deliver according to actual consumption.
Category Management represents a method for managing increasingly complex consumer demographics. To face this challenge distributors and retailers intensify their efforts to understand and meet changing customer needs. Thus retailers started to systematically manage the products offered to the consumer, seeking to maximize the profitability of retail space, while simultaneously improving the value for the customer. According to Coopers and Lybrand (1996) category management has three focus areas:

- *Efficient Product Introduction* – deals with efficient and effective developing and introducing new products and services strictly based on consumer needs. The primary goal is to reduce the number of failed product introductions and the costs associated with them. Hence only value adding products will be on the store-shelves.
- *Efficient Product Promotion* – aims for efficient and effective promotion strategies. Thus using consumer advertising, consumer promotion and trade promotion in order to improve the application of the promotion budget.
- *Efficient Store Assortment* – deals with offering costumers an assortment of products and services that satisfies their needs whilst simultaneously aims to maximise profitability.

The other major innovation introduced by the grocery industry is efficient replenishment, i.e. instead of waiting for an order the supplier delivers according to consumption. The grocery industry realized that the easiest way to improve operational efficiency was to change retailer practices. Most improvements in operational activities can commonly be found in the way a store is replenished (Bhulai, 1997). Efficient replenishment therefore deals with efficient delivery of the right products at the right time at the right place in the right quantities. To achieve these goals efficient replenishment tries to integrate trajectory processes between supplier, manufacturer, distribution centres and retailer. There are four major initiatives to implement this objective:

- *Continuous Replenishment* – aims to coordinate the information trajectories and stream of goods in the logistic chain in order to create a continuous stream of products. This ideally enables retailers to keep lower inventories and thus lead to cost reductions and shorter product lead times.
- *Direct Store Delivery* – constitutes a direct order-delivery link between stores and manufacturers. The main advantage of this is the omission of any warehousing activities. This concept is however very much dependent on the particular product, ordered quantities, order policies and trading relations. Its practical use has been largely questioned.
- *Cross Docking* – deals with moving goods in a warehouse with minimal handling. Incoming goods are rather shifted into trucks instead of traditional storage. This concept decreases inventory and handling costs as well as product lead times. Cross Docking however requires close cooperation between manufacturers, warehouses and stores. It is thus only applicable to products with short lead times and high order quantities.
- *Order Support Systems* – deals basically with IT supported, electronic ordering systems. The goal of Order Support Systems is to make order processes faster and better. This does not only affect ordering for consumers, but also for retailers and warehouses. Procter and Gamble, Campbell Soup and other leading suppliers in the grocery supply chain achieved significant cost reductions by encouraging customers to aggregate demand from retail locations, and passing this information with minimal delay to the supplier (Fisher, 1997). For this case, the improvement is just as much a result of reduced ordering delay - that is the delay between consumption at the point of sales and reordering from the supplier - as it is a result of consolidated material flows. The reduction of this delay is important, especially in product categories with much variation and difficulties for the supplier in forecasting demand (Holmstroem *et al.*, 2002).

Efficient consumer response (ECR) finally combines category management and efficient replenishment and their underlying methods on a conceptual level. Its main achievement is thus to show how these techniques can be used with each other and in combination with new technologies. In this setting the focus moves to a total chain optimization instead of independent optimization of parts in the chain. The goal is obviously to decrease the costs throughout the chain and a more dynamical reaction to consumer needs.
Another supply chain initiative that became popular even before ECR is *Quick Response*. QR focused on the idea of a partnership between retailers and suppliers aiming to respond more quickly to consumer needs via sharing information. The QR initiative resulted in the industry-wide adoption of the Universal Product Code (UPC), point of sale scanning systems and common standards for electronic data interchange (EDI). It was the first widespread attempt to incorporate marketing information on promotion and discounts to forecast manufacturing and distribution planning. The main goal was to maximize profitability of inventory by placing the company's dollars where and when they are needed based on point of sale data and historic sales figures (Mullin, 1994).
Finally, one more approach for mitigating the communications problems between retailers and their suppliers is to let the vendor manage the retailer's inventory. The initiative called *Vendor Managed Inventory* (VMI) developed out of continuous replenishment that was described earlier and also became a key issue under QR and ECR. In a VMI partnership the manufacturer (or any other supplier/distributor) makes the main replenishment decisions for the consumer. In practical terms the manufacturer monitors the customer's inventory levels and decides about periodic replenishment actions regarding delivery time

and quantity (Waller *et al.*, 1999). Consequently, within VMI partnerships the customer grants the manufacturer access to actual demand sell-through information. This allows manufacturers to control the entire cycle of sales and order forecasts, order placement and replenishment. It also allows them to pull the forecasting risk across all their customers (Bernstein, 1997). Thus more accurate and timely deliveries can be made due to removing one level of order batching. A further advantage is the possibility for the manufacturer to recognise and possibly delay non critical replenishments to smooth demand peaks and rank delivery requests according to actual priority (Kaipia *et al.*, 2002). Retailers, on the other hand, profit from lower inventory carrying costs since the suppliers carry the product until it is sold (consignment stocks).

Despite all these unilateral efforts, an important link is missing: Retailers, distributors and suppliers still plan their individual operations independently. This shortcoming was meant to be tackled by an initiative called CPFR.

1.3.6 The CPFR System

While many of the initiatives introduced above found their way into a wide range of industries where some were adopted more widely than others, clearly they all contributed to the recognition of the need for cooperative information exchange. However, many of the expected benefits of these ideas failed to materialize since trading partners could not work with enough partners for the collaboration to scale, and thus none of these initiatives developed a critical mass of participants (Sheffi, 2002). Nevertheless they all promoted a tighter coupling of the supply chain by allowing for better forecasting and planning through information sharing, leading to synchronized channels.

One of the main reasons why previous approaches had only limited success was the lacking reliability of demand forecasting systems due to disjoint business plans among collaboration participants.

Out of these shortcomings an adjusted collaborative replenishment approach evolved within the consumer product industry called Collaborative, Planning, Forecasting, and Replenishment (CPFR) where manufacturers, distributors, and retailers work together to plan, forecast, and replenish consumer products. CPFR is the latest advancement in a series of innovations such as ECR and VMI and describes the sharing of forecast and related business information among business partners in the supply chain to enable automatic product replenishment. The main concept behind this approach is that retailer and manufacturer work off a common forecast. They both gather market, demand and product information and exchange this data frequently, optimally in real time.

This joint sales forecast can drive production scheduling, distribution planning, and store activity planning. Any significant changes from any of the individual forecasts (i.e. for sales, orders, production, deliveries) are defined as exceptions, which trigger collaborative actions by both parties to realign the planning for the channel. Moreover the manufacturer should share this information with its suppliers and so on. This creates a system of transparency since every echelon within the supply chain can rely on the same data (VICS, 1998).

In its fullest implementation, CPFR is an iterative nine-step process that begins with the agreement to establish a collaborative relationship and ends with generating orders. CPFR can nevertheless be accomplished effectively without rigidly adhering to each and every one of the steps. The steps are listed as follows (Andraski and Haedicke, 2003; VICS, 1999).

1. Develop collaborative arrangement – In this initial step, guidelines, expectations, actions, performance measures and necessary resources are laid out. This process is annually reviewed.
2. Create joint business plan – Beginning with the exchange of corporate strategies a partnership strategy is created that identifies the things to be collaborated upon and the tactics to be used to achieve the joint objectives.
3. Create sales forecast – Based on the availability of data and forecasting expertise a sales forecast is to be developed by the retailer, supplier or both on a monthly or weekly basis.
4. Identify exceptions for sales forecast - Done monthly or weekly, figures that fall outside the pre-agreed sales forecast constraints are identified.
5. Resolve/Collaborate on exception items – This is the process of actually resolving the identified exceptions through shared data, emails, meetings etc. Any resulting changes are incorporated and actual forecast is updated.
6. Create order forecast – Based on various information sources a specific order forecast is generated that supports the shared sales forecast and the joint business plan.
7. Identify exceptions for order forecast
8. Resolve/Collaborate on exception items
9. Generate order – Finally the retailer or supplier generates the order. This step is carried out on a weekly or daily basis.

The above process may seem rather complex at the first sight but it must not be forgotten that once the partners reach a certain state of maturity within the system, the whole process basically iterates efficiently through steps 3, 6 and 9 only. Once such a state is reached exceptions encountered would be handled routinely through jointly adopted procedures (Tenhiaelae, 2003). This is the point where CPFR starts yielding its benefits which can according to Accenture (2002) initially be classified in the following way:
Firstly, the increase in collaboration should improve the overall relationship between partners and thus possibly opens new opportunities in cooperation. The single shared forecast combines the information of participants and thus increases shared knowledge and forecast accuracy. Through increased forecast accuracy, the need for buffer inventories is reduced and capacity utilisation is increased since production planning can be based on more reliable data. Moreover, more efficient replenishment and forecast to order adaptation should reduce stock outs and delivery times and thus enable increased responsiveness to customer demand which leads to increased sales and customer satisfaction. Aligning forecast and production planning horizons can also lead to shorter setup times and reduced administrative effort (Accenture, 2001).
Altogether there are numerous fieldwork studies existent that clearly reveal benefits arising from CPFR in real world environments (for more information see Cachon and Fisher, 1997; Fraza, 1998; Holmström, 1998; VICS, 1999; Daugherty *et al.*, 1999). Broadly speaking, the benefits from CPFR come from higher sales and lower supply chain cost. The main actual benefits can be divided into "soft," subjective benefits and "hard" numbers. Soft benefits are to be found in an improved relationship between trading partners due to increased amount of communication since CPFR implicitly strengthens existing relationships and substantially accelerates the growth of new ones. Buyer and seller work hand in hand from inception through fruition on business plan, base, and promotional forecasts. Continual CPFR related meetings strengthen this relationship.
The hard benefits can be classified into demand or supply related subjects: Demand-related benefits are commonly greater sales, implied category management and improved product

offering; whereas improved order forecast accuracy, inventory reductions, improved technology/overall ROI and increased customer satisfaction are rather supply related benefits. Globally it leads furthermore to an overall increase in profits, reduced working capital and the potential of reducing the amount of fixed capital (VICS, 1999).
Despite its distinct features, CPFR is seen as a continuation of many previous collaborative business trends. As such, it will be only as successful as the underlying willingness to actually commit to collaboration. While CPFR may be supported by more robust software than earlier collaborative initiatives, it still requires a significant dedication of effort on the part of the collaborating partners. Although companies may be able to establish numerous CPFR contacts, actual fully functional relationships will most certainly be restricted to primary business partners.

1.4 Supply chain management implications for Small and Medium Sized Enterprises

Whilst there is a great deal of awareness of the challenges that have to be faced by the manufacturing sector in general, there is a distinct group that is particularly threatened by constantly changing business and market environments. The sector of small and medium enterprises is a large and growing element of all economies. It is overall amongst the most volatile and active sectors both in terms of growth and failure. It is furthermore one of the most competitive and can be seen as the "nursery" sector through which new major players often emerge to the market (Hall, 2002). The group of small or medium sized enterprises is commonly abbreviated by SME or SMB. The range of this group of companies is generally limited by the number of employees or overall turnover. Although there are several regional standards considering the size of these figures, a common approach is to categorize companies with up to 50 employees as "small", and those with fewer than 250 as "medium" (European Commission). This group of companies accounts for about two third of total employment within the EU and about 50% in North America (SME Database 2006).
Considering the challenging environment, management tools and techniques applied by the companies within this sector should be in the forefront of modern practices. However, the sector often lags behind major players in terms of deployment of modern management tools and techniques. According to Hall (2002), this is due to various structural reasons. First of all the sector includes a large number of companies which have limited and often overstretched financial resources. Furthermore, SMEs commonly do not seek and utilise advice from consulting companies due to cost reasons and unfitting solutions that are often designed for large clients beyond the scope of typical SMEs. Possible examples for such modern management tools are automated systems for performance measurement, integrated manufacturing and production control, or collaborative planning, forecasting and replenishment. Besides the lack of sophisticated management systems, the business performance drivers of small/medium enterprises such as yields, efficiency or sales growth are the same as for large corporations. Both have to cope with customers that demand ever-increasing delivery-reliability and shorter lead times. Apart from that, there is an omnipresent pressure for constant productivity improvement, cost reduction and shorter life cycles. All these activities need to be supported by management tools which SMEs are often unaware of their existence or reluctant to implement them due to unsuitability or high cost.
A major barrier within the adoption and implementation of more sophisticated support tools are unwillingness to invest in extensive IT systems to capture and manage data. Apart from that, many private owners of SME companies are unable to restructure their business

to get increased value from it. Although they are eager to improve performance, they struggle with limited budgets and cash resources. Moreover, most SMEs have small management teams which cannot afford spending substantial time away from the business to gather knowledge and work on developing and implementing new systems. Any solution that will truly be beneficial to such companies must thus be individually tailored to a client's business and therefore must be developed with and around the team. Furthermore it needs to be developed and implemented rapidly at relatively low cost.
Although the need for improvement is obvious, designing management support systems that can cope with all these restrictions and are in addition easy to use is remarkably difficult. Apart from all this the challenge to convince managers and owners of SMEs that installing such systems will deliver real benefits that outweigh the cost and effort of introduction must not be underestimated either.
Overall, the enthusiasm of improving and growing their business is unmatched amongst small or medium size enterprises. The desire to learn and improve with the help of modern tools and techniques is often just as high as within large companies. The reason for insufficient business support systems nevertheless is a lack of accessibility of information and the money to get and implement them. Collaboration between practitioners and academia should thus be very fruitful particularly considering the business context of SME companies. They will more than others welcome external expertise that is available to them without implying significant costs and as a result of that move their businesses significantly forward.

1.5 Research Targets

Generally speaking, the research carried out aims to fill certain gaps of awareness regarding opportunities and threats within supply chain processes by examining the value of information sharing and thus demand transparency. The particular context evolves around evaluation and optimisation of issues like production planning, delivery strategies and schedules, inventory and production capacities, order and demand forecasting approaches, impact and value of promotional efforts, inventory dispatch policies etc.
Since such issues have already been discussed to a wide extent the new spotlight of this particular research will be amongst other things on evaluating the above subjects in the light of varying levels of heterogeneity regarding the scope of collaborative replenishment. In particular the above matters ought to be investigated in environments that feature several distinct levels of cooperation and replenishment setups simultaneously. As it was previously mentioned, there are strong concerns within actual supply chain systems regarding trust and cost of undifferentiated large-scale collaboration systems that rather suggest only a limited engagement into collaborative effort instead of involving all possible trading partners. Moreover, a further motivation for studying such heterogeneous setups is recent market developments within the group of small or medium sized enterprises. Numerous small to medium sized suppliers nowadays face the decision to participate in some sort of joint business forecasting system of various large retail companies that offer the possibility to utilise demand data on distribution centre and store level. The very idea behind this being increased visibility for both, retailer and supplier as to share demand and production data to optimise replenishment. Participation within these collaborative supply systems requires a substantial financial commitment from the SMEs as participation requires additional investments in equipment, skill and people and additionally necessitates a change in production scheduling and delivery schemes that need to be adapted to the new system. Due to the variety of customers a typical company has, the practical issue in most cases cannot be to totally switch planning and replenishment

approaches from a ROP to a VMI/CPFR framework since most often either financial considerations or simply non-availability of joint-data-systems prevent a complete switch. Most companies are thus faced with the question to what extent their production and delivery planning process can benefit from a heterogeneous approach where some or even most customers still use traditional order approaches whilst other customers share demand data and agree to VMI or CPFR delivery and replenishment approaches.

Collaborative SCM research has mainly focused on either the relationship between one vendor and one customer or the ideal situation of a manufacturer collaborating with all its downstream partners. This evidently provides only limited support to companies struggling with the above mentioned problems. A company that will only selectively choose trustworthy partners to engage in collaboration due to a fear of revealing vital information to too many market participants, will necessarily need a heterogeneous replenishment approach. The same accounts for a typical medium sized company that just cannot rely on either a pure ROP or a universal collaborative scenario.

The idea of this research is thus to emphasize on these conditions which constitute an intermediate approach in between traditional isolated echelons and fully transparent data-sharing systems which is a field that has commonly been neglected by SCM research.

In the rare cases where heterogeneous scenarios are evaluated in the literature the main focus lies on impacted inventory levels rather than production utilization, delivery performance, demand forecast accuracy or service level. Waller *et al.* (1999) use simulation of a supply chain to examine the effect of VMI adoption rates strictly on inventory levels. The focus lies rather on increased replenishment frequencies and increased inventory review. The analysis is limited to VMI scenario considerations lacking any CPFR related considerations.

Småros *et al.* (2003) use discrete event simulation to evaluate how to use increased demand visibility for production and inventory control. They focus on how the manufacturer benefits from reduced production load volatility as the number of VMI customers increases. They find that the value of visibility greatly depends on replenishment frequencies and length of production planning cycle employed by the manufacturer. The analysis has various interesting findings but focuses on inventory issues rather than order fulfilment and service level. Moreover it centres on VMI scenario considerations not accounting for CPFR related implementations.

The forthcoming research approach will thus utilise a very detailed discrete event simulation model that enables expanding the ideas of Waller *et al.* (1999) and Småros *et al.* (2003) by combining several new ideas with them. Furthermore, instead of focusing all the attention on global efficiency achievements, the investigation concentrates on scenario analyses for each individual market participant whether or not it is engaged in a collaborative process. This expands the investigation in a way to give very practical recommendations and helps to answer typical questions management has to face in this kind of situation. Although the core elements of the analysis evolve around supply chain management, collaborative replenishment and computer simulation, there is a variety of additional underlying concepts that will be discussed as part of the framework. These are for example various forecasting approaches, techniques and accuracy measures, data-decomposing methodology or complex discrete event simulation methodology.

Supply Chain Management and particularly advanced collaborative replenishment systems like CPFR constitute very new and dynamic fields for any kind of investigation compared to other areas of Operational Research that exist virtually unchanged for many decades. Research within this area thus has to cope with all sorts of dynamic changes of assumptions and different points of view. The core of this research will therefore not just rely on one particular case existent under stiff pre-requirements and investigate this further no matter what happens in the outside world. It rather aims to tackle the problem of dynamics and investigate relationships, influences and dependencies within such a system on a number of practical, real life scenarios. Consequently, a detailed simulation model is going to be developed to serve as the core investigation means to establish a qualified platform that exhibits a typical supply chain to examine logistic processes quantitatively and qualitatively in order to understand the effects of key variables. Furthermore, attention has to be paid to address several less than ideal conditions often found within existing supply chains in order to assess the robustness of the approach and test recent developments as outlined above.

The outcome of the investigations might hopefully contribute to further clarification of a multitude of supply chain issues and give practitioners and researchers recommendations regarding *what would work in which way to what extent*. Overall, the research aims for nothing less than to support the ongoing adjustments within supply logistics with recommendations that help developing efficient solutions that can be applied in practice and in the end of the day save cost, gain in efficiency and generate competitive advantages.

1.6 Thesis outline

After the initial introduction that explained the background of the research and gave a brief outlook of the investigation to come, the thesis will further progress as follows.

Chapter 2 discusses various methods of supply chain modelling with a focus on simulation modelling as the method of choice.

Chapter 3 defines the specific problem scenarios that will be addressed and propose a plan for investigation and possible resolution.

Chapter 4 describes the applied research methodology with a major focus on developing an appropriate simulation model as means of investigation. Furthermore the business background and individual requirements of the three participating companies are introduced.

Chapter 5 presents the process of collecting, pre-processing and editing obtained raw data. Furthermore, evaluation, selection and parameter adjustment of appropriate forecasting techniques are discussed and issues regarding implementation in computer simulation models outlined.

Chapter 6 commences the main investigation stage. In the initial part the reference scenarios are introduced and discussed and a preliminary analysis of a homogenous improvement context is carried out.

Chapter 7 constitutes the very core component of the thesis as it addresses a multitude of heterogeneous improvement proposals to advance the distribution system of the considered supply chain frameworks.

Chapters 8 and 9 investigate various issues complementary to the analyses in Chapters 6 and 7. Chapter 8 will evaluate the impact of altering customer prioritisation policies and the effect of shortage gaming whilst Chapter 9 addresses the issue of improving supply chain efficiency in environments with perishable goods. These investigations do very much fit in the overall research context and give additional valuable insights and improvement suggestions.

Chapter 10 finally summarises the main implications and findings of the thesis. To support the main targets of the research, common conclusions are stated and suggestions for practitioners and researchers are made that help to deploy and exploit the obtained knowledge.

Chapter 2 - Supply Chain Modelling

A supply chain often constitutes a very complex entity connecting various echelons that interact with each other through processes such as procurement, production and distribution to achieve the common goal of fulfilling customer demand effectively and efficiently. In order to run these processes in an optimal manner, collaboration across all echelons is required as laid out before. Within such a challenging environment, modelling is very helpful for designing, testing, and implementing a new supply chain or to improve an existing one. According to Vernadat (1996), a supply chain model should be capable to capture enough complexity and facilitate supply chain integration. Consequently, all relevant processes and interactions need to be included to allow for a realistic but manageable system analysis. Li *et al.* (2002) summarize four core aspects of supply chain modelling:

1. Capture a wide range of supply chain complexity to facilitate understanding and expose interdependencies.
2. Establish and incorporate the vision shared by supply chain partners.
3. Improve supply chain management processes that are crucial for performance targets.
4. Understand and reduce supply chain dynamics within the supply chain design phase.

Based on these concepts, the following chapter will evaluate various methods that allow modelling supply chain processes. Simulation modelling, particularly discrete-event simulation, will be in the centre of these approaches as the most appropriate and capable technique. As such, simulation methodology will be outlined and various software packages evaluated for their suitability to support the proposed research framework.

2.1 Classification of Supply Chain Modelling Methods

According to Beamon (1998) there are four categories to classify multi-stage models for supply chain design and operation analysis:

1. Deterministic analytical models
2. Stochastic analytical models
3. Economic models
4. Simulation models

Deterministic models assume all variables are known and are able to be specified with certainty. Stochastic models on the other hand have at least one unknown variable assumed to follow a probabilistic distribution. Both are purely mathematical approaches. Economic models commonly evolve around game-theoretic frameworks for modelling the buyer-supplier relationship in a supply chain. Finally, simulation models focus on recreating real or proposed systems in order to replicate the behaviour of their real world equivalents.

Min and Zhou (2002) use a similar classification but categorise apart from deterministic and analytical models into hybrid models and IT-driven models. Hybrid models are defined to have characteristics of deterministic and stochastic models. As such they include theoretic calculation and simulation and can be based on deterministic as well as stochastic variables.

IT-driven models reflect the recent development of IT based modelling techniques as a result of vast improvements of calculation power of standard PCs and user-friendly software applications. Such models allow the integrating and coordination of a wide range of activities within a supply chain such as warehouse management, enterprise resource planning, geographic information systems and aspects of various forecasting, distribution and transportation systems.

Apart from mathematical structure, Min and Zhou (2002) classify supply chain models according to problem scope and application area (Figure 2.1).

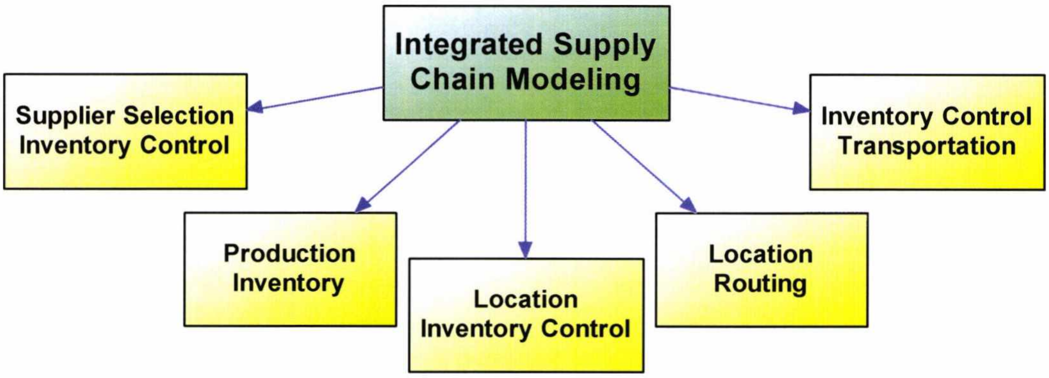


Figure 2.1: Types of integrated supply chain models (Min and Zhou, 2002)

Although the major focus of a model is commonly shaped to follow one of the types, individual models can incorporate aspects defined across all five categories.

2.2 Techniques for supply chain modelling

In the field of supply chain problem solving, there are four commonly used techniques: Linear programming, mixed-integer programming, network models and simulation modelling. These techniques are presented in somewhat more detail.

2.2.1 Linear Programming

Linear programming is an important field of mathematical optimization as many practical problems in operational research can be expressed as linear programming problems. LP is often used to model various situations in order to identify optimal solutions using a set of linear mathematical equations. Overall there are no qualitative implications which means that only problems that can be mathematically expressed can be considered. Solutions can be obtained by manual calculation or with computer support. Overall the technique is quite useful for optimization in problem sets containing a large number of constraints. However, the application of the method is somewhat limited due to the variable, highly complex, non-standard or non-linear nature of many real life systems that cannot sufficiently be accounted for.

2.2.2 Mixed integer programming

(Mixed) Integer programming is similar to linear programming as the underlying optimization algorithms are based on the same principle with the restriction of some (or all) variables taking integer values. Within supply chain modelling mixed integer programming is used typically with integer variables defining model configuration and non-integer variables for material flow.

Altogether the use of LP/MIP used to be quite common before increased computer power and more user-friendly software initiated a shift towards more flexible, less constrained modelling methods. They are still very much used within facility location optimisation or inventory movement scenarios under stiff external framework conditions. If they are applied for modelling supply chain processes including various levels of uncertainty, the problem definition gets very large, leading to extreme complex mathematical challenges. Defining and solving such systems is very time consuming and often altogether infeasible.

2.2.3 Network Models

Network models represent a (supply chain) system graphically. The network is constructed by multiple nodes and connections. Within the supply chain framework, nodes represent plants, distribution centres, suppliers or customers whilst connections represent transportation. The networks can be represented mathematically and can be solved by LP or MIP procedures. A typical example of this combination of methods is the minimization of transportation cost from factories to distribution centres with certain production output and storage capacity restrictions in place. The outcome represents the optimal production and shipping quantity for each plant and distribution centre.

Due to its simplistic nature, this kind of analysis is also used within supply chain design considerations that aim to set up a virtual enterprise. Within such a framework it serves as an initial assessment tool to evaluate the capability and responsiveness of virtual enterprises. Typical key issues that feed into such a system are lead-time for each component, time for transportation, minimum order sizes, cost of materials and transportation or inventory levels held at various stages of the system. Network models combined with LP/MIP solution approaches can be useful to obtain valuable output in a supply chain framework as long as the number and variation of parameters do not exceed a certain level. They are of value for gaining an understanding of general supply chain principles and effects.

2.2.4 Simulation modelling

The major limitation of the previously described methods arises out of their limited capability to account for a wide variety of additional issues and constraints that have to be considered in a model to obtain realistic results that can be applied in practice. Most analytical modelling techniques are highly simplified and cannot cope with a wider scale real life oriented framework that goes far beyond modelling only a few parameters.

Simulation modelling however is defined as the process of designing and creating a model of a real or proposed system using abstract objects in order to replicate the behaviour of their real world equivalents (Pidd, 2004). The parameters in a simulation environment are dynamic and change over time to demonstrate the behaviour of the system under given internal and external conditions.

A simulation model is based upon a set of beliefs and assumptions about how the system should or is intended to behave. The model incorporates rules that are believed to govern the behaviour of the elements and objects of the system. These beliefs and assumptions are to be tested in some way or another to bring them as close to reality as possible to achieve a realistic and useful model outcome (Pidd, 2004).

Simulation as a time-based modelling tool allows researchers to calculate time-based statistics and just as important, transferable model-code and animation provide an understandable representation of the system acceptable even to non-modellers. Wyland *et al.* (2000) argue that the particular appeal of simulation modelling within a supply chain environment lies within evaluating system variation and interdependencies. The modeller has the power to apply changes at one part of the system, visualise the impact of those changes on other parts and simultaneously assess the overall performance of the system. Maloni and Benton (1997) recommend using simulation models in particular to critically evaluate possible benefits of supply chain collaboration. One of the main advantages within that framework is the ability to evaluate interdependencies among random effects that may cause a serious degradation in performance even though average performance characteristics of a system appear to be reasonable (Shapiro, 2001). Overall, simulation is considered as one of the most powerful techniques to apply within a supply chain environment (Terzi and Cavaleri, 2004). For these reasons, discrete event simulation has most successfully been used to study flexibility in numerous supply chain and manufacturing systems (Gupta and Goyal, 1992; Nandkeolyar and Christy, 1992; Caprihan and Wadhwa, 1997; Albino and Garavelli, 1999; Borenstein, 2000; Garg *et al.*, 2001).

2.3 Implementation of Simulation Modelling

2.3.1 Distinct characteristics and opportunities of simulation modelling

Contrary to other system analysis approaches, a simulation study does not commonly result in a definite solution but a variety of possible scenario outcomes and an increased understanding of the interactions within a modelled system which ideally leads to valuable recommendations how to setup or improve the system. As the major pre-requirement to any analysis within a simulation study, a model has to be prepared that simplifies but at the same time sufficiently represents a real world system. Such simulation models can take many forms depending on the applied simulation method. Their target is to either analyse the current state of a system or investigate possible changes or "what if scenarios". The main advantage of such a methodology is being able to assess the consequences of changes without costly and time consuming real-life testing. Altogether, basing a system analysis on a model instead of experimenting within the actual system bears a number of advantages (Carson, 2003):

- *Cost* advantages are due to the simple reasoning that building a model should most likely always be much cheaper than testing on a real system. Although creation, validation and analysis of a computer simulation can be time consuming and thus expensive as well, the afterwards very inexpensive trial and error process to achieve the best possible setup should be clearly more cost effective than experimenting with actual physical systems that can often lead to a total write-off in case of possible failure.
- *Time* benefits clearly result from simulations since they can run much faster than real-time which is impossible for a physical system. A model may thus only run for a few minutes to simulate the future behaviour of the system over many years.
- *Repeatability* advantages result from the possibility to set up all external and internal framework variables to behave exactly identically once the model is repeated with different parameter settings. This allows analyses that are free from external influences and thus investigation of precise cause and effect relationships.
- *Safety* advantages are due to uncritical investigation of extreme situations using simulation modelling. Real life testing of such conditions may be dangerous or even illegal. Moreover simulation provides a safe environment for convenient training by allowing mistakes to be made without serious consequences.
- Finally, simulation also opens the possibility to investigate systems that are not feasible with current technology or under actual legislation. For these cases experimenting with the real world is not an option.

2.3.2 Types of simulation models

There is a wide variety of simulation techniques and tools existent including various simulation languages, general and special purpose mathematical tools, continuous simulation, or discrete-event simulation. Following the outline of Kelton *et al.* (2002) it is common to classify different approaches according to three factors:

Static/dynamic models

Static models assume no change of fundamental conditions over time whilst within dynamic models all conditions are open for readjustment.

Discrete/continuous models

Within a discrete model, state-changes happen at particular points in time whereas changes in a continuous system taking place gradually not being assigned to a particular trigger event. Discrete Event Simulation (DES) within this context concerns the modelling of a system as it evolves over time by representing the changes as separate events. This is the opposite of Continuous Simulation where the system evolves as a continuous function.

Deterministic/stochastic models

Deterministic models are considered as having no random inputs. All necessary parameters are predetermined or certainly known. Stochastic models on the other hand incorporate often more realistic assumptions of variable, uncertain or unknown parameters. Instead of assigning a fixed value, such variables are represented by appropriate probabilistic distributions.

Most simulation models include a combination of the individual factors outlined above. However, either one of the two approaches within the three categories usually dominates the character of a simulation model. Amongst practical oriented simulation studies within operational research that cover e.g. manufacturing and distribution processes, dynamic, discrete and stochastic models are most common.

2.3.3 Simulation Methodology

Simulation modelling is a nowadays a well-accepted and somewhat matured methodology of operational research. Although its benefits are undeniable, a successful simulation study has to rely on a profound methodological foundation in order to achieve meaningful and reliable results. Law and McComas (1990) outline a number of critical skills needed for a sound simulation study:

- Good project management understanding and techniques
- Know-how of operations research principles and simulation methodology
- Selecting suitable simulation software
- Modelling system randomness and uncertainty appropriately
- Establishing model validity and verify correct implementation
- Using correct statistical procedures to analyse output

The methodology of conducting a simulation study itself typically follows a sequence of investigation stages that need to be conducted successively. Exemplary for this process, seven steps are briefly outlined hereafter following the simulation methodology recommendations of Law (2003). The detailed outline of actual methodological steps carried out within the investigation framework of this thesis is presented in Chapter 4.

Step 1 - Problem Formulation

Before any meaningful simulation study can be carried out, it is vital to clearly define objectives that enable customising the simulation in order to define its scale and scope. This is necessary to limit the complexity and development efforts to ultimately answer only such questions that are relevant to address identified problem areas. Typical issues that need to be addressed before initiating a study include

- global objectives and problem specification
- identification of performance concerns within the existing system
- in what way the model is meant to help within the decision making process
- who will be the actual or potential users of the model
- what are the key performance characteristics/measures that need to be included

Step 2 - Data collection and Model specification

Building a conceptual model makes up the centre of the second stage of conducting a simulation study. This includes defining the model's purpose, inputs, outputs, content, assumptions and simplifications. To build a conceptual model necessitates having sufficient knowledge and data to define logical relationships in the model that adequately represent the problem entity for its intended use. Which data are actually required depends on the level of detail that is implemented into the model. Overall, there are three categories of information that need to be acquired:

1. Preliminary data to understand the system,
2. Data and information necessary to build, set up and run the model, and
3. Data that allows validating the outcome of the model for its appropriateness.

Data collection is commonly considered as one of the most difficult and complex stages within the modelling process due to the multifaceted nature of information that needs to be acquired from a wide range of possible sources. One common mistake in simulation modelling is making the model too elaborate in an attempt to capture as much realism as possible. This so-called over-elaboration often occurs because a simulation approach offers a relatively low level of abstraction compared to for example mathematical models. However, it is also all too easy to over-simplify a model. A good model needs just about sufficient detail to adequately handle the full complexity of the simulated system.

Step 3 - Creating the computer model

The main purpose within this step is to transfer the ideas of the conceptual model into a computer program that utilises the acquired information and data. The actual implementation process is commonly done via general purpose programming languages or simulation software packages. The degree of implementable detail, model validity, run-time, variability, visualisation, experimentability etc. depend strongly on the chosen software.

Step 4 - Validation and Verification

A typical question most often asked by participants of a simulation study is "How do we know that the outputs of the simulation program correctly represent the behaviour of the real system?" The processes used to determine whether the answer to this question is "Yes" are known as verification and validation. Briefly, model validation is the process of ensuring that the conceptual model correctly represents the behaviour of the real system. Thus model validation deals with building *the right model*. On the other hand, model verification is necessary to make sure that the model is transformed from one form into another as intended by the researcher and with sufficient accuracy. Thus model verification deals with building *the model right* (Archibald *et al.*, 1999). A fundamental problem of any validation process arises out of one of the main purposes of simulation which is to understand the behaviour of a system that does not exist in reality. The best possible option within such circumstances is testing the model under a combination of known and somewhat predictable extreme conditions. If the outcome of such scenarios can be considered as reasonable it is also likely that the model will perform sensibly under unknown conditions. However, a model can never be validated to an exhaustive degree since the complexity of real life can ultimately not be accommodated in any artificial system.

Step 5 - Determining Run Parameters of the Simulation

Any performance outcome that is captured by a simulation model does not naturally state the actual figure but is represented by a statistical estimate of it. Consequently, a model needs to be set up in a way to minimize possible biases and limit the occurring variance to an acceptable amount. Some of the framework parameters of a simulation that need to be accounted for include:

- length of a simulation run (time interval that will be simulated)
- number of trials (number of repetitions to limit variability in the outcome)
- initial conditions for each run (warm up period if appropriate to reduce initialisation bias)

Step 6 - Performing experiments

Once a simulation is set up adequately to incorporate a sufficient level of validation and verification, a variety of what-if scenarios can be run that aim to evaluate the behaviour of the system if one or several framework parameters are altered. This stage is considered to be the most interesting one since interrelationships between parameters can be revealed or the impact of certain variable/constraint adjustments estimated. As a result of this stage, output data are collected that can be further analysed to verify or disprove set out hypotheses.

Step 7 - Output data analysis

Within this final methodological step, data obtained within the experimental stage are evaluated to find sufficient indication or proof of cause and effect relationships between investigated parameters. A common concern within this stage is assuring that conclusions are based on accurate data analysis not on premature assumptions. Since a simulation analysis is usually performed on the basis of probabilistic variable distributions and stochastic parameters, the outcome of a single simulation run is highly unlikely to represent the true system behaviour. To be truly meaningful, any conclusion must be based on e.g. multiple runs, sufficient intervals or numerous sets of random number streams and the investigation of confidence limits of obtained figures.

2.3.4 Using discrete-event simulation for Supply Chain Analysis

As outlined before, (discrete-event) simulation is a well-accepted and somewhat matured methodology of operational research (Law and Kelton, 2000; Pidd, 2004; Brooks and Robinson, 2001). Traditionally, spreadsheets often were the analytical tool of choice when it came to studying supply chain related issues due to their ease of use and reasonable ability to cope with SCM flexibility. Nevertheless, the time-based nature of supply chain performance measures (max/min/average inventories, throughput, transportation timing, numbers and extent of delayed deliveries etc.) are hard to capture within static spreadsheet-modelling. To tackle these limitations and due to the widespread availability of computing capacities, discrete event simulation evolved to a powerful alternative within the last decade.
Although discrete event simulation is in almost any way superior to traditional modelling approaches its actual adoption speed has been rather slow throughout academia and industry. According to Shapiro (2000) and Tiger (2003), particular difficulties for quick adoption can be found within following areas:

- lack of detailed, readily available data
- modelling tools/software languages require commitment, are expensive, proprietary and rapidly obsolete
- lack of modelling expertise
- poor modelling design that prevents adaptation to a ever-changing real-life system
- general complexity of many supply chains

Most of these issues can nevertheless be tackled to exploit the potential discrete event simulation has to offer, particularly for investigating complex system dynamics as they are typical for multifaceted supply chain processes.
First of all modern data acquisition facilities rapidly improve the possibilities for effortless data collection and automatic integration. Typical examples are bar code scanners to obtain POS data or radio frequency identification (RFID) to keep continuous track of inventory items which can, combined with Electronic Data Interchange (EDI), be used to transmit detailed movement and sales information. Moreover, simulation software packages have continually improved and have become less expensive due to a wide range of competition.
To tackle the lack of modelling expertise, Tiger (2003) proposes a partnership between academia and industry where academia basically maintains the model and industry maintains the data. Through this partnership, academics have the opportunity to be involved with practical business problems whilst industry profits from long term development and adjustment of the models that will not have to be shelved as soon as the original developer vacates his position.

2.3.5 Software selection for Supply Chain modelling

In this section we evaluate a range of common simulation software packages in terms of their suitability to support analysing a supply chain operations framework in general and in particular the proposed research outline. To be able to obtain comprehensive recommendations, we will first review already existing comparison studies and afterwards evaluate the suitability of popular software packages on the basis of meeting certain crucial criteria.

To start with, it was decided not to take high level programming languages (C++, Java, VB) into consideration since they do not provide the level of user friendliness or advanced visualisation (animation) that is required. Furthermore software that focused predominantly on system dynamics instead of simulation is excluded from the evaluation due to their lacking visualisation capabilities and inability to handle stochastic processes. Altogether discrete event simulation was in the centre of attention since most software developing companies focus on creating and improving toolkit-packages based on this functionality. Out of the eight finally considered simulation packages three were found suitable to meet all or most of the identified requirements. Each of them should be able to effectively support the proposed research within this thesis and any similar investigation framework.

Simulation Software Comparison Studies

One of the most comprehensive surveys regarding discrete event systems simulation and related products is the biannual survey conducted by OR/MS today (Lionheart Publishing/Informs, 2005). The survey has been conducted for the seventh time in December 2005 and includes 48 simulation software products. Overall it summarises most important product features of those packages including price, easy of use, experimental run control, animation, independent runs etc.
Another overview for the selection of appropriate simulation software is provided by Tewoldeberhan *et al.* (2002). They apply a two phased evaluation and selection method to initially reduce the numerous software applications to a more appropriate short list by choosing key features necessary for the intended simulation framework. Within the second step they look at how the requirements of the company match with the features of a simulation package in detail. Overall they identify seven main areas and assign scores within each of these areas which are accumulated to a final result upon which a selection decision is made.
A third analysis focusing on comparing discrete event software packages comes from Simulation News Europe (SNE 1991-2006). They published a series on comparisons of simulation software based on simple, easily comprehensible real life applications within various industries. Comparison 14 within this series focuses on Supply Chain simulation by evaluating 12 software packages according to their features and ease of implementation. The main focus is on material flow, order flow and distance-dependent control strategies.

Simulation Software Selection Procedure

Based on the selection methodology of the three studies above, we evaluated 30 of the most common simulation packages for their suitability to our project. The initial selection stage was meant to create a shortlist of up to 10 packages based upon certain hard criteria such as discrete event focus, supply chain framework appropriateness, easily comprehensible programming interface or the availability of a software-demo. Information to support this selection process was obtained from the three surveys mentioned before and from the web-pages of the particular software suppliers.

As a result of this initial selection process, 8 software packages were identified as most suitable:

AnyLogic, Arena, AutoMod, Extend, Flexsim, ProModel, SIMUL8 and Witness

Following closely the approach outlined by Tewoldeberhan *et al.* (2003), the eight candidate- packages were evaluated according to following eight feature categories:

1. Model development: Aspects regarding model development and modeling approach. Includes features like model building tools, reusability of libraries, coding aspects, conditional routings, queuing policies, programming interface etc.
2. Input modes: This includes data input modes such as batch mode, from external files (spreadsheets, database, text files, etc.), internal spreadsheet capabilities, random variable generation and variety of probabilistic distributions.
3. Testing and efficiency: The issues in this category include debugging features and error control.
4. Execution: The questions in this category cover features such as multiple replications, automatic batch run, warm up period, and reset capability.
5. Animation: The problems in this category cover animation development features, animation running features, display features, and icon development.
6. Output: The points in this category include features used for displaying outputs either in terms of numbers, reports or business graphics. It also includes simple statistical analyses and the capability to communicate with external packages.
7. User: The issues in this category include cost, speed, compatibility of packages with particular operating systems and hardware.
8. Learning effort: This is a more subjective measure since it takes into account the individual prior experience of the modeller, available help, examples and supporting literature.

Each of the eight categories was given a weight in between 5% and 25% with weights adding up to 100%. Within each category, software packages could obtain in between 0 and 3 points. Table 2.1 shows the individual figures and provides an overall score for each package.

Criteria	Weight	AnyLogic	Arena	AutoMod	Extend	Flexsim	ProModel	SIMUL8	Witness
Model Dvlpmnt	25%	2	2	1	2	2	1	3	3
Input modes	10%	3	2	2	1	1	2	3	3
Testing	5%	1	2	2	3	1	2	2	2
Execution	10%	2	3	3	2	2	3	3	3
Animation	15%	2	1	1	2	1	2	3	2
Output	5%	2	2	2	2	3	1	2	2
User	10%	1	2	2	3	1	1	3	1
Learning effort	20%	1	2	1	1	2	2	3	1
Overall Score	100%	1.75	1.95	1.5	1.85	1.65	1.7	2.9	2.15
Rank		5.	3.	8.	4.	7.	6.	1.	2.

Table 2.1: Results of the Simulation Software evaluation procedure

Overall it seems SIMUL8 is the most appropriate package considering the particular strengths in the categories that matter the most. Its major strengths within *Model development* are the very easy to use visual interface and the harmonic implementation of Visual Logic which allows steering the model via a Visual Basic like programming interface. Within the *Animation* category SIMUL8 seems to have the most attractive visualisation facilities with certain presets for typical applications that are very easy to set up and a wide variety of customization options. Within the *User* category, SIMUL8 achieves a high score due to the considerably low cost of the package compared to most other solutions. Finally the *Learning effort* would be considerably reduced due to simple programming interface, availability of support material and prior experience. Apart from these main categories, SIMUL8 obtains reasonably good scores for all other criteria which makes it overall the software of choice.

Despite losing out to Simul8, Witness and Arena obtained remarkably good overall and individual scores as well which would make them very appropriate solutions to support the proposed analyses within this research framework. The main reason they fell behind is due to the substandard visualisation front-end (Arena) and the remarkably higher cost (Witness).

2.4 A brief overview about Supply Chain Simulation Literature

Altogether, there are a number of supply chain simulation studies available in the literature. The following review focuses on research in which simulation is used as a primary analytical tool to study the behaviour of multi-echelon or supply chain systems under various operational and/or strategic conditions. In addition to this, numerous supply chain studies use simulation basically as a tool for verification or illustration. As a general finding it can be stated that investigations within early research proceedings are mostly limited to a single performance measure in an effort to study specific problems related to specific supply chain environments. Later work approaches investigation scenarios with a wider – more universal – point of view and made it thus possible to obtain more general principles. Following furthermore the outline of Beamon and Chen (2001), supply chain simulation studies can be distinguished into strategic and operational analyses.

2.4.1 Strategic Supply Chain Simulation Studies

One of the first simulation analyses of supply chains may have been done by del Vecchio and Towill (1990). Within their *Conceptual Modelling of Industrial Production & Distribution* they validated and verified the use of simulation modelling in production/distribution systems. Towill (1991) and Towill and Naim (1992) expand previous work in using simulation techniques to evaluate the effects of various supply chain strategies like just-in-time, echelon elimination, order quantity modification or information incorporation on demand distortion and demand-variance amplification. After applying the above mentioned supply chain strategies to their reference model, the authors conclude that the just-in-time and the echelon elimination strategies are the most effective ones for smoothing demand variation.

Further early work was obtained by Wikner *et al.* (1991). They also used simulation techniques to evaluate the effects of supply chain improvement strategies like time delay reduction, distribution stage elimination, decision rule improvement, and information flow integration. It is concluded that the most effective improvement strategy is enhancing the flow of information throughout all levels of the supply chain.

To tackle the issue of limited reuse value and timely developing procedure, Swaminathan *et al.* (1998) provide a supply chain modelling framework, which enables rapid development of customized decision support tools for SCM. This allows for rapid reconfiguration of the supply chain based upon studies of several different chains using library-based modelling components. To address the same matter, Van der Zee (2005) describes the use of different agents in the supply chain and how to provide each agent with certain authorities to utilise a subset of control elements that help in decision making at the agent level by employing several policies. These policies are derived from rather analytical models such as inventory management, just-in-time processes, and routing algorithms for demand, supply, information and materials control within the supply chain.

2.4.2 Operational Supply Chain Simulation Studies

Within operational supply chain simulation studies, Gupta *et al.* (1992b) started to develop certain lot-sizing scenarios using a supply chain simulation model to evaluate various lot-sizing techniques for their suitability. The authors conclude that Wagner-Within as a method was best suited for single stage problems with short planning horizons and small forecast errors. This work was later extended including an even wider range of factors (Gupta and Brennan, 1994).

Focusing more on inventory issues, Amin and Altiok (1997) use simulation to study the effect of various manufacturing control policies as well as prioritizing structures in order to identify a set of control policies that may be appropriate for use in a Supply Chain environment. They use three product types and three echelons operating under a continuous review inventory policy. As performance metrics they employed average warehouse inventory levels, average buffer work in progress, average backorder levels, average backorder size per customer within unfulfilled demand, and probability of backorder per customer arrival. They conclude with commenting on the observed relationships between the various tested control policies/priority structures and the certain performance measures.

Bhaskaran (1998) illustrates the magnitude of a supply chain reengineering project for a blanking and stamping operation at General Motors, using simulation as the primary analytical tool. The study emphasizes on the high level of detail that is necessary to understand material and information flows and evaluates different system configurations to identify improvement.

Van der Vorst *et al.* (2000) furthermore develop a simulation modelling approach using a case study from the food industry. Their more advanced model uses eight different performance indicators (three cost based and five service based) to investigate the effects of introducing EDI and a real-time inventory system. As a result they conclude that particularly increasing order and delivery frequency, shorter manufacturer's lead time and advanced information sharing improve overall supply chain performance.

The referred literature above is in no way meant as an exhaustive overview of proceedings within simulation modelling of supply chains. It rather aimed to presents a reasonable insight into the developing field taking some significant milestone publications at hand.

2.5 Supply Chain Performance Measurement

Depending on the particular character and targets of a supply chain investigation study, a wide variety of possible performance measures is applicable. All metrics will to some extent describe the level of efficiency and effectiveness of moving goods through the entire chain. Commonly, supply chain metrics are classified to broadly fit into three categories: customer service, time & response and financial measures (Boone *et al.*, 2000). Customer service elements typically include fill rates, on-time delivery, accurate orders and related measures. Time and response metrics measure the response of the supply chain to customer orders. They typically capture the time it takes to process and transport requests from any entity in the supply chain to a particular destination. Time and response metrics can furthermore evaluate the time spent by the product (or various components) at different entities in the supply chain at different points of time. Finally, the financial performance of a supply chain can be evaluated by looking into issues such as cost of raw material, revenue from goods sold, activity-based costs (material handling, manufacturing, assembling etc.), inventory holding costs, transportation costs, cost of expired perishable goods, penalties for incorrectly filled or late orders delivered to customers or cost of goods returned by customers.

Biswas (2000) classifies Supply chain performance measures broadly into two categories - qualitative measures (such as customer satisfaction and product quality) and quantitative measures which are again split into non-financial and financial.

Gunesekaran *et al.* (2001) classify supply chain performance metrics along the major four supply chain objectives namely plan, source, production (make) and delivery. Additionally a customer service category is introduced to capture further global performance indicators. The detailed metrics are outlined in Figure 2.2.

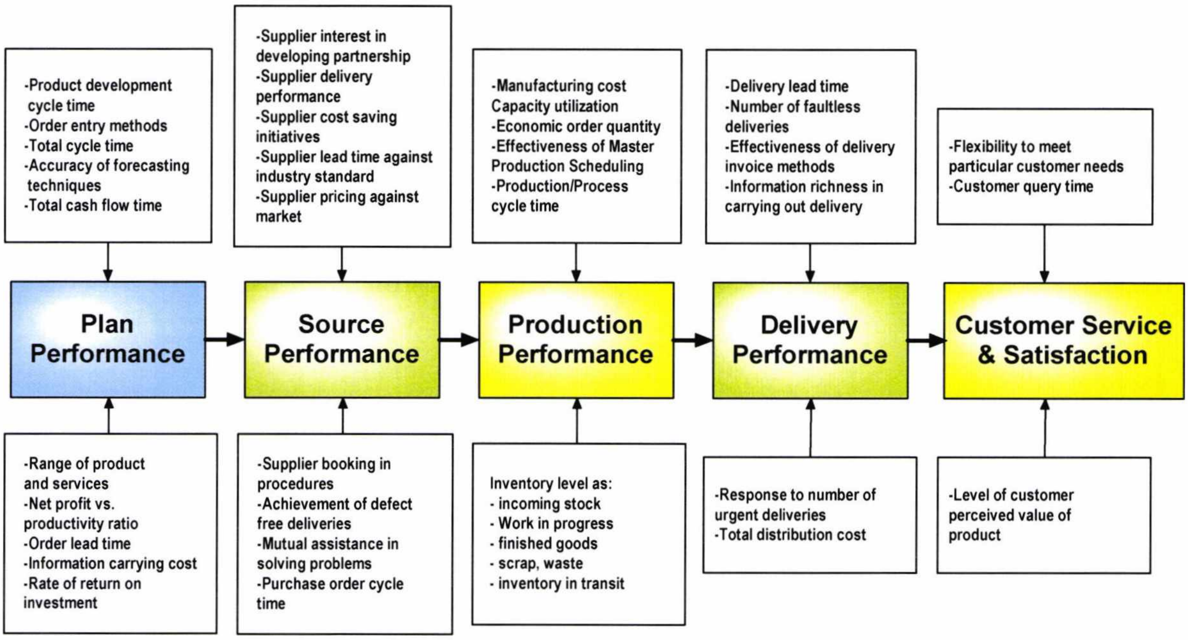


Figure 2.2: Supply Chain performance metrics along 5 basic links (Gunasekaran et al. 2001)

VIVACE (2004) investigate a variety of performance measure systems in the literature and propose a three category approach divided into metrics based upon cost, customer service and capability. The target of their system lies on defining a framework to assess the efficiency of a simulated supply chain in the aerospace industry. Their proposed framework is outlined in Figure 2.3.

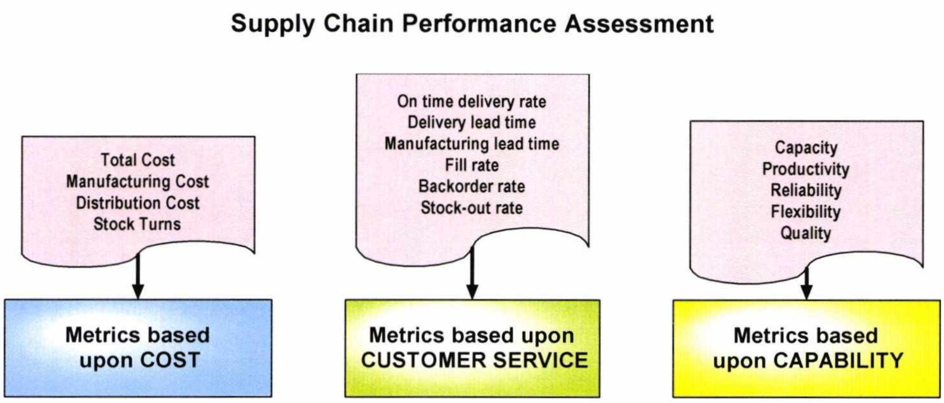


Figure 2.3: Supply Chain performance assessment criteria (VIVACE, 2004)

Apart from the above performance metrics approaches, the balanced score card, developed at the Harvard Business School, is a comprehensive, top-down view of organisational performance with a strong focus on vision and strategy (INPHASE 1998, Paylor 2002). Its basic idea is to avoid the typically retrospective financial perspective to include metrics that provide historical and future insights. Therefore the balanced scorecard approach defines four dimensions: financial, customer, internal and innovation and growth. Example metrics for these four key areas suitable for supply chain simulation models are:

- Financial - average inventory value, average labour cost, shipment error cost, warehouse cost, transportation cost.
- Customer – order accuracy, on time delivery, number of complaints, order backlogs
- Internal – production, shipments per hour; number of trucks in transit, in system or at dock; average truck turnaround time; inventory accuracy; storage facility utilisation; number of products damaged; dock utilisation etc.
- Innovation and growth – overtime hours worked, training cost

Altogether there is a wide variety of possible supply chain metric classifications as it can be seen from the above outline. Since every simulation study will be somewhat different and will aim to address distinct issues, chosen performance metrics will necessarily have to be adapted to set out requirements. Focusing on generic measurement frameworks proposed by literature is thus often practically of less value. It can however help within grouping chosen measures and not to miss out on important key performance indicators. A decision upon which measures to include and how to individually define them should nevertheless solely be made having the particular supply chain framework under investigation in mind.

Considering the performance assessment within the research study carried out for this thesis, the applied metrics are classified into three less conventional groups. Firstly there is *planning accuracy* which includes measures to judge about efficient resource and capacity planning (production capacity utilisation, average and maximum inventories) or demand prediction accuracy (demand forecast deviation, demand variability amplification). The second group are *distribution related metrics* where the main focus lies on effectiveness and efficiency of distribution. Particular metrics are e.g. immediately fulfilled delivery requests, shortly delayed deliveries, critically delayed deliveries, delivery frequency, lead time or fill rate. The third group, named *global performance metrics* is typically concerned with out of stock times at retail level and thus not potential but direct loss of sales. Individual and accumulated service-level or service-level gaps, as measures of what percentage of customers' demand could (not) be fulfilled throughout a period of time, are thus the main overall indicators of how well the entire supply chain operates.

More details about development and application of particular metrics and the way they were actually measured within the research framework of this thesis will be given in the methodology chapter.

3. Problem Description and Plan of Solution

Having introduced the general research target together with supply chain management and simulation modelling as the focal points of the investigation framework, in this chapter we outline the actual investigated problem in more detail and propose a plan of investigation that is carried out within the following chapters.

3.1 Problems addressed by the research

Chapter 1 already introduced a wide range of possible problem areas that are arising within the area of collaboration in supply chains, computer simulation of supply chains and particular implications for small and medium enterprises. These three main subjects constitute thus the core areas the research is focused on. This chapter will clearly identify specific problems that arise within these areas and depict individual issues in need of further clarification that also offer significant potential for improvement. Areas of investigation will thus be selected according to possible benefits for the research community in general and the participating companies in particular.

3.1.1 Supply Chain Collaboration – the struggle to make it work

A few years after first CPFR initiatives were launched, where does CPFR stand today in terms of acceptance and adoption? A brief answer could be that adoption has been slow but steady with a somewhat increasing momentum. A recent study by AMR Research (AMR Research, 2004) amongst various US companies found that about 20% of survey respondents have CPFR in place and about 35% are running pilots or planning implementation within the next two to four years. Another survey carried out by Computer Science Corporation in conjunction with Supply Chain Management Review (Poirier and Quinn, 2004) confirms that significant progress has been made in a number of important collaborative areas but it also reveals a widening gap between those companies already reaping the benefits of advanced supply chain management and those still struggling to do so. Altogether there is a lot of potential which has been validated by the rather few companies that have successfully implemented demand collaboration processes. Nevertheless adoption rates have been rather low and many of the companies that have attempted it were rather disappointed by the results. So why, despite its obvious advantages, do many companies struggle to make CPFR work for them? Common issues are the desire to partner but not commit to execute the communicated plans (Crum and Palmatier, 2004), difficult implementation (Sabath and Fontanella, 2002), over-reliance on technology in trying to implement it (Mc Carthy and Golocic, 2002), fear of relinquishing control (Moberg and Speh, 2003), a lack of trust between trading partners (Ireland and Bruce, 2000; Nesheim, 2001) and general fear of complexity (Andraski and Haedicke, 2003). Additionally to the above mentioned a very often stated reason for disappointing results is the missing ability to differentiate between whom with and in what order to collaborate and to effectively differentiate the most profitable customers from the rest (Sabath and Fontanella, 2002). Similar to this, the involvement in too many supply chains, both horizontally and vertically, is an often criticised issue (Moberg and Speh, 2003). The problem in that sense often is that many manufacturing companies sell their products to multiple retail customers that directly compete with each other. The retailers on the other hand sell products from several competing manufacturers. If all these exchange vital information and work off common forecasts, the threat of giving away crucial information

is evident. This is a main issue why collaborative initiatives fail due to a lack of trust and explains partly why most collaboration success stories only involve a limited number of engaged trading partners (VICS, 1998). Another issue within this context can be found in the nature of the relationship of manufacturers and retailers. Whilst collaboration concepts define them as partners to align supply and demand to create a seamless flow of products that ultimately satisfy the final customer, reality is often far from that. Apart from their common interest to serve the customer, they also antagonistically argue about margins, assortments, quantities, promotions, delivery times and service level commitments. Within this atmosphere of controversy, collaboration is often difficult to achieve and prevail. Apart from the above issues, supply chain collaboration requires the input of significant resources to implement it. Hence organisations that attempt unilateral agreements with a vast number of customers or suppliers will usually not succeed since the cost of such wide scale implementation would simply outweigh the achieved benefits (Barratt, 2004).
A detailed research study carried out by Syncra Systems and Industry Directions summarises the mentioned concerns. The study surveyed several hundred manufacturers, retailers, distributors and logistics providers ranging in size from under $100m in sales to over $5bn, the major challenges for implementing collaboration were common difficulties with internal process change, cost and lack of business-partner trust (Fraser, 2003).

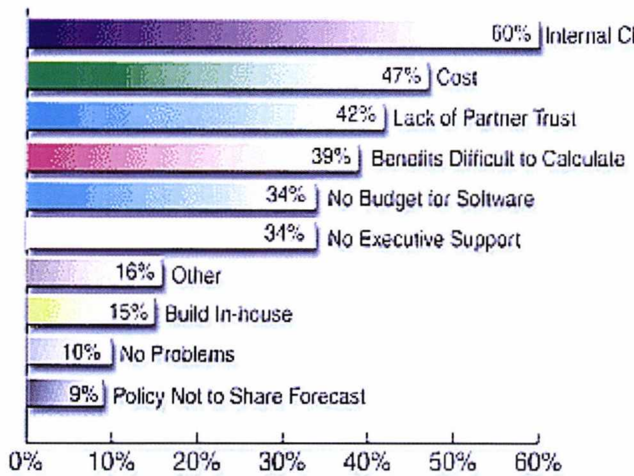


Figure 3.1: Challenges for implementing collaboration – survey results (Fraser, 2003)

Overall, the demand collaboration debate today might be understood as a natural phase of evolution, typical for any new way of conducting business. It starts with understanding the potential and recognising the beneficial aspects. As a next step, business process models are developed, tested and refined, and technology is established to support the new business processes. Thus, following the views of Crum and Palmatier (2004) or Andraski and Haedicke (2003), demand collaboration will be commonplace in 10-20 years just as category management, vendor managed inventory (VMI) or joint sales and operations planning are in the process of becoming commonplace in industry today.

3.1.2 Heterogeneous collaboration frameworks

One of the major practical conclusions of the above considerations is that manufacturing and retailing companies commonly prefer to involve only part of their customer base in collaborative replenishment systems (Tang and Gattorna, 2003; Christopher and Towill, 2002). Thus manufacturers necessarily need to set up their operations in a way that both

collaborating as well as non-collaborating customers can be served effectively and efficiently – they need *heterogeneous collaboration frameworks* (Smaros *et al.*, 2003).
A further motivation for studying such heterogeneous setups is recent market developments within the group of small or medium sized enterprises. Numerous small to medium sized suppliers nowadays face the decision to participate in some sort of joint business forecasting system of various large retail companies that reveals the opportunity to obtain demand and inventory data on distribution centre and store level. The very idea behind this being increased visibility for both retailer and supplier as to share demand and production data to optimise replenishment. Due to the number and diversity of customers a typical company has, the practical issue in most cases cannot be to totally switch planning and replenishment approaches from an isolated to a full collaborative replenishment framework since most often either financial considerations or simply non-availability of joint-data systems prevent a unique switch. Most companies are thus faced with the question to what extent their production and delivery planning process can benefit from a heterogeneous approach where some or even most customers still use a traditional order process whilst others share demand data and agree to collaborative delivery and replenishment approaches. A company that will only selectively choose trustworthy partners to engage in collaboration due to a fear of revealing vital information to too many market participants, will necessarily need a heterogeneous replenishment approach. Until recently, collaborative SCM research has mainly focused on either the relationship between one vendor and one customer or the ideal situation of a manufacturer collaborating with all its downstream partners. In the rare cases where heterogeneous scenarios are evaluated in the literature (Waller *et al.*, 1999; Smaros *et al.*, 2003) the main focus lies on impacted inventory levels rather than production utilization, delivery performance, demand forecast accuracy or service level. There are furthermore no investigations available about strategic issues within such a framework e.g. regarding customer prioritization, shortage gaming or impact of collaboration on non-collaborating customers to name only a few. Consequently, the available literature and case studies provide only limited support to companies struggling with the aforementioned problems within the business conditions outlined earlier on.

3.1.3 Particular problems of SME manufacturers

The variety of problems regarding heterogeneous collaboration frameworks are often even more apparent for small and medium size companies that just cannot rely on either pure traditional or universal-collaborative replenishment scenarios. Due to a lack of resources, SMEs commonly struggle to implement management improvement systems at the same pace as the major market players do. Within this context, Vlachos and Bourlakis (2006) examine the impact of key factors on collaboration performance including trust and the duration of collaboration between retailers and SME food manufacturers. They illustrate that individual food supply chain partners perceive critical collaboration factors differently which leads to supply chain ineffectiveness and casts doubts on the viability of current collaboration efforts which aim to achieve mutual benefits across the supply chain. They conclude that the effectiveness of collaboration, and thus the functioning of a food supply chain, is highly dependent on retailers' initiative to build and foster trust with their partners. The e-Business W@tch 2004 Sector report issued by the European Commission (e-Business W@tch, 2004) investigates major challenges for a wide range of SME companies within various sectors and constitutes a typical reluctance amongst many smaller firms to abandon traditional business cultures and models. They consider this as a major obstacle towards cooperation and collaboration with supply chain partners. The

report concludes by suggesting to educate SMEs about opportunities of using improved management techniques and sensible IT applications.
According to our own experience whilst contacting various German SME food manufacturers, there seems to be a significant gap in knowledge regarding common supply chain management tools and techniques as well as advanced collaboration concepts. This is also supported by a more general SME sector research carried out by Hall (2002). The majority of businesses investigated seem to be in a state of ignorance until major players pressure them into upgrading their systems and adopting improvement concepts. For example, 8 out of 10 SME enterprises contacted did not incorporate seasonal sales deviations into their production forecast beyond a simple biannual e.g. summer/winter approach. A similar percentage of companies moreover did not adjust their production according to promotional activities of their own or of competitors' products. In most of the cases this was due to non-awareness of times or impact of individual promotional activities since retailers did not share this information. The same companies had very little or no control and often insufficient knowledge about when and in what way their products would be advertised by large retailers. Promotional deals were commonly pre-agreed on an annual basis including payment of advertisement cost surcharges by the manufacturers without specifying particular times or ways of conduction. Delivery was most commonly arranged on a fixed interval basis with production planning just based on historic sales figures and a "feel for the market". Five out of ten companies were in the process of utilizing sales and inventory data provided by their customers to feed back into their production and delivery planning. Only three out of ten companies were considering collaborative forecasting and replenishment programmes as option to improve their sales and delivery accuracy. About half of these predominantly family owned businesses did not consider demand overstating reorder behaviour ("shortage gaming") of their customers to be a major issue although admitted that a further analysis would be helpful.
A major concern within the process of introducing more IT-driven automated replenishment systems to replace the predominant uncertain demand, fixed reorder interval procedure are cost and expertise to implement, run and utilise the new systems.
There seems to be in general a lack of awareness about what kind of improvements these new systems can bring and what to be aware of within the implementation phase.

Particular issues that were raised within this context were:

- What different choices are there to update my demand and delivery forecasting tools and techniques?
- Will the benefits outweigh the cost of acquiring and running the system?
- Is there an urgent need to update my approved legacy system and technique?
- How running two types of systems parallel will affect the delivery performance overall and for each customer?
- How can I find out about reasons for seasonal sales deviations of particular products and markets?
- Will I need third party logistics providers to run a collaborative system?
- Which performance measures will improve the most?
- Will I need a complete IT infrastructure or just an internet connection?
- Will customers not being involved in collaboration be disadvantaged?
- Do I need a complete change or can I pick the improvement modules that generate the most benefit for the company?
- In what way will collaboration and data sharing influence price and promotion activity cost negotiations with the retailers?

- Is there a way to test what if scenarios including different levels of change and individual products and customers?
- Will my competitors be able to access crucial data?
- What kind of forecasting approaches can be used to improve demand forecasting?
- Does improved collaboration and shared forecasting solve issues of premature expiry of perishable products?

These and many more questions raised show the need for understanding the possible opportunities, threats, strengths and weaknesses of implementing more advanced supply chain management, planning and coordination techniques within a business environment that is surprisingly unaware of modern supply chain management developments. Such tools and techniques are regarded as common knowledge amongst major retailers and large manufacturers. However, the particular implications of these tools for traditionally operating SME manufacturers have not been considered sufficiently with supply chain collaboration research.

3.1.4 Expanding the scope of supply chain simulation

In many cases, discrete event simulation is a natural approach in studying supply chains as their complexity obstructs analytic evaluation (e.g. Ridall *et al.*, 2000; Huang *et al.*, 2003). However, its suitability does not guarantee adequate decision support. Altogether, the success of a simulation study largely depends on the joint availability and use of the analyst's skills, the utilized data, and the features offered by the simulation tool. Apart from such issues, supply chain simulation models can play an important role as "communicative means" between the analyst and the problem owners.

Ideally, a visual interactive simulation model should serve as a vehicle for obtaining insight and oversight with regard to alternative supply chain scenarios. In this respect, an adequate model can help to build trust among supply chain partners, increase the acceptance of solutions, create alternative, possibly better, supply chain scenarios and reduce costs of alternative research efforts (Zee, 2005).

Following the general outline of applicability of discrete event simulation modelling of previous chapters we have already seen the wide scope of utilisation. Focusing more on the specific area of discrete event simulation modelling for decision support in multi echelon supply chains, previous literature and case studies are much more rare. Apparently, the majority of discrete event modelling applications can be found in production plant design and in the evaluation of production policies, lot sizes, work in progress (WIP) levels and production plans/schedules. The majority of case studies have been reported in the semiconductor and the automotive industry. Discrete event modelling appears particularly appropriate in these industries, which are characterized by production lines and continuous production with stable, automated processes.

According to Semini *et al.* (2006) who conducted a broad literature review of applications of discrete event simulation, very few real-world applications for multi-echelon supply chain decision-making have been reported. They suggest that this may be due to the involvement of many case specific "soft" issues and to supply chain simulations being a relatively new concept altogether. In either case, it seems that requirements for supply chain simulations are slightly different from those for traditional application areas. Considerable research in this field can predominantly be found at a conceptual/prototype level. Altogether it can be stated that papers reporting real-world applications within this area are scarce and thus strongly encouraged by many authors of relevant literature.

The following issues, not investigated hitherto, are worthy of consideration:

- multi echelon supply chain decision making implications
- simultaneous inclusion of ROP, VMI and CPFR into a single simulation model
- implementation of a forecasting system to support CPFR planning
- simulation framework based on real life data (demand, distribution, production)
- inclusion of non-stationary demand including promotions, seasonalities, trends etc.
- complex framework including multiple suppliers, distributors and retailers expanding previous approaches that focused on single supplier, single manufacturer, single distributor and single customer relationships
- wide range of performance metrics and framework parameters deployed distracting focus away from typically investigated replenishment intervals or inventory reductions towards service level commitments, stock throughput policies, expiry control, deployed forecast accuracy
- investigation of a variety of control aspects across multi-echelon supply chains
- include a higher level of complexity within production and distribution planning by including variable capacity constraints, strong seasonalities, promotions, competitor activities or external influences (weather, "fashion trends", quality issues etc.)
- highly flexible, modular simulation structure that allows adaptation to several business frameworks without major rework being carried out
- implementation of a high level of self-steering model intelligence that allows readjusting parameters throughout a model run

Altogether there is a wide variety of shortcomings or neglected areas within previous simulation studies of supply chain interaction frameworks. The research focus and modelling framework of this thesis should provide a range of opportunities to expand earlier modelling approaches to obtain interesting insights beyond previous considerations.

3.1.5 Central Research Purpose

The purpose of this research is thus to emphasize on the above-mentioned heterogeneous framework conditions which constitute an intermediate approach in between traditional isolated echelons and fully transparent information exchange systems which is a field that has not been much explored by SCM research. In the rare cases where heterogeneous scenarios are evaluated in the literature the main focus lies on impacted inventory levels rather than production utilization, delivery performance, demand forecast accuracy or service level. Waller *et al.* (1999) use simulation of a supply chain to examine the effect of VMI adoption rates strictly on inventory levels. The focus lies rather on increased replenishment frequencies and increased inventory review. The analysis is limited to vendor managed inventory (VMI) scenario considerations lacking any collaboration (e.g. CPFR – collaborative planning forecasting and replenishment) related considerations. Småros *et al.* (2003) use discrete event simulation to evaluate how to use increased demand visibility for production and inventory control. They focus on how the manufacturer benefits from reduced production load volatility as the number of VMI customers increases. They find that the value of visibility greatly depends on replenishment frequencies and length of production planning cycle employed by the manufacturer. The analysis has various interesting findings focusing more on flexible inventory and production metrics rather than order fulfilment and service level as performance measures. Moreover it centres on VMI scenario considerations with

underlying stable demand not yet accounting for more complex non-stationary demand and CPFR related implementations.
The system simulation approach applied within this research expands previous undertakings and additionally addresses some of the typical problems within supply chain collaboration as it focuses on practically more relevant heterogeneous collaboration setups and applies actual sales, production and distribution data obtained from supply chain frameworks of three SME manufacturers. The choice of discrete event simulation as the method of analysis aims to integrate obtained data and market intelligence to a sufficient detail to obtain valid results that give valuable insights into a widening collaboration framework.
Furthermore, the investigation will – instead of focusing all the attention on global efficiency achievements – concentrate on scenario analyses for each individual market participant whether or not it is engaged in a collaborative process. This will allow evaluating the impact of collaborative replenishment from the point of view of a non-participating customer which is a new perspective within collaboration research.

3.2 Specification of research objectives and proposed solution strategy

The following subsections will define specific objectives of the research framework in detail and present a plan to address the problems to obtain valuable insight and problem resolutions.

3.2.1 Research objectives

After introducing particular areas of interest, recent developments within these and recognition of possible problem scenarios we can summarize the challenges and investigation targets of the research framework within two main objectives:

First objective: Develop an appropriate simulation framework to enable investigating the proposed ideas and areas of interest.

> The research aims to develop a computer simulation model that is able to represent the relevant supply chain framework of various participating companies with a focus on supply chain order and delivery interactions and various levels of collaboration. The model must on one hand be flexible enough to adapt to different supply chain context settings and on the other hand generic enough to ensure the general applicability of the conclusions.
>
> Specific features necessary to allow adequately investigating the outlined supply chain framework are therefore:

- implementation and representation of interactions between up to 200 entities
- stretching over 5 supply chain echelons (multiple suppliers, manufacturer, multiple distribution centres, multiple retail outlets, multiple consumer demand pattern)
- handling of numerous different products (different manufacturers, perishable and non-perishable goods)
- wide variety of performance metrics measured at all stages
- reasonably fast replication of a simulation timeframe spanning over several years
- incorporation of adequate level of variability to represent real life variation but overall still being able to manage a large number of parameter changes

- generic enough to be easily adjustable to different framework circumstances
- ability to adequately represent numerous methods and levels of collaboration in between supply chain echelons
- incorporate real life demand data
- flexible and powerful forecasting system to predict demand, order timings and quantities

Second objective: Investigate the impact of enhanced coordination and scheduling of production and distribution in the light of various levels of collaboration within retail supply chains of several SME manufacturers.

To support the ongoing changes and challenges within the business environment of SME food manufacturers we aim to investigate a variety of practical issues that were raised by the companies that participated in the research. Furthermore we aim to address a number of academic issues raised within the prior literature arising against the background of emerging heterogeneous collaboration frameworks amongst various supply chain participants.

The main issues targeted include:

- performance impact of various stages of collaboration on the supply chain (performance altogether, particular supply chain echelons and individual members of echelons)
- the impact of emerging collaboration on non-collaborating members of a supply chain
- the influence of distinct collaboration modules on performance of the entire supply chain as well as on particular echelons and individual members
- impact of fill-rate dependent reordering behaviour (shortage gaming) within supply chains with emerging collaboration frameworks
- various strategies of customer prioritisation within heterogeneous collaboration frameworks
- impact of enhanced coordination and collaboration within perishable goods supply chains

3.2.2 Proposed solution strategy

In order to allow for the initiation and successful progression of the research it was essential to obtain the support of various SME food manufacturers and their customers. From a wide range of contacted companies, three firms were willing and able to provide the necessary assistance that also fit into the overall outlined supply chain framework. The companies provided a vast amount of invaluable expertise, insight into actual market processes and necessary sales, production and distribution data that constitute the foundation of the simulation model and all further analyses. The particular companies and their individual business backgrounds are introduced in Chapter 4.
After ensuring a sufficient level of practitioners' support, the second major challenge is the creation of a capable computer simulation model based on a suitable software package. Following the outline of Chapter 2, the software package had to provide a number of crucial features that are necessary to successfully create a model that supports the proposed analysis framework. Apart from this the package also had to be available to the modeller

which can be considerably difficult due to high prices for this kind of software. Ultimately, Simul8 was chosen since it obtained the highest score within the simulation software evaluation presented in section 2.3.5 and the company's generous support for promising PhD projects which included providing a Simul8 Professional package to the researcher over the time-span of the investigation free of charge[1].
The actual creation of the simulation model will follow a standard simulation modelling methodology proposed by Robinson (2003) which is outlined in detail within Chapter 4. The preparation, dissemination and integration of the underlying data are described in Chapter 5 together with evaluating suitable forecasting methods and their implementation.

After the preliminary research requirements could be sufficiently lined up, we need to specify in more detail how the proposed target issues of the actual investigation can be successfully addressed to provide answers to the questions raised by practitioners and academic literature. The following section will thus state the previously identified investigation issues and give a brief outline of the proposed analysis and method of resolution.

- Performance impact of various stages of collaboration on supply chain performance altogether, particular supply chain echelons and individual members of echelons

To address the issues arising out of this problem framework, we first investigate the reference scenarios that constitute the actual state of replenishment for each of the three supply chain frameworks before any alterations to the system. These will serve as basis to compare changes step by step whilst the distribution layout is adjusted and demand visibility increases through raising the number of customers that feature collaborative replenishment. To be able to evaluate how increasing the scope of collaboration affects individual performance measures on a global and individual basis, we will investigate a large set of possible scenarios. Starting from the default non-collaborative scenarios, we will increase collaboration step by step by engaging one, two, three and finally all customers in collaborative replenishment which can be either VMI or CPFR. All supply chain frameworks will be investigated for the case of fixed-date as well as flexible-date delivery setup as reference settings. Altogether we thus investigate 6 base scenarios which are then altered to obtain 30 extended collaboration settings grouped into three collaboration categories.

- The impact of emerging collaboration on non-collaborating members of a supply chain

One of the concerns that arise when considering introducing collaborative replenishment partnerships is how that change would affect the delivery reliability of the remaining ROP customers. As outlined before, collaborative replenishment research in general suggest a higher total efficiency thus less delayed deliveries, lower inventories or better overall service level after the introduction of a CPFR replenishment system. Hence there is agreement about the global achievements but there is a obvious lack of investigation as to what extent the remaining non-collaborating customers are affected by the changes. This problem is investigated by evaluating the individual customers' as well as the overall performance outcome of four chosen key performance metrics for each of 16 possible collaboration settings (every possible combination of either one, two or three customers

[1] Other providers of computer simulation software made similar offers i.e. Witness, Arena, Flexsim but did overall not provide the level of suitability to support the research project.

being replenished via CPFR) and 6 supply chain frameworks (three different manufacturers frameworks with two different reference settings each). Within the investigation, manufacturer inventory will be held at a predefined level to allow evaluating resulting impact on service levels and other performance indicators.

- The influence of particular collaboration modules on performance of the entire supply chain as well as on particular echelons and individual members

Here we will analyse which particular components of a collaborative replenishment framework promise to be most rewarding. We will therefore evaluate a variety of supply chain scenarios to obtain detailed information about which considered collaboration modules are worth implementing and to what extent other elements can possibly be neglected. This would be of particular interest for companies that might want to pick the individual elements out of a VMI/CPFR framework that are most rewarding for their specific situation whilst avoiding having to take less important components. One of the reasons for doing so can simply be wishing to avoid the costs associated with the introduction of collaboration, another would be companies' obvious wish to protect their data and avoid having to share crucial information with other market participants.
To be able to address the outlined investigation subject it is preliminarily necessary to clearly identify, isolate and later individually reintegrate particular collaboration components in the supply chain model. After investigating the practical aspects of a typical CPFR system and considering the participating companies' circumstances, four components could be isolated that should be somewhat representative for a typical collaborative replenishment system. These collaboration modules were defined after in-depth evaluation of typical collaboration layouts among SME manufacturers within the investigated industries. They should thus be representative for such supply chain constellations but will surely not be exhaustive or necessarily applicable for other industries and markets. The four defined modules are promotional activities, seasonal sales deviations, short/mid term sales-trend forecast and an "intelligent" allocation system.

- Investigating the impact of fill-rate dependent reordering behaviour (shortage gaming) within supply chains with emerging collaboration frameworks

The purpose of addressing this issue is to point out to what extent demand overstating reorder behaviour can be accommodated for in an altering supply chain. We thus carry out individual analyses for the supply chain frameworks of the three manufacturers to give recommendations what ordering behaviour to encourage or condemn in the light of varying levels of demand transparency. The investigation covers a wide range of mixed scenarios reaching from very basic fixed date, fixed interval ordering behaviour to more advanced VMI and CPFR systems. A wide range of performance metrics is applied within 15 distinct distribution scenarios for each of the three frameworks to be able to evaluate 7 different types of reordering behaviour. As an outcome, recommendations are given as to what behaviour is most beneficial for global supply chain performance and which others are supposed to be abolished.

- Various strategies of customer prioritisation within heterogeneous collaboration frameworks

The issue of prioritization evolves around the strategic business concern of how to deal with clashing incoming orders that combined request more of a scarce product than is available. If more than one order is requested at a period of stock shortage we face the problem of fulfilment prioritization as to decide which order request to fulfil first to what extent and which others are to be delayed. Within this context a variety of issues can play a role in deciding about a prioritization policy. Often particularly small and medium enterprises have key customers that account for a large amount of total demand and thus often insist to be treated with priority. On the other hand major customers could be considered as "safe" and thus smaller (new) customers may be prioritized as to not drive them seeking out alternative sources of supply. Another method of priority ranking could evolve out of the idea to balance in between customers to keep the supply gaps of the most unfortunate customers as low as possible which would somewhat drop performance of other customers subsequently but still keep them satisfied enough not to search for alternative sources of supply. Apart from these issues there are additional concerns arising within a partly collaborative replenishment framework. If several customers are engaged in VMI or CPFR replenishment their actual order fulfilment urgency level would be known due to information exchange systems whilst incoming non-collaborative ROP requests could not be judged for their urgency. The question arising is thus how to deal with this situation to either minimize the overall lost sales, meet punctuality targets or avoid upsetting particular customers. To investigate such issues we define various prioritization strategies and test their impact on a global as well as individual customer level. Additionally we consider such issues within a purely non-collaborative as well as partly collaborative replenishment framework and give recommendations how to balance in between collaborative and non-collaboratively replenished customers.

➢ Impact of enhanced coordination and collaboration within perishable goods supply chains

To address this final raised issue we evaluate various supply chain advancements and their impact within a perishable goods environment. The analysed aspects will be somewhat similar to the previously described points but the perishable nature of the products investigated will require a substantially different investigation focus. Altogether, perishable goods frameworks seem to have distinct conventions and priorities that are substantially different from environments with non-perishable or long term perishable products. The most substantial difference within this context evolves around the omnipresent issue of goods that need to be individually dispatched or replaced within various echelons due to risk of expiration of their shelf-life. Considering that concept, several possible scenarios arise about how to produce, store, deliver, control and replace these goods. All those issues arise in addition to the already complex interrelations of distributing goods within a supply chain. Overall, the field of perishable products distribution frameworks constitutes some sort of "extreme case" scenario within the otherwise reasonably investigated field of supply chain management and has not been explored to a wider extent. Some of the additional considerations arising against the background of perishable goods include:

- level of safety inventory held, as a higher inventory will necessarily add to the average age of the product at the moment of sale and thus lead directly to more expired products
- inventory throughput strategies such as FIFO, FPFO, FDFO, SIRO or LIFO have a strong influence on the quantity of goods being rendered obsolete
- customised product expiration schedules to define the strategy at what point of time or what place it is sensible to take a product out of the flow of goods

- frequency and place of expiration control such as manufacturer storage, DC or retailer-shelf determine the timeliness of expiry/product flow information that feed back into the distribution and production forecasts

Apart from addressing and clarifying the above issues the investigation also focuses on the impact of various stages of demand transparency as a result of increased collaboration between the certain echelons of the supply chain.

Investigating particular problem sets and answering questions set out by the numerous points above should jointly reveal a comprehensive overview about practical issues arising within the outlined research framework. The choice of investigation subjects allows answering relevant questions, significant to practitioners as well as academics researching the field of collaborative supply chain management within a food-retail SME context. The ambitious spread of subjects has been encouraged by individual participants' requests as well as unresolved issues uncovered throughout literature review and preliminary analyses. Due to their apparent relevance for several key stakeholders of the study framework they should all contribute to clarify key issues of the subject matter.

3.3 Limitations of the research

Unquestionably, supply chain design and simulation always heavily rely on real life data; on one hand to be able to set up the particular stages of the chain and to connect them and on the other hand to verify and validate the simulation outcome later on.
Revealing this kind of data always requires a certain degree of trust from individual companies and is therefore often only available to insiders. Due to the availability of a profound data base, the research that is carried out focuses on the supply chain of the particular three food manufacturers and their four major retail customers. As a result, the supply chain model is to some extent customised for these particular market circumstances since this makes it possible to reasonably construct, verify and validate the model. The manufacturers furthermore agreed to provide necessary data under the obligation of strict data protection. Additionally, they provided expertise in logistical and sales process related issues to outline the underlying logistical processes within the investigated supply chains that allowed the creation of an adequate simulation model. Nevertheless, there should be no doubt that after the adequate modelling and simulation of the particular scenarios, the simulation model is flexible enough to allow adaptation towards other companies or even different markets or industries.
It needs moreover to be mentioned as well that a simulation model as the main means of investigation can only be a simplified description of a complex entity or process. Naturally, there will be limitations within the implemented level of detail. This can be strength and weakness: A model as a simplified representation of the real system intends to promote the development of understanding. All that matters within modelling and simulating approaches is to find the right balance between "realistic enough" and "still manageable and understandable". For the research scenarios investigated within this research framework that basically means that each particular modelled scenario has a certain degree of fixed and therefore unconsidered variables whilst others are varied and evaluated to a greater detail. Hence, we needed to limit process complexity to an understandable and manageable degree even though it always raises the threat of missing out on possibly important interactions between various factors. Each scenario setting therefore needed a comprehensive evaluation of necessary degree of detail to result in practically useful outcome and to still be understandable.

Although the actual research framework suggested by the title of the thesis and described in the previous chapters could include investigating a much broader variety of analysis subjects and areas of interest, the focus of the research is clearly directed towards the outlined particular issues raised by participating manufacturers and retail companies. The research altogether was set out to tackle the identified problem areas in the most straightforward way to evaluate possible solutions within somewhat simplified scenarios. Common simplifications for the sake of containing the necessary investigation effort to a reasonable amount and obtaining useful, comprehensible results were:

- Focus on three German SME food manufacturers as subjects of investigation
- Discrete Event Simulation as means of investigation appropriate but naturally limited
- Focus on individual products or product groups instead of a detailed assortment mix
- Selection of fast-cycling top sellers (A-class inventory items) as investigation subjects due to their major importance to the manufacturers
- Simplified in-store reordering and product movement
- Simplification of different collaboration strategies to fit into main categories
- Number of investigated supply chain frameworks limited to three due to sheer amount of investigation effort and availability of suitable data
- Choice of similar supply chain frameworks due to limited availability of supportive companies that fulfil the investigation requirements
- Limited transferability of simulation results to real world processes due to the assumption of preset framework conditions
- Limitation of investigated scenarios concerning enhanced coordination and scheduling of production and distribution to the scenarios outlined above for the sake of manageable effort and to fit companies' requests
- Chosen companies do not necessarily exemplify a representative sample of typical SME companies but the range of issues, concerns and problems should be somewhat typical for this group of companies

Altogether, the somewhat narrowed research focus sacrifices a rather broader applicability for the sake of obtaining useful results that address the outlined research objectives. Particular simplification assumptions have been made regarding the products that were chosen for the investigation as they are fast-cycling top sellers that do not have to cope with life-cycle dependencies or extreme demand volatility. Results might thus be different for dissimilar products. Furthermore, the particular CPFR process and the integrated joint forecasting system implemented in the simulation model were somewhat customized to fit the framework and do not necessarily follow a standard approach but should be sufficiently realistic to obtain valid results. Within the investigation layout, manufacturers' inventories were assumed to be stationary within most scenarios in accordance with particular business circumstances. The findings of the simulation runs were nevertheless quite comparable to the actual outcome the companies experienced after they engaged in their initial collaborative replenishment agreements. However, performance metric figures might understate the real life outcome to some extent since they are obtained under the assumption of perfect framework conditions like no obsolescence, no breakdowns or no human or technical errors. Nonetheless, even though the absolute figures may be somewhat idealistic the relative achievements should be quite akin to real life outcome. Altogether we can state that although the results and recommendations of the forthcoming investigations are based on simplified simulation models of three particular companies' business environments, the findings should be applicable to a wider range of manufacturer-distributor relationships and all kinds of situations where the introduction of some sort of VMI/CPFR system is considered as an option. The findings should thus be understood as a theoretical indicator what could be achieved under certain circumstances. In real life replenishment systems commonly have to operate under conditions being far from optimal and thus may lead to a broad and rather unpredictable range of achievements. Since a simulation and thus model based analysis can always only be an approximation of real life and thus a simplification, a further increase in complexity involving even more variables of variation could be helpful to improve robustness of the approach and increase validity of the obtained outcome.

3.4 Research design and practical & scientific validity and relevance

The research design employed within this study roughly follows the outline of "innovation action research" proposed by Kaplan (1998). The aim of IAR is to give researchers a structure for developing relevant new knowledge within management research by developing new solutions that alter existing practice and test the feasibility of the innovation. According to Karkkainen (2005), the process behind IAR is to initially document limitations found in contemporary practice, identify new tools and concepts to overcome the limitations and to apply and improve the tools and concepts through publication and active intervention in companies. The strength of IAR is the focus on relevant feedback loops to ensure both, the practical and scientific relevance and validity of the obtained outcome. The importance of such feedback loops is also documented in the double-loop learning procedures research framework developed by Mahoney and Sanchez (2004). Within this context, a practical feedback loop is created by discussing the identified problem and proposed solution design with managers of companies that experience such or similar problems. This is necessary to assure the relevance of the identified problem and to judge upon the credibility of the proposed solution concept. The scientific feedback loop is instated by presenting the research design and relevant outcomes to the research community via international conferences or journal publications. The refereeing process within academic publications often fosters further clarification of problems, tools and proposed solutions whilst validity of the analyses is also reviewed. Any obtained tribute, reaction, criticism or advice expands the scientific relevance, validity and general applicability of the research. Figure 3.2 below visualises the feedback flow in between proposed solution design, practical implications and academic exposure/publications.

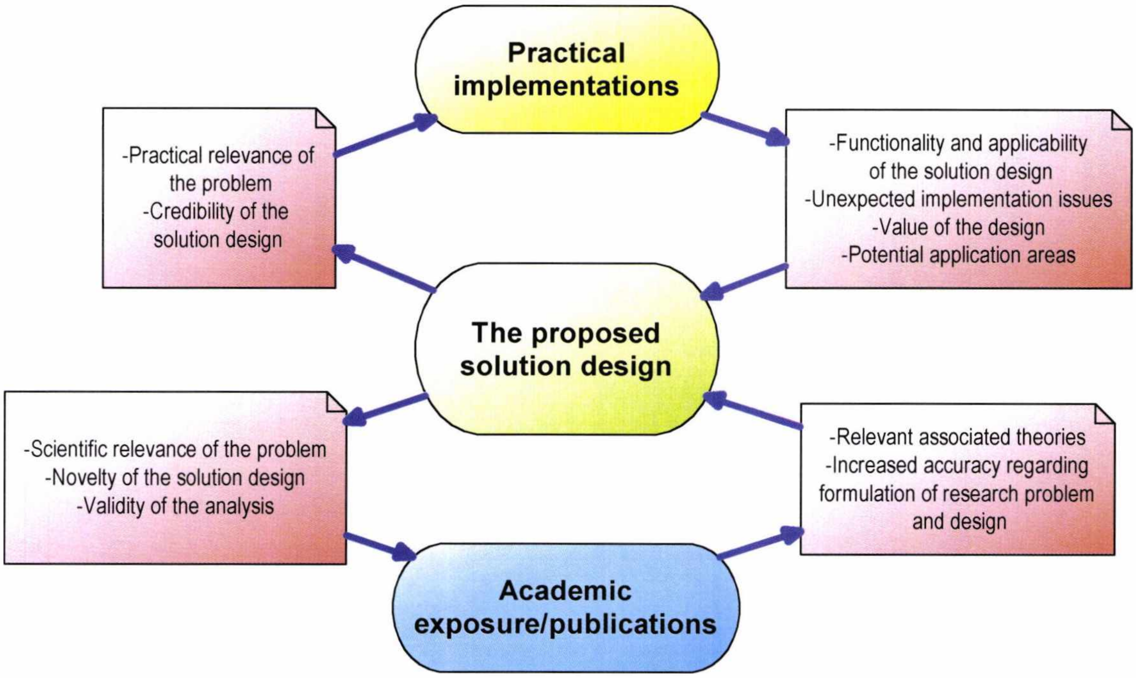


Figure 3.2: Feedback-loops within Innovation action research (Kaplan, 1998)

Overall, the research framework presented in this thesis heavily relied on such feedback loops as outlined above to obtain inspiration and direction and to ensure sufficient relevance, validity and verification of the study. Consequently, continuously cooperating with practitioners and using real life information was an integral part from the very beginning. Considering academic exposure, results from the research were presented at about 10 conferences and published within three journal articles and four conference proceedings (Thron *et al.* 2004, 2005, 2006a, 2006b, 2006c, 2007a, 2007b).

4. Modelling framework and methodology

After having sketched out research context, objectives and solution approaches within Chapter 3, this chapter presents a wide range of information about the supply chain frameworks of the participating companies. Thereafter, we engage in formulating conceptual models and discuss the used production, distribution, sales, demand and further market data that constitute the basis for the forthcoming systems-modelling and result analyses. In the final sections we describe the actual model built within a simulation software environment and discuss issues regarding validation and verification. Overall, the structure of this chapter follows the steps of the general simulation study methodology outlined by Brooks and Robinson (2001), Robinson (2002) and Pidd (2004) which is visualised in the following diagram.

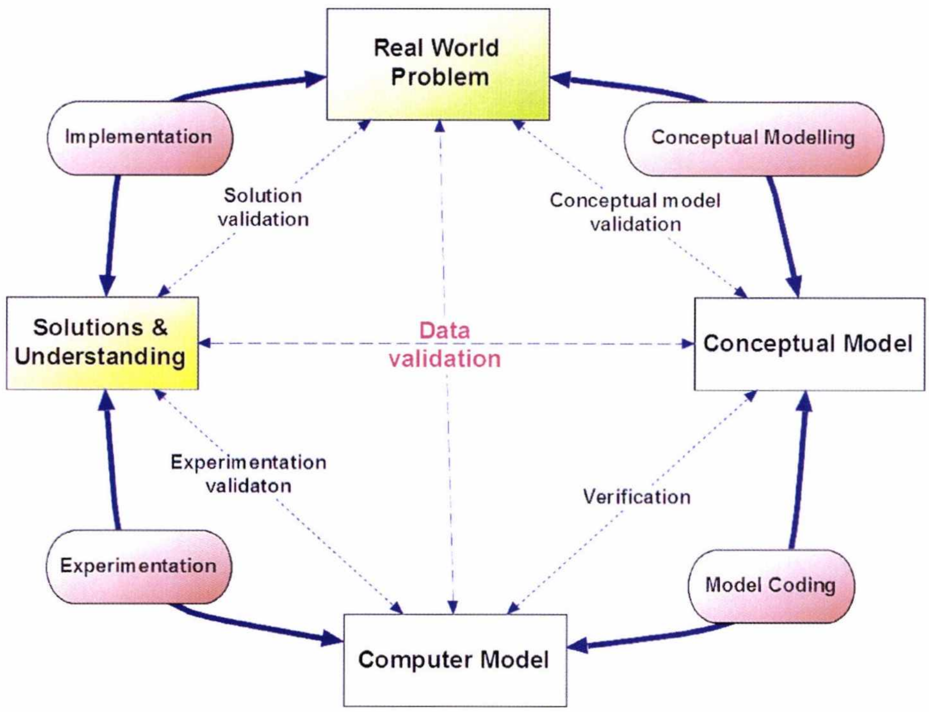


Figure 4.1: Stages and activities in a Simulation study according to Brooks and Robinson (2001)

4.1 Background information about the investigated supply chain frameworks

Within this section we will present a wide range of background information to foster a better understanding of the investigation framework. We will thus introduce each of the three supply chain frameworks and give some specifics about the products used for the investigation.

4.1.1 Common characteristics

The investigated supply chain frameworks are somewhat similar considering their overall structure (see Figure 4.2 below). All three feature three main suppliers of pre-processed material, a small or medium size food manufacturer and four major retail-customers. All customers receive delivery via distribution centres that supply various retail outlets thereafter. There is no direct shipping to retail outlets.

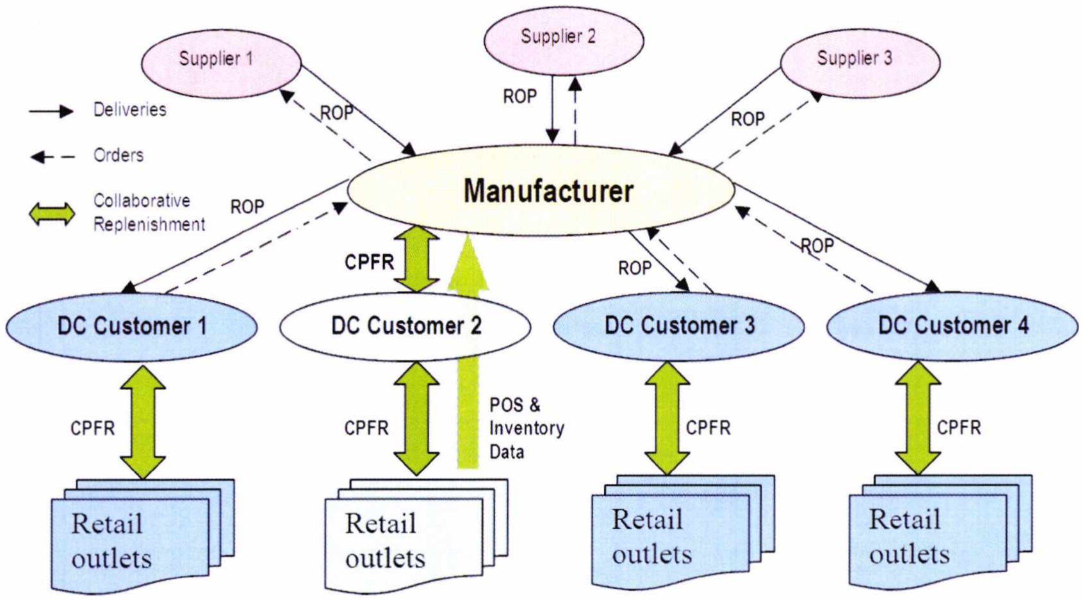


Figure 4.2: Outline of the modelled Supply Chain (single collaboration customer)

Considering the replenishment of the customers' distribution centres, deliveries are either scheduled via non-collaborative fixed or flexible date order policies (ROP) or incorporate some sort of collaborative replenishment (e.g. CPFR). The numerous retail outlets are commonly connected with their distribution centre via a highly integrated replenishment system. Actual replenishment procedures are still very versatile ranging from purely manual reorder to more advanced automated store ordering (ASO) or most commonly computer assisted ordering (CAO). The actual level of automation of ordering processes at store level typically varies. Within the investigated frameworks there are three primary methods for ordering products to retail outlets: completely manually, assisted ordering and automated ordering. This variety seems to go along with general industry standards as described by Garry (2004).

- Manual ordering – orders are placed by store clerks when refilling the shelves, typically via an electronic hand-held device
- Assisted ordering – computer generates order suggestions based on inventory level and POS data which have to be acknowledged or amended by store personnel
- Automated ordering – computer generates and executes orders based on inventory, POS data and demand forecasts

Although the individual methods seem very distinct, perceived differences are rather blurry in practice. Assisted ordering is most common amongst the retail outlets investigated within this research project. Nevertheless, even stores that feature an automated ordering system do not seem to have any superior performance records compared to assisted ordering. There is nevertheless a significant difference between pure manual ordering compared to the more technological supported methods. Overall it should be most reasonable to assume assisted ordering as the default method of store ordering. The actual ordering performance seems to heavily depend on certain human factors since although ordering systems have become more automated, they still depend on reasonable human intervention to operate effectively. The actual store delivery is on a daily request basis with average replenishment intervals approximately once a week for a particular product.

4.1.2 Supply Chain Framework 1

The supply chain framework evolving around manufacturer 1 is structured as presented in Figure 4.2 above. This SME manufacturer has an annual turnover of 150 million Euros and produces a variety of mustards, ketchups, spicy-sauces and salad dressings. The product under investigation is a special kind of spicy mustard which is one of the company's key products. The product comes in a standard package and size and there is no substituting product from the same company in case of non-availability. Hence out of stock occurrences directly lead to lost sales. The production is commonly carried out on weekdays operating two shifts a day. Altogether there is a standard weekly output of produced mustard-jars which can be reduced stepwise down to as low as zero in times of extensive inventory and can be increased by up to 50% over standard output in times of extensive demand. Production planning horizon is one month in advance with a general weekly production level setup on Monday morning. Production typically runs rather smooth without significant risk of machine breakdown. Due to the nature of the product, storage of ready-made items is somewhat constrained since from the point of bottling the product has to stay cool and dark and needs to be consumed within a period of three months. Inventory at the factory distribution centre is set to a rather lean level due to limited storage capacity and the somewhat perishable nature of the product. The average held ready made goods inventory equals about two weeks demand. For the particular product under investigation, raw materials are produced and stored in-house apart from the packaging. Since consistent supply of these are not critical there is no perceived problem within the supply process of the manufacturing company. Within the original distribution outline, all four customers are replenished via a non-collaborative fixed-date, fixed-interval and flexible quantity ROP approach. Thus the reordering occurs at particular pre-defined weekdays whilst the quantity is set up by each retail-company according to forecasted demand within the forthcoming inter-replenishment period. The default reorder interval for all four customers is two weeks according to the following order timetable: Customer 1 reorders each Friday of an even week, Customer 2 reorders each Tuesday of an even week and Customers 3 & 4 order each Monday of every odd week. The ordered quantities of each retail-company are defined according to anticipated demand within the two-week inter-replenishment period. The level of demand is obtained via a retailer-internal forecast and adjusted by the actual stock level at the distribution centres at the time of ordering to avoid overstocking but retain a certain level of safety-stock as well. The average inventory held at the retailers' distribution centres varies but is commonly between 10-15 days of standard demand.

The considered product is frequently promoted via price promotions as well as secondary placements. There is some additional event-sponsoring but apart from that no further advertisement activities. Price promotions usually consist of a price discount of about 10%-20% accompanied by a product placement within the weekly sales brochure of the particular retailer. Secondary placements represent additional sales space for a limited time period, usually at particularly high-profile spots within stores. Within the investigated region and for the particular retailers, the product is promoted by about four price promotions and three secondary placements per year. Type, time and scope of the promotions are typically pre-agreed at some point of the year but especially timing and scope commonly change at short notice, often without notifying the manufacturer. The product itself seems to be quite immune against competitor promotional activities due to superior quality, upper-price range positioning and strong loyalty of customers. Apart from promotions, the demand of product 1 is strongly affected by seasonal deviations with particular high sales in spring and early summer and around Christmas. In addition there seems to be some weather dependency during summer since within hot periods sales increase noticeably whilst they tend to weaken during cooler periods. The market share of the product is somewhat increasing whilst the overall market size is slightly diminishing over the observed timeframe (2001-2004). The transportation between manufacturer and retailer is carried out by 3rd party logistics companies that charge a weight dependent fee for each transported pallet. Various discounts apply if the transported quantities reach certain levels. Transportation has to be scheduled several days in advance with premium fees applying in case of short-term adjustments. The minimum fill rate to fulfil a particular order is typically about two third of the original ordered quantity. Thus orders will commonly only be carried out if they cover at least about 65% of the requested quantity. In case actual inventory held by the manufacturer is not sufficient to fulfil several incoming delivery requests, orders are carried out on a first come-first served basis. Fill-rates are commonly reduced within such cases (not below 65% though) to assure fulfilment of temporary postponed orders within a reasonable time. The four retail customers considered in the supply chain framework account combined for about 75% of total demand of the product. Out of this total quantity, 26% go to retailer 1 and 31%, 24% and 19% to retailers 2, 3 and 4 respectively. Traditionally, the manufacturer relies on historic order records to estimate demand rather than utilising some kind of actual sales data to improve forecasts.

4.1.3 Supply Chain Framework 2

The second investigated SME manufacturer is a pasta-producer which specialised in producing normal and fresh high-quality pasta in various forms, sizes and flavours. The company has an annual turnover of 60 million Euro, generating most sales from traditional dried pasta but also recently engaged into the developing fresh pasta market which promises substantial growth rates. The particular product investigated is 10mm wide noodle-shape dry pasta which comes in a 250g pack and is one of the best selling items of the company. Apart from cash & carry markets, the product comes only in one package size. Although the company also sells similar styled noodles which are either smaller (3mm) or wider (20mm), customers clearly prefer the standard size and non-availability thus generally leads to lost sales. The production of the item needs special equipment due to its unusual shape. Thus the particular processing line can only be used for the particular kind of noodles (3mm, 10mm and 20mm). Production runs over six days a week in three shifts during weekdays and two shifts on Saturday. On Sundays there is no production since machines need to be cleaned and maintenance is carried out. The weekly production output can be adjusted according to actual demand with no lower bound but an upper limit of 37% above standard output. This upper limit is achieved via extending the production of the main item (10mm noodle) at the cost of the other two (3mm and 20mm noodle) and should thus not be exploited for a longer period. Production planning horizon is three weeks in advance with weekly production levels being determined on Monday mornings. Typically there are no significant machine breakdowns recorded due to extensive maintenance once a week. Overall the storage of the items is rather uncritical since expiration period is about one year. Nevertheless, due to a wide assortment of products and limited storage facilities the company cannot afford extensive inventory. The average held stock of the investigated product throughout the year is about 10-12 days of average demand. In case of simultaneously incoming batched orders this frequently leads to delayed delivery. Altogether there are three major suppliers of raw or pre-processed material namely fresh eggs, durum wheat flour and packaging. The supply of fresh eggs is a common problem but in times of shortages the key products are prioritized. Therefore no significant production impacts were recorded for the considered product. Supply of durum wheat flour and packaging is generally not a problem since they are easy to stock in larger quantities. The default distribution framework evolves around a non-collaborative flexible order-date, target interval and flexible quantity ROP approach. Thus reordering is not bound to particular points in time but is triggered by retailers' DCs inventory reaching a predefined lower-limit. The actual reorder barrier is variable and is set up according to forecasted demand. Altogether reorder intervals are agreed to be about two weeks whilst the order-quantity is determined by each retail-company according to estimated demand within the forthcoming two weeks inter-replenishment period. Due to the flexible nature of the reordering process the necessary safety stock at DCs can be lower compared to the fixed order date framework since an urgent reorder request must not be delayed to match the pre-agreed order date but can be placed at any time. Due to this ordering behaviour the manufacturer is vulnerable towards orders coming in unexpectedly, batched and often simultaneously at particular weekdays or times within a month which leads to frequent delivery delays. The considered product is frequently promoted via price promotions as well as secondary placements. There is no independent media advertisement of any kind. Price promotions usually involve a 10%-25% price reduction and depending on the retailer combined with a placement in advertisement leaflets and newspapers. Secondary placements are carried out providing additional sales space at high profile spots within stores. These are sometimes combined with product-test tasting facilities to attract supplementary attention. For the particular region there are commonly three to four price promotions and about four secondary placement events carried out within each retail chain. Promotion timings are not synchronised being spread out over the year with no particular pattern. Timing schedules are roughly outlined between manufacturer and individual retailers once a year but are rarely adhered to. Due to its upper price high quality positioning, the product is not very much exposed to competitive influence. The small size makes it ideal for senior citizens or single people who prefer single use packages. Seasonal sales deviations do not appear to be very extensive nevertheless there is an obvious distinction between low demand in summer and high demand in winter, particularly in December and January. Other influences are due to fashion-food trends (dietary waves in spring, light food in summer) which are hard to predict but have a noticeable sales impact. The product's market share is stable whilst the market altogether has shrunk by about 10% over the investigated timeframe (1999-2004). Transportation between manufacturer and retailers is carried out by 3PLs (third party logistics service providers) that charge a certain fee for each transported pallet independent of its weight. Various discounts apply if the transported volume reaches at certain levels. Transportation has to be scheduled several days in advance with premium fees applying in case of short-term adjustments. The minimum fill rate is assumed to be about 75% of the original ordered quantity but can be adjusted if necessary. In case actual inventory is not sufficient to fulfil several incoming delivery requests, orders are carried out on a first come-first served basis. This applies with the exception for a particular retailer which is the key customer for the manufacturer. Thus orders of this customer are commonly prioritized. In case of insufficient stock, fill-rates are commonly reduced within such cases (not below 50% though) to assure fulfilment of temporary postponed orders within a reasonable time. The four retail customers considered in the supply chain framework account combined for about 73% of total demand of the product. From this total quantity 24% go to retailer 1 and 46%, 21% and 9% to retailers 2, 3 and 4, respectively. Considering internal demand planning, the manufacturer uses historic sales data to generate seasonal sales deviation factors for each sales-region on a monthly basis. Promotional impact analysis is carried out as well but rarely feeds back into production scheduling due to unreliable promotional schedules that are often changed by the retailers without prior warning. Overall production scheduling mostly depends on historic order records to estimate demand.

Collaborative replenishment pilot study

Within supply chain framework 2, the manufacturer and its largest customer recently initiated a collaborative replenishment testing project. Within this project, both companies agreed to maintain a joint demand forecast for the involved products which forms the basis of replenishment decisions. The actual collaboration outline is as follows:

1. Retailer provides historic sales data which form the basis of a detailed seasonal factor analysis
2. Promotional activities are laid out clearly and fixed schedules are agreed upon
3. According to previous sales data and personal expertise of management a promotional impact analysis is carried out to estimate how the various promotional activities affect sales of the involved products
4. OMP Planner software (OM Partners, 2007) is installed at the manufacturer to handle forecast and order generation process electronically, the system is connected to the retailers' ERP systems
5. Retailer provides daily updated sales and inventory data that feed into the demand forecast

Within this collaboration outline the manufacturer has the task to generate and maintain a demand forecast predicting the retailers' demand on the basis of seasonal factors, general market trends, forthcoming promotions and short-term trends based on recent POS data. This forecast is forwarded on a weekly basis to the retailer to be acknowledged or adjusted if necessary. On the basis of this demand forecast and actual inventory data, the software recommends replenishment points. These are acknowledged or adjusted by the manufacturer and replenishment quantities are assigned depending on available inventory and expected orders from other retailers. Finally order dates and quantities are determined and proposed to the retailer who can accept them or request changes.
The project resulted in encouraging outcome to some extent but overall did not achieve the level of improvement that was anticipated. On the positive side the accessibility of historical sales data allowed for a detailed seasonal factor analysis which improved production planning. The project also succeeded in extending previous knowledge about the impact of promotional activities. Another beneficial outcome was the short and medium term market trend analysis that was carried out as part of the forecasting procedure. In particular, historic sales quantities and demand signals from a selected group of retail outlets were captured and trends highlighted via regression analysis.
Apart from these positive aspects, the collaboration initiative failed to reach the high level of expected improvements due to missing support or a lack of transparency within the retailer's ERP system. The insufficient forecast accuracy as one of the main issues was for example due to the missing forecast adjustment required of the retailer in case of unreported changes. These were in particular last minute amendments considering the scale and scope of a promotional activity which directly impacted on the actual quantities required to fulfil promotional demand. Overall the manual adjustment activities were commonly neglected or carried out without due diligence.
However, the collaboration initiative surely advanced the demand forecast accuracy and as a result of that production scheduling was improved. Additionally the number and extent of delayed deliveries could be reduced noticeably. Overall collaboration can reveal its true potential as long as it is carried out with the necessary diligence and complying with crucial operations-alignment procedures is enforced. The project also showed that there is some significant improvement potential from information exchange even though a higher level of planning synchronisation cannot be achieved.

4.1.4 Supply Chain Framework 3

The third SME manufacturer that became part of the investigation produces a range of tinned vegetables and fruit including pickled gherkins, cabbage, pepper, apple dessert, cucumber snacks etc. The company has an annual turnover of about 70 million Euro and can rely on a strong local customer base. For the investigation we chose once more one of the key products due to their major importance since over 80% of turnover of most SMEs is commonly generated by very few or even single products (SME Database, 2006). The actual product chosen was the jar of horseradish flavoured pickled gherkins. This product is a speciality within the geographical region of production but has also many fans elsewhere. The product comes in two sizes but the larger jar often can only be found in cash and carry environments. The production of the item is somewhat unusual since the main ingredients (cornichons and horseradish) are harvested throughout a rather short period (summer) and then stored to suffice an entire year's demand. Packaging (glass jars, lids, labels) is sufficiently provided by long-term contracted suppliers and is commonly not a reason for shortages. For the final product, the ingredients (cornichons, horseradish, vinegar and spices) are mixed in the jar which is then sterilised/homogenised in a heating facility and finally locked air-tight and labelled. This last minute mixing and sealing process gives the product its special taste and look since most competitors simply fill the jar with pre-processed brine instead which is easier, cheaper and ensures a longer durability. The in-jar mixture of fresh ingredients nevertheless gives the product its superior quality but leads to an overall reduced durability of only about three months. Since the processing and the packaging facility are also used for many other products of the company weekly production has to be determined in advance. Production runs over five days a week in two shifts. The weekly production output can be adjusted according to inventory held and forthcoming demand. Altogether there is a minimum production level of 40% of the standard weekly output due to the fresh preparation of the brine and ingredients (minimum batch sizes apply). The upper limit can be as high as 200% of standard output but only for a limited time since this would restrict processing other products. Production planning is four to five weeks in advance with production scheduling being determined over each weekend. Commonly there are no major threats of machine breakdown. The storing facilities are commonly sufficient but storage time is intended to be kept at a minimum due to the perishable nature of the products, energy cost (facility must be kept above 15 degrees Celsius all the time) and expanding range of the manufacturer's assortment. The inventory held on average is sufficient to buffer about 2-3 weeks' standard demand. Similar to the products investigated for manufacturer 2 the default distribution framework evolves around a non-collaborative flexible order-date, target interval and flexible quantity ROP approach. Thus reordering is not bound to particular points in time but is triggered by DC inventory reaching a predefined lower-limit. The actual reorder barrier is variable and is set up by the retailers according to forecasted demand. Default reorder intervals are either one or two weeks depending on customer. Whilst the two dominant customers receive delivery each week, the less important ones are commonly re-supplied every second week. The actual order-quantity is determined by each retail-company according to estimated demand within the particular forthcoming inter-replenishment period.

The traditional inventory policy of the manufacturer is to keep somewhat extensive stock for class A inventory items. The investigated product group in particular has an average stock level of 13-20 days of standard demand. The considered product is frequently promoted via price promotions as well as local advertisement campaigns including radio and newspapers. Price promotions usually involve a 20-30% price reduction depending on the retailer, often combined with placements in advertising leaflets. Price promotions have a substantial sales impact resulting from forward buying of regular customers and additional demand from irregular customers. Apart from price promotions there are also frequent secondary in-store placements combined with test-tasting presentations. Overall there are commonly 6-7 price promotions and 2-3 secondary placements a year depending on the considered retailer. Overall the product is also vulnerable to price promotions of competitor products. These have a substantial sales impact although products offered by competitor brands are somewhat dissimilar in taste, price and durability. Seasonal sales deviations for the product are remarkable with particular high spots during Christmas, Easter, early summer and early autumn. There also seems to be some weather related influence which has not been investigated previously in detail. Within recent years the market-share of the company is on a significant upturn. Within the investigated period (2000-2004) market share was increased by about 10% annually. The overall market showed some up- and downturns within this period but overall it remained rather stable. Transportation between manufacturer and customers used to be carried out by a company truck-fleet but has recently shifted towards third party logistics providers which charge a certain fee per 100kg unit delivery. Transportation used to be scheduled one or two weeks in advance but due to utilising 3PL companies this can be arranged on a shorter time basis at a premium rate. In case of incoming order requests exceeding the inventory held, the two larger customers receive prioritized delivery. The minimum fill-rate is sought to be at least 70% of the standard order quantity but can in times of insufficient stock be reduced (not below 50% though) to assure fulfilment of temporary postponed orders within a reasonable time. The four retail customers considered in the supply chain framework account combined for about 68% of total demand of the product. From this total quantity 14% go to retailer 1 and 36%, 33% and 17% to retailers 2, 3 and 4 respectively. Considering the internal demand forecast, the manufacturer relies on safety inventory, production capacity adjustment and backorders to cope with demand uncertainty. No seasonal deviations or promotional activity effects are commonly included in production scheduling.

4.2 Conceptual modelling

Following the solution proposal outlined in Chapter 3, the goal in this section is to lay out a conceptual model that is capable to investigate the identified shortcomings and proposed improvement techniques whilst at the same time taking into account the individual framework parameters and information of the three manufacturers introduced in section 4.1. In the following subsection we will thus outline the purpose of the model, describe input and output parameters, decide about the content, and define framework assumptions and reasonable simplifications. Based on this we will furthermore present graphical representations of the proposed model in the form of flow-charts.

4.2.1 Purpose of the model

The main purpose of the model is to investigate various improvement scenarios within the three supply chain frameworks outlined above. The model should represent a simplification of the actual process flow but still be sufficiently detailed to allow drawing realistic conclusions from the results. Overall the model must be capable to address the following issues:

1. Realistically represent the actual state of the three supply chain frameworks including key echelons, processes and participants to foster a high level of understanding of the operations within the system.

2. Determine the impact of advanced information integration, e.g. possible advantages arising from utilising actual market data and incorporating gained knowledge into supply chain processes such as demand, production and distribution planning.

3. Assess the effect of collaborative planning forecasting and replenishment, in particular the potential benefits from active collaboration between manufacturer and retailers including issues such as planning forthcoming business activities (e.g. promotions), sharing common demand forecasts and independent inventory replenishment (VMI).

4. "What if" scenario analysis investigating the effect on the entire system caused by varying levels of inventory, different types of reordering behaviour and customer prioritization policies.

5. Analysis of heterogeneous distribution setups including a wide variety of different degrees and methods of collaboration between manufacturer and individual retail customers.

4.2.2 Model Inputs, Outputs and Content

After the objectives have been laid out we need to consider the content of the model itself. In the first step we will generate a pool of possible and necessary input and setup parameters that will be adjusted throughout the process of conducting the wide range of analyses to investigate the issues outlined before and address the study's objectives. At the same time we need to define useful output data that allows us to sensibly evaluate the impact on the system due to the changes applied to the input parameters. Such system-performance measures need to cover all aspects of possible effects resulting from implemented changes to enable a comprehensive interpretation of the output data and identify interdependencies between certain variables.

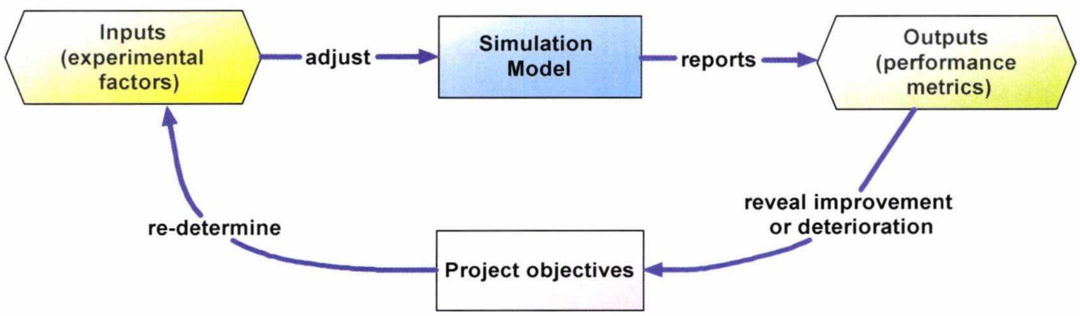


Figure 4.3: Feedback flow within the modelling process (Robinson, 2002)

Apart from determining reasonable input and output factors we also have to define the required model content. Altogether the model needs to contain all major elements of the supply chain frameworks outlined before and must be capable to utilise the identified experimental factors (input variables) to allow for comprehensive performance reporting (output data). The general process is outlined in Figure 4.3.

Model Inputs (experimental factors)

In order to present the necessary input parameters we identified the main decision making echelons within the three investigated frameworks and assigned experimental factors to each of them. The identified echelons were: Suppliers of raw/pre-processed material, manufacturer, retailers' distribution centres, retail outlets, consumer demand. These five main echelons can be broken down into the following eleven activity blocks:

1. Transportation from raw/pre-processed material suppliers to manufacturer,
2. Raw/pre-processed material order planning & execution by manufacturer,
3. Production planning by manufacturer,
4. Delivery planning and execution by manufacturer,
5. Transportation from manufacturer to retailers' distribution centres,
6. Order planning and execution by retailers' distribution centres,
7. Delivery planning and execution by retailers' distribution centres,
8. Transportation from retailers' distribution centres to retail outlets,
9. Order planning and execution by retail outlets,
10. Point of sale,
11. Consumer demand.

For each of these 11 activity blocks we identified a variety of input factors that could potentially be of importance to draw conclusions about the project objectives.

1. Transportation of raw/pre-processed material from suppliers to manufacturer

- Transportation time
- Transportation cost

2. Raw/pre-processed material order planning & execution by manufacturer

- Order frequency and standard quantity
- Active/passive replenishment (VMI or ROP)
- Reorder trigger
- Inventory capacity
- Minimum/maximum deliverable quantities
- Fill rate adjustment factor (to ensure sufficient quantity in times of shortages)
- Inventory dispatch policy
- Materials requirement forecast approach

3. Production planning by manufacturer

- Production capacity
- Target average inventory
- Inventory-target execution policy
- Safety stock level
- Inventory capacity
- Planning horizon
- Demand forecasting approach

4. Delivery planning & execution by manufacturer

- Delivery prioritization rules
- Active/passive replenishment
- Reorder trigger
- Minimum fill-rate
- Minimum/maximum deliverable quantities
- Inventory dispatch policy
- Product expiration schedule
- Demand forecasting approach

5. Transportation from manufacturer to retailers' distribution centres

- Transportation time
- Transportation cost

6. Order planning & execution by retailers' distribution centres

- Active/passive replenishment
- Reorder-trigger
- Minimum fill-rate
- Minimum/maximum deliverable quantities
- Fill rate adjustment factor (to ensure sufficient quantity in times of shortages)
- Safety stock level
- Inventory capacity
- Demand forecasting approach

7. Delivery planning & execution by retailers' distribution centres

- Delivery prioritization rules
- Active/passive replenishment
- Reorder trigger
- Minimum fill-rate
- Minimum/maximum deliverable quantities
- Inventory dispatch policy
- Product expiration schedule
- Demand forecasting approach

8. Transportation from retailers' distribution centres to retail outlets

- Transportation time
- Transportation cost

9. Order planning & execution by retail outlets

- Active/passive replenishment
- Reorder-trigger
- Minimum fill-rate
- Minimum/maximum deliverable quantities
- Fill rate adjustment factor (to ensure sufficient quantity in times of shortages)
- Safety stock level
- Inventory capacity
- Demand forecasting approach

10. Point of sale

- Transaction capacity
- Inventory dispatch policy
- Product expiration schedule

11. Consumer demand

- Consumption characteristics

The above list is not necessarily exhaustive but should give a comprehensive overview about possible input parameters. The actual way and detail of implementation will depend on the necessary level of complexity which will be considered later in this chapter.

Model Outputs (performance metrics)

There is a wide variety of possible supply chain performance measurement classification as it was outlined within Chapter 2. The decision upon which measures to choose and how to group them will thus be made having the particular supply chain frameworks under investigation and the stated objectives in mind. For a rough segmentation of possible output data, applied performance metrics can be classified into three groups.
Firstly there is ***planning accuracy*** which includes measures to judge about efficient resource and capacity planning (production capacity utilisation, average and maximum inventories, production and delivery volatility) or demand prediction accuracy (demand forecast deviation, demand variability amplification). The second group is formed by the ***distribution related metrics*** where the main focus lies on effectiveness and efficiency of distribution. Particular metrics would be number of deliveries; non-, short or critically delayed deliveries; perfect deliveries (100% fill-rate and on time); order lead time; fill rate.
Finally ***customer service performance metrics*** are typically concerned with out of stock times at retail level and thus not potential but direct loss of sales. Individual and accumulated service-level or service-level gaps, as a measure of how many percent of customers' demand could (not) be fulfilled throughout a period of time, are thus the main overall indicators how well the entire supply chain operates. Other metrics within this group are average impact and duration of out of stock incidents or percentage of perfect weeks (100% service level). Most of these metrics must be obtained for each stage of the supply chain (manufacturer, distribution centres and retail outlets) and for each individual stream (each of the four modelled retail channels). More details about individual metrics used and the way they were actually measured will be given in section 4.5.4.

Model Content

Deduced from the common structure of the three individual supply chain frameworks we identified the most essential entities that are necessary to be implemented in the model. These evolve around the five modelled stages within the supply chain (suppliers, manufacturer, distribution centres, retail outlets and consumer demand). Although the actual level of underlying complexity varies greatly in between the various entities, all of the ones displayed in Figure 4.4 are accounted for within the model.

Entities included

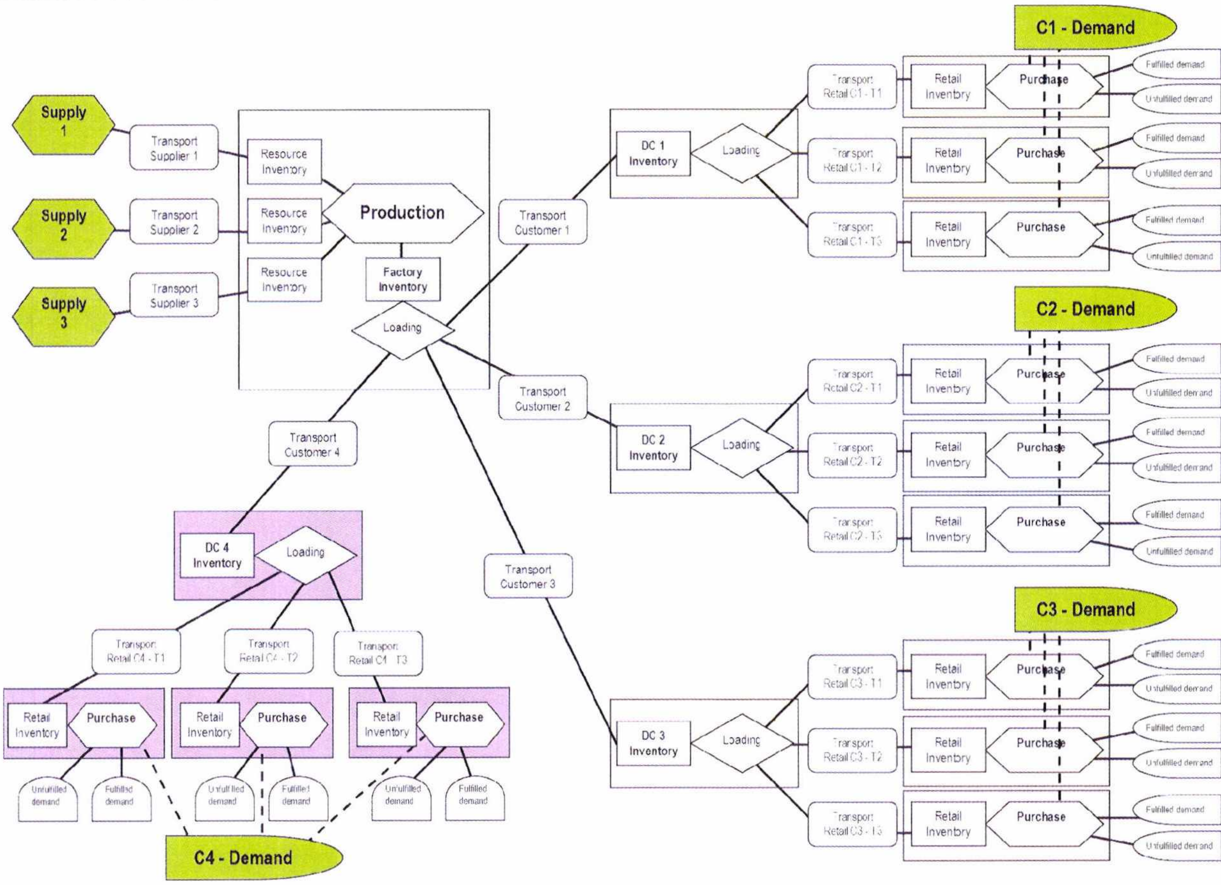


Figure 4.4: Ninety distinct operational entities included in the conceptual model

Figure 4.5 shows the logic flow process of order placement and replenishment throughout the various echelons of the system. The replenishment flow is triggered by consumer demand on the left hand side and is carried backwards through the system to eventually trigger production adjustments. Demand forecast and order prioritisation are represented as black-box processes but are further outlined in section 4.5.3.

Logic Flow

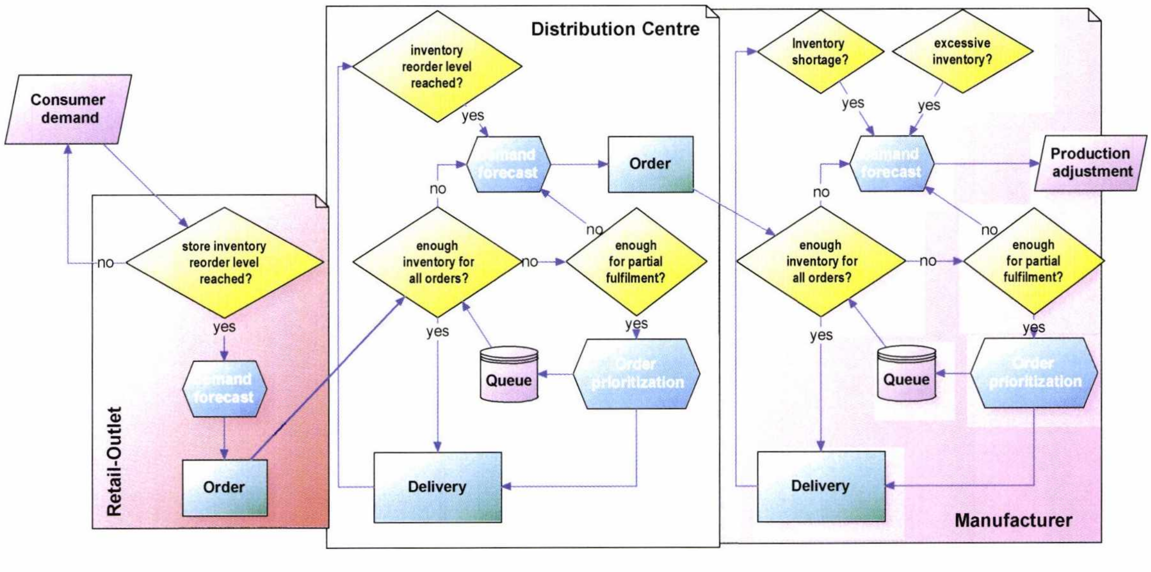


Figure 4.5: Logic flow of reordering activities

Item assembly and disassembly flow

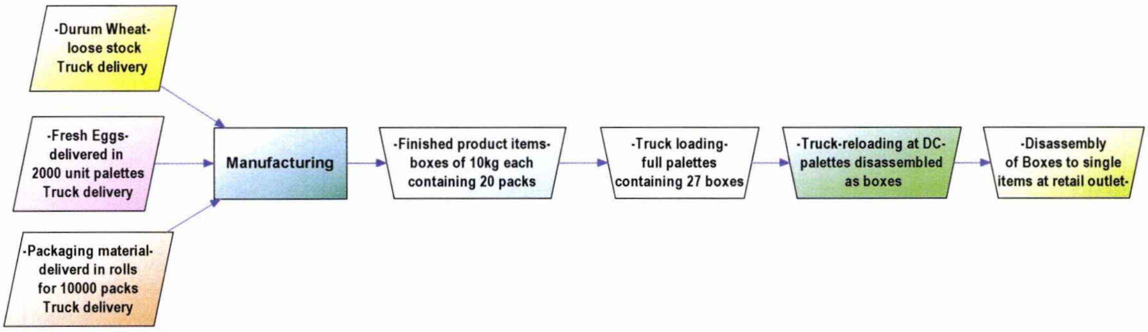


Figure 4.6: Item assembly and disassembly process - example from Supply Chain framework 2

Figure 4.6 describes the assembly and reassembly process of product units throughout various stages of the supply chain.

4.2.3 Model assumptions and simplifications

It is a profound principle in simulation modelling to model the minimum scope and level of detail necessary to achieve the project's objectives (Brooks and Robinson, 2001). Some of the benefits of a simplistic model are shorter development time, ease of understanding, fewer errors and faster runs. Moreover, validation and verification should be much simpler to carry out. In order to make the model as simple as possible we used the approach of successive inclusion where we added entities and logic to the model up to a point where any further addition would not result in any major increase in accuracy or realism that would support achieving the investigation objectives. As a result of that there were a number of simplification assumptions made in order to keep the model understandable and manageable to run.

1. Even though they are part of the conceptual as well as the final simulation model, the investigation does not discuss any issues arising out of the relationships between the particular manufacturer and its suppliers of raw material. Data that is used to run this part of the system (supplier order and transportation) is rather taken as a given. Hence the model is set up in a way to ensure sufficient supply of raw materials.

2. The investigation does not attempt to carry out detailed cost impact considerations due to adjusting existing supply chain frameworks. Hence the analysis is focused on improving supply chain efficiency through improving outlined performance metrics but resulting monetary implications will not be considered.

3. Transportation times are set to fixed values representing the average duration obtained from historic data. Thus possible delays within transportation such as breakdowns, traffic congestions, weather etc. is not considered within actual simulation runs.

4. The large number of retail outlets is represented by three demand groups (distribution tours) within each retailer's distribution framework.

5. The demand data are approximated on the basis of actual sales data obtained from the retailers over a 3-5 years timeframe. Since actual sales data does not include dissatisfied demand, the overall demand had to be approximated taking out of stock records and out of stock impact estimations at hand.

6. Various activities within the model are carried out in zero time even though in reality they would surely need a certain duration. Such activities are truck loading and unloading (average time is included in total transportation time), movement of goods within and between certain entities (e.g. production to inventory, inventory to loading, inventory to point of sale etc.)

7. The retail outlet entities do not model actual store shelves. Incoming consumer demand is thus directly connected to a common storage facility that contains all items within a store.

8. No breakdowns or human errors are included in the model by default. Activities are run with historic data values that exclude particular breakdown events.

9. The various collaboration scenarios (fixed order date ROP, flexible order date ROP, VMI, CPFR) are approximations of decision flows and operational procedures within typical real-life systems. Whilst the core elements of these replenishment approaches are incorporated, less significant details are omitted.

10. The various retail outlets in the model are by default connected with their distribution centre via collaborative planning and forecasting as well as a vendor managed inventory replenishment system and automated store ordering. The model thus assumes the actual ordering procedure at store level as blackbox. The actual process of store ordering is very complex and can be carried out in various other ways (manual, assisted, automated etc.) with very diverse and unpredictable degrees of efficiency.

The simplifications and framework assumptions outlined above represent only the most apparent cases. Additionally, there will be necessarily a certain degree of implicit simplification due to the very nature of modelling as outlined above.

4.2.4 Replenishment policies to be incorporated into the model

Rounding off the framework of simplifications and assumptions, this section will define in what way the wide range of practically existing distribution and collaboration policies are represented in the model and in the analysis. Following previous descriptions about various forms and stages of reordering policies, distribution setups and collaboration we will define four main settings as they appear within the investigated frameworks. These are fixed order date ROP, flexible order date ROP, VMI and CPFR. The forthcoming overview outlines possible characteristics of each approach and the way they are thought to be implemented in the model. Altogether, the four categories go along with common practice within the investigated supply chain frameworks and should be representative enough to distinguish different stages within supply chain collaboration. Since the general concepts behind the four replenishment procedures have already been laid out in previous chapters we will focus here on the way each of them is represented in the model.

Non-collaborative, single echelon focused delivery policies

The two policies within this group (fixed and flexible order date ROP) represent a very old fashioned non-collaborative business environment where supply chain echelons operate predominantly in isolation. Table 4.1 gives an overview about typical characteristics of the non-collaborative, single echelon focused delivery policies implemented in the model.

	Fixed order date ROP	Flexible order date ROP
Background	- Date of delivery is predetermined at a fixed interval (once a week or once a fortnight) - Requested quantity varies	- Date of incoming order/delivery unknown - Requested quantity unknown
Data availability	- Only historic order data	- Only historic order data
Collaboration activities	- Annual arrangements to re-adjust demand volume, delivery timings and extent of promotional activities	- Annual arrangements to re-adjust demand volume, delivery parameters and extent of promotional activities
Demand Prediction parameters	- Historic sales records - individual judgment/market development expectations	- Historic sales records - Individual judgment/market development expectations
Advantages	- Orders can be anticipated - Standard delivery time-slot can be assigned - Resources can be scheduled	- System is more responsive in times of shortages since replenishment can be requested at any time

Table 4.1: Characteristics of non-collaborative delivery cases

The echelon-flowcharts presented in Figure 4.7, illustrate the considered range of strategic decision parameters as well as operational input and output figures in case of operating a non-collaborative replenishment system. The outline follows the proposed simplified supply chain framework, whereas distribution centres always collaborate with their retail outlets via CPFR and automated store ordering. Hence only the distribution between manufacturer and retailers' distribution centres is affected by a lesser or higher degree of collaboration.

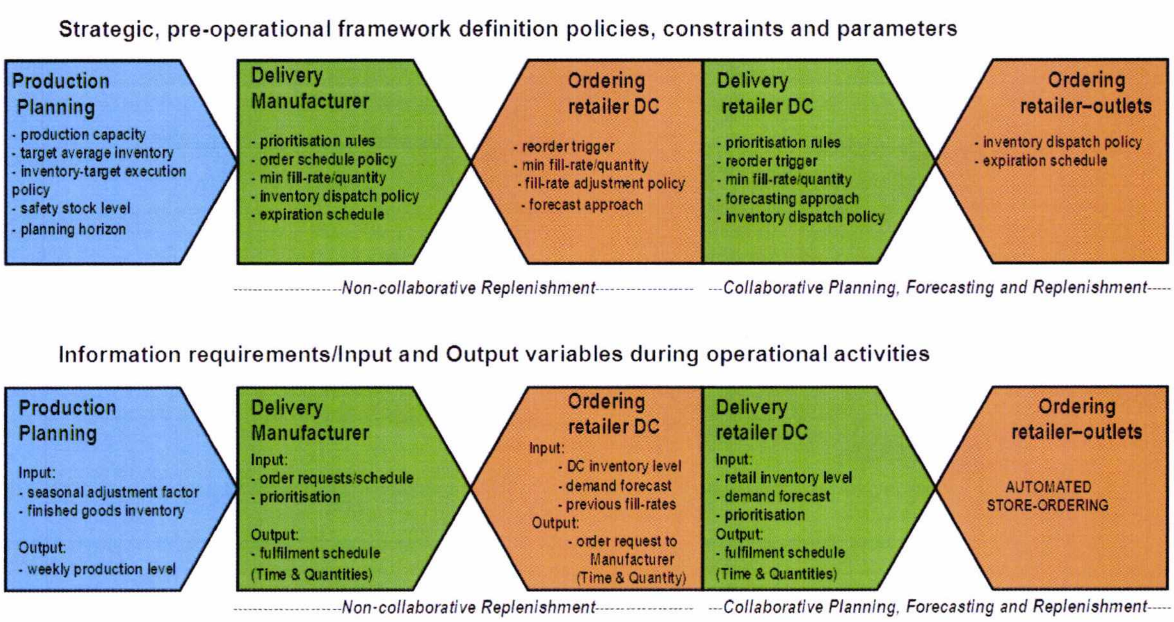


Figure 4.7: Input, output and operational parameters for non-collaborative replenishment framework SC stages

Collaborative replenishment approaches

	VMI	CPFR
Background	- Supplier has responsibility to replenish retailer's distribution centre inventory, no autonomous orders placed by retailer	- Same as VMI plus increased level of collaboration between manufacturer and retailer - Joint planning and execution of demand, replenishment, promotions, inventory levels, inventory dispatch policies, sales forecast
Real-time Data availability	- Current DC inventory level, data available to manufacturer on a daily updated basis	- DC inventory data (daily), POS sales data for particular product & category overall (weekly)
Further Data availability	- Promotional activities (updated biannually) - Seasonal demand deviation (monthly historic figures) - Market and category sales trends (updated biannually)	- Category-wide promotional activities (updated monthly) incl. sales impact estimate - Seasonal demand deviation (weekly figures) - Market and category sales trends (updated monthly)
Collaboration activities	- Bi-annual or quarterly arrangements to update promotion schedules, adjust replenishment parameters and update seasonal factors	- Impact analysis of promotional activities, frequent readjustment - Exception management in case of (unexpected) short-term deviations - Detailed seasonal deviation analysis to obtain more precise weekly figures (biannual adjustments) - Joint sales forecast (generated by manufacturer and adjusted by retailer) based on preliminary data analysis
Further agreement about	- Delivery frequency, safety stock and average inventory level at DCs	- Same as VMI
Demand Forecast parameters	- Default sales quantities, monthly seasonal factors, promotional activities (impact estimation according to past experience of manufacturer), mid-term/long-term market trends	- Default sales quantities, weekly deviation figures (exception and seasonal), promotional activities (based on joint sales impact estimate), mid-term/long-term market trends, short term sales trend based on most recent sales figures
Main advantages	- More easy to implement - Does not rely on revealing crucial information - Maintenance cost/effort much lower - Does not raise too many trust issues - Once set up it does not need constant input/effort	- Demand/order forecast much more precise and trustworthy - Prioritisation decisions in case of demand clashes much more reasonable - Better service level, distribution reliability and lower inventory levels - Bilateral exception management in case of changes

Table 4.2 Characteristics of collaborative replenishment approaches

The table above states the key characteristics that sketch out the two collaborative replenishment cases which numerous settings are based on later in the analysis. The echelon-flowcharts presented in Figures 4.8 and 4.9 illustrate the differences between the previously stated non-collaboration cases and VMI/CPFR enabled frameworks. Initially, strategic policies, constraints and parameters are stated followed by input and output parameters.

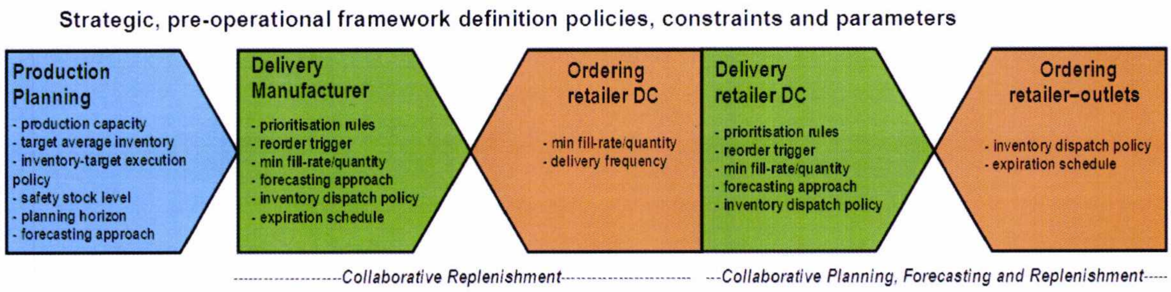


Figure 4.8: Operational parameters for collaborative replenishment framework SC stages

Figure 4.9 shows input and output variables as well as incorporated information which reveal significant differences to the non-collaborative framework. Most apparent are the increased information exchange and input requirements.

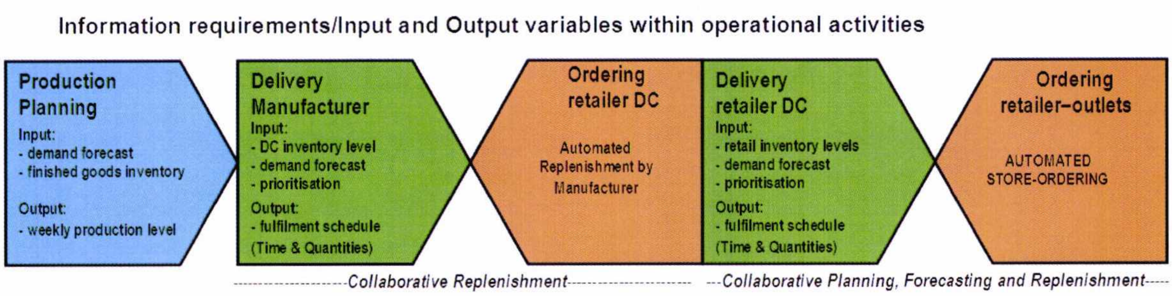


Figure 4.9: Input and output parameters for collaborative replenishment framework SC stages

4.3 Data collection and analysis

After having laid out a conceptual model within the previous section, we have to identify the data that is necessary to convert this model into a computer simulation model. According to Pidd (2003) three categories of data are required to be able to build a valid simulation model:

1. Preliminary data to understand the system.
2. Data and information necessary to build, set up and run the model.
3. Data required for model validation.

Considering the availability of these data, we can classify the accessibility of information into three categories as well:

1. Data that is already available and just needs to be analysed
2. Data that is not yet available but can be obtained
3. Data that is not available and cannot be obtained or is not accessible

Altogether, data requirements and availability have already been accounted for during the layout of the conceptual model. The essential model components are thus based on data that is already available or is within the reach of the investigator.

4.3.1 Preliminary data to understand the system

Obtaining information that promotes understanding of the system should most likely base on previous experience with similar systems or appropriate literature to form a foundation on which fieldwork observation and expert consultation can build on. Once the basic underlying concepts and procedures are understood, particular details about the system under investigation are most likely to be obtained by: Interviewing several experts that have a profound experience in working in and with the system on various levels and stages, personal observation of the system as detailed as possible and studying relevant documentation about the system (input, output, performance records etc.).
Obtaining a sufficient level of familiarity regarding the issues addressed within this research project followed very much this outline. To gain an initial understanding various inside experts were consulted to obtain a good understanding of all relevant parts of the system. Accordingly, information was obtained from raw material suppliers, logistics service providers, procurement, sales management and store managers. Furthermore, it included observation of production processes and facilities and analysis of additional material that was provided from various sources inside and outside the system.

4.3.2 Data and information necessary to build, set up and run the model

Taking the conceptual model at hand it becomes apparent which data and information is necessary to be able to build and run the final simulation model. Overall each entity had to be set up with reasonable information to account for realistically representing the particular part of the actual system. Depending on how much variability a particular setup is meant to contain, the necessary data have to be very detailed or can be rather vague. The main areas where empirical data are essentially required are:

1. Historic demand data to realistically represent the incoming *consumer demand.* The data used in the simulation model was generated using actual POS sales data for the investigated products and categories obtained from the four retail companies that were involved in the project. Since sales cannot be equated with demand due to out of stock incidents, we also needed out of stock records to sufficiently generate realistic demand data for the period of investigation.

2. *Demand forecasting* also depended heavily on the supply of historic data since actual sales/demand data had to be decomposed using information about promotional activity schedules for the investigated product and for competitor brands. Using those, demand data could be decomposed from promotional activity influences which allowed conducting a reasonable seasonal factor and market trend analysis. After the demand data have been decomposed to such extent, reasonable judgements could be made about short term influences including single incidents (i.e. food poisoning scandal, flooding etc.) and short term trends (food fashion trends, weather dependencies etc.). Further detail about the data decomposition will be provided in Chapter 5.

Apart from these two main issues which are essential for the entire modelling framework, a vast amount of particular information was required to set up individual entities:

- Production scheduling, capacity and flexibility
- Transportation times, capacity, flexibility and cost
- Inventory capacities

- Loading and unloading procedures
- Prioritisation policies
- Inventory level enforcement procedures
- (Re)order and fulfilment policies and processes
- Safety stock levels
- Forecasting techniques
- Common performance measures
- Typical collaboration procedures
- Effectiveness of store ordering procedures

All these data were necessary in order to set up and run the simulation model.

4.3.3 Data required for model validation

Apart from the previously mentioned information there were additional data required to be able to test the model for validity. Model validation is needed to confirm that the model, within its domain of applicability, behaves with satisfactory accuracy, consistent with the study objectives. In other words, in model validation, "we substantiate that the input-output transformation of the model has sufficient accuracy in representing the input-output transformation of the system" (Balci 1995). Since model validation is commonly conducted by running the model under the same input conditions that drive the system and by comparing model behaviour with the corresponding system behaviour, a certain range of data and information are necessary to assure this can be done. Examples for such kind of data were:

- Inventory level time-charts from various stages within the supply chain framework
- Demand prediction records for demand throughout the period of investigation
- Past performance measure outcomes
- Past order and delivery records
- Market data of the period covered within the investigation

4.3.4 Variability incorporated into the model

As it was already mentioned in Chapter 3, the simulation model built to investigate the three supply chain frameworks is meant to run case studies and what-if analyses and will for reasons of cause and effect traceability incorporate only a limited degree of variability within and in between the incorporated entities. Overall most activity times are therefore fixed values apart from production and demand. The reason for that is the persistent difficulty to identify root causes in a very complex system. Since the aim of the investigation lies on strategic implications as to what degree of collaboration would be useful with which partners, optimising underlying operational processes is only of secondary importance. Considering the simulation runs over an extensive timeframe of more than three years, duration of less crucial activities have been excluded from the analysis whilst some others have been set to fixed values. Such activities include loading and unloading time, internal transportation or loss of products during dispatch. The actual most time critical processes (production, transport and incoming demand) are accounted for in more detail. Production uses average output capacity values taken from historic records. These values incorporate a certain variation (expressed by a bounded normal distribution) but do not take any breakdowns into account. Transportation times between the certain echelons are expressed using fixed timings. This was mainly necessary to be able to trace causes for out of stock incidents which seemed to be looking for a needle in a haystack if various transportation times were variable. The incoming consumer demand was modelled taking the actual historic sales data at hand after they have been adjusted to account for lost sales during out of stock times. Since those values were recorded on a weekly basis, we obtained daily store data to generate typical demand variations for certain weekdays (e.g. Friday and Saturday have higher demand than Monday or Tuesday). Finally we used exponential arrival distributions for the demand set up in a way that typical daily deviations were obeyed and the weekly sales quantities fitted the historic sales data obtained.

4.4 The simulation software

The simulation software used for the analysis is Simul8 Professional 2006 (Simul8 Corp, 2006). The reasons for using this software package out of the wide range of available analytic toolkits have been laid out within Chapter 2 already. In the following there will only be a brief outline about this simulation software package to underline its capabilities.
Overall, Simul8 is one of a number of commercial packages used for modelling the business process systems in factories, hospitals, call centres and other organisations. It was initially released in 1995 with the objective of making the power of commercial simulation packages accessible to a wider market. Since it is much more affordable compared to many of its competitors considering the implemented capabilities, it is within recent years being widely used in industry and academia to simulate workflows in production, distribution and office environments to identify improvements in operations and processes. Nowadays it is considered the preferred simulation tool of thousands of engineers in enterprises such as Ford, McDonald's, Fidelity and Hewlett Packard as well as many smaller organizations (Concannon *et al.*, 2003).
Simul8 Corporation (previously Visual Thinking), the company behind SIMUL8, claim that the program was "designed for use by mass market simulation users who require point-and-intuitive interfaces". In particular, the graphical interface allows users to build relatively complex models without needing to learn a programming language. A first time user can normally build, run and change simple models within an hour. After a few further hours of training, users are usually ready to tackle a moderate sized project.
A basic SIMUL8 model consists of five key elements: an entry point, queues (or storage areas), work centres, an exit point and resources (people and other items required to do work at work-centres). The model is built by selecting these entities (visualised as icons) from the tool bar, arranging them on the screen, connecting them and changing links as necessary. The entities have numerous default settings which allow adjusting a new model in a short time. These defaults can also be changed easily by using appropriate dialogue boxes. Common settings selectable from drop-down menus include inter-arrival times and distributions, activity durations, travel times, queuing behaviour, priority and batching rules. Attributes (called labels), for unique identification of different types of work items, can also be added. The software also contains many of the standard probability distributions commonly used by business analysts to approximate process timings when conducting a simulation study. Other system settings such as time-units, initiation (warm-up) period, multiple runs (trials) and run-times can all be easily set up and adjusted from the program tool bar. The package also comes with an extensive set of examples covering many areas of possible application. Moreover, there is an extensive library of graphics symbols and animated icons including various graphical framework presets such as Business, Call-centre, Healthcare and Manufacturing. Using these graphics facilities appropriately allows the presentation of a model to be enhanced significantly.

Results and performance measures, such as throughput rates and queue statistics are collected automatically as the model runs. Individual results can be accessed via result dialog boxes within each entity and can also be customised within a global results summary report sheet.
Although the above features allow reasonably detailed models to be built, more complex simulation projects often have the need for including additional constraints or custom model behaviour. For such projects which require more non-standard logic processes, Simul8 has an in-built programming language, called Visual Logic. This programming interface allows incorporating versatile control rules to be linked to any event and every entity. If necessary, a Visual Basic extension is available should significantly more complex rules be required.
Overall, Simul8 is a highly capable object oriented, general purpose computer package for visual discrete event simulation. As such, it is a powerful and flexible platform for visualizing and dynamically simulating nearly any kind of physical, financial or organizational system. A particular strength of the package is its cutting edge graphical interface which is quite intuitive and its animation capabilities are very useful to develop intuition and promote outside understanding. Altogether this enables tackling detailed hands-on tasks with a high progress to time ratio. Throughout conducting the analysis for this research project it was a more than appropriate tool to support systems modelling and investigating a wide range of "what if" scenarios. The software can therefore be highly recommended for any future enquiry related to this research's framework.

4.5 The simulation model

In this section we provide details of the actual simulation model that was developed within the Simul8 discrete-event simulation software environment. We will first give an overview about the model layout, explain how the obtained data and information were implemented, outline the employed forecasting and priority ranking approach and finally introduce a wide range of potentially useful performance metrics.

4.5.1 Model Layout

The model layout has been developed to include as many features as possible in a generic way that can easily be altered to accommodate a different supply chain scenario. Consequently, we tried to standardise as much decision-logic and parameters as possible but assured that distinct features amongst the three investigated supply chain frameworks can still conveniently be implemented. Thus, the included entities represent the most reasonably detailed common base of all three scenarios. This simplified common base also goes along with one of the main targets of the model, the ability to represent an appropriate structure of a wide variety of supply chain settings applicable beyond the scope of the investigated frameworks. The developed model follows very closely the conceptual model layout presented earlier. Thus, it contains 20 main entity groups (e.g. individual suppliers, manufacturer, distribution centres, retail outlets) as laid out in Figure 4.10 and Figure 4.4 earlier on. To incorporate the degree of detail necessary to sufficiently investigate the project objectives, more than 200 objects such as work-centres, resources, queues, item-entry and exit points etc. were included. Since Figure 4.10 shows an actual screenshot from the simulation software environment, Figure 4.4 should be re-viewed beforehand to understand the layout of the displayed entities.

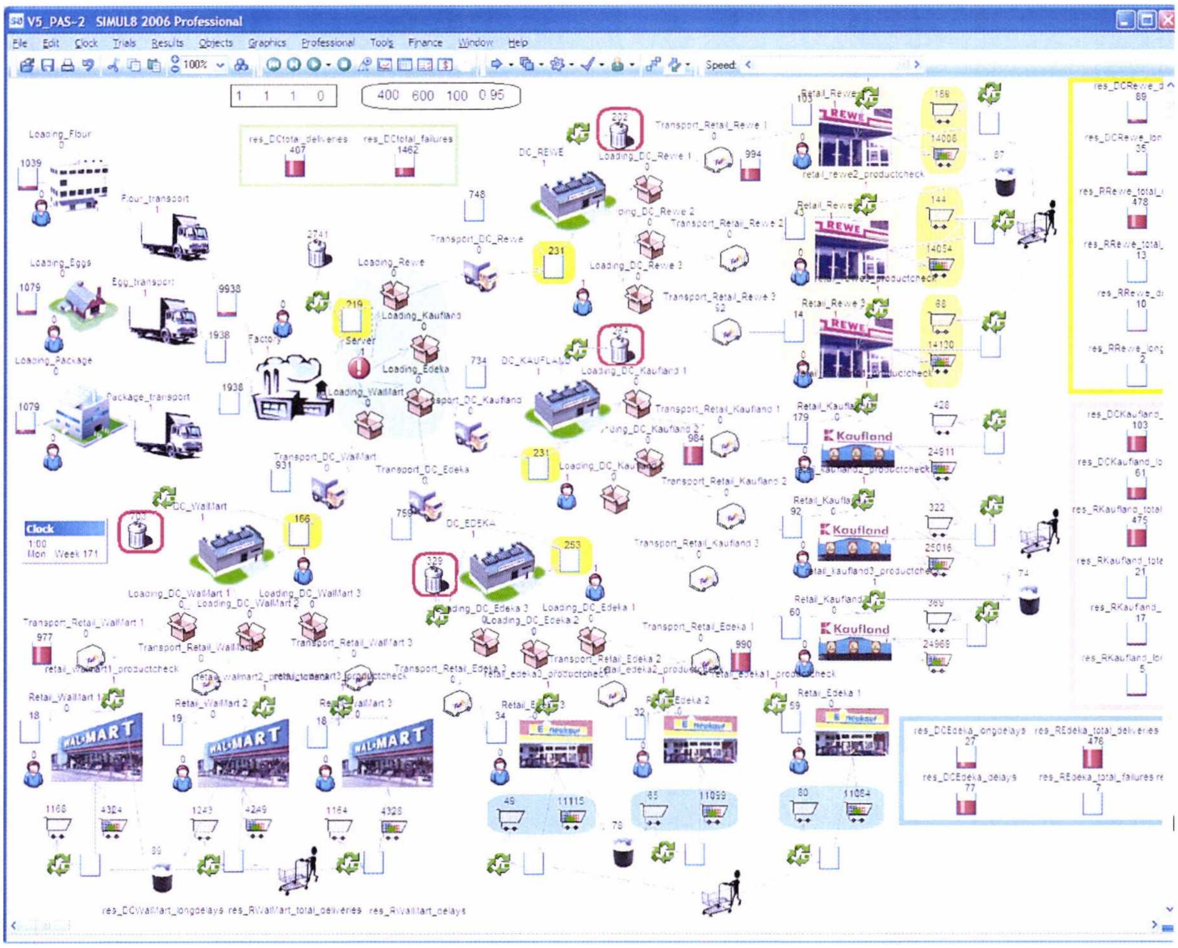


Figure 4.10: Model layout within the simulation software environment

4.5.2 Implementation of obtained data and information

Within the underlying model structure it was intended that experimental factors and general model data were somewhat distinguished from the actual model front-end. Thus, historic demand data used to simulate the consumer demand are implemented via linked spreadsheets. Once the layout of these spreadsheets had been standardised, complete consumer demand information blocks (including promotional activity schedules, seasonal deviations, market trends, market share etc.) could easily be substituted without any necessary adjustment of actual model outline or logic. Most of the model intelligence was furthermore implemented via Visual Logic/Visual Basic code to control the behaviour of the entities on a higher level[1]. Throughout the model such code can be executed either event or time based. If it is event based then i.e. a certain work item entering or leaving a particular entity can trigger a logic event. Since such code is evaluated each time a work object initiates or finishes a certain activity it can slow down a simulation significantly in case of extensive item throughput. In such cases it is more advisable to shift logic events to be time based. Here certain logic checks are carried out at particular points of time (i.e. every full hour) independent of how many items move through the system. This is often more appropriate for higher level logic to make the model faster and keep most of the logic combined. It also helps model verification since a certain event can be traced better looking at the time it occurred.

[1] The main control code steering the model logic can be found in the appendix.

Most of the flexible model input parameters are also included via visual logic code since they can be easily visible and adjustable en-bloc instead of searching throughout hundreds of entities which is prone to errors and potential miss-outs. The parameters can thus be grouped into initiation-adjusted and operating adjusted. The first group needs to be set up at the beginning of each run and will not change throughout the simulation. Other factors will be set to a certain initiation value which will be altered later on according to a prefixed schedule or operational feed-back.
Earlier on in this chapter we outlined the degree of simplification that was necessary to keep the model manageable and allow for meaningful interpretation of the output. Following that summary and considering the wide range of input variables that will be adjusted in order to evaluate resulting impact, we decided to significantly limit randomness within the system. As a result of that, activity times of many events will either be ignored (if average activity time is insignificantly small) or set to an average (most likely outcome) level. The main area of variation is therefore consumer demand which is the major force to drive the supply chain system (for more details see section 4.3.4).

Additional model framework condition parameters

Initial setup - Prior to each run the model is set up with sufficient start-up inventories to be able to fulfil replenishment and incoming orders respectively.
Model type – The simulation will be non-terminating as there is no natural end point (apart from the period of available data) terminating the length of the run. The output of most performance measures will commonly reach steady state since they are taken as averages over time.
Warm-up period - To further reduce most of the initialization-bias and assure an unflawed observation, result-collection is initiated after a 13 week warm-up period. This time span has been set after investigating the initialisation progress of the model content. From this analysis it was found that a steady state was reached after circa 10 weeks. Setting the warm up period to 13 weeks allows thus sufficient time and leaves exactly three years (157 weeks) of result collection period remaining.
Run-time - Overall the model runs over a timeframe of 170 weeks according to the range of demand information that was obtained from the involved companies. This period should also reveal long term effects of possible parameter adjustments which goes along with the general project objectives.
Computing speed - Due to the substantial degree of complexity it takes about three minutes for a single full framework run on a Pentium 4 3.6GHz machine. Due to the limited degree of incorporated variation regarding inter-arrival/processing distribution timings, each setting is run at least five times to achieve a sufficient confidence level for all output variables of interest.

4.5.3 The embedded forecasting and priority ranking systems

Within the logic flow diagram in Figure 4.5 we could already see that there are two decision modules that influence several stages within the order fulfilment flow. These two modules are the *demand forecast* to estimate forthcoming orders and consumption and fulfilment *prioritisation* to decide how competitive orders are fulfilled in times of stock shortage. These will be outlined in more detail.

Demand forecast

Since the purpose of the demand forecast was already outlined before we will focus here on the way it is implemented into the model. The actual components and possible degrees of refinement of each stage leading from raw data to a sophisticated forecast are outlined in Figure 4.11.

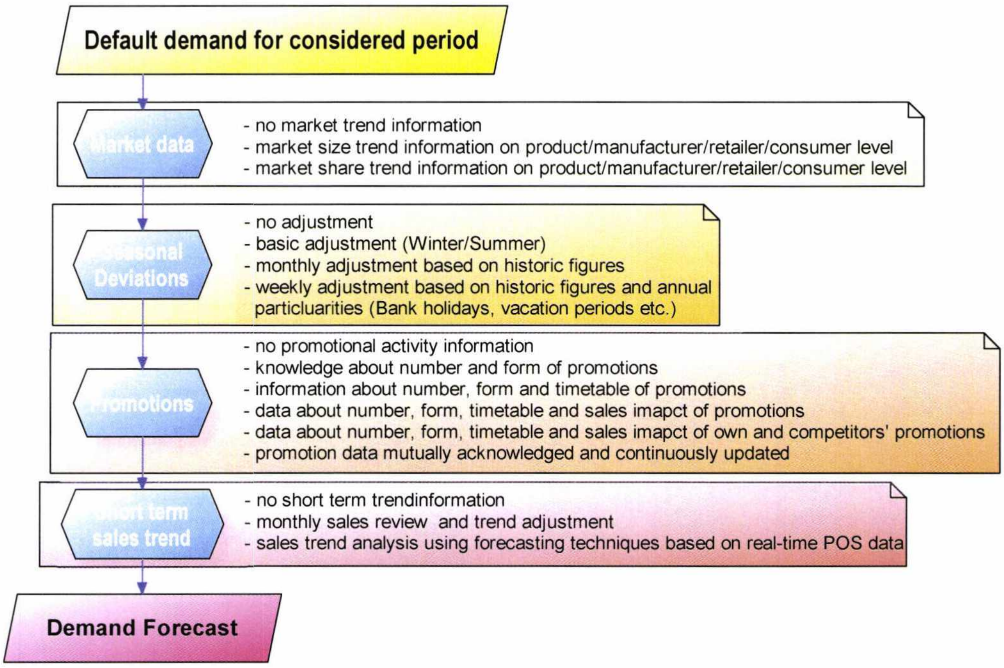


Figure 4.11: Outline of demand forecast components, stages and refinement

The demand forecast is used at various stages within the process flow. These stages are

- Determination of the weekly production level
- Order fulfilment prioritisation at manufacturer's loading stage in case of stock shortage
- Reorder point and quantity determination by manufacturer (in case of VMI/CPFR)
- Reorder point and quantity determination by retailer's distribution centre (DC) for orders from manufacturer
- Order fulfilment prioritisation at retailer's DC loading stage for retail outlet orders
- Reorder point and quantity determination for retail outlet orders

The actual calculation procedure of the forecast is similar at each stage but depends on the information that is available. For the best case, full scale prediction, the forecast takes following factors into account:

- Recent sales data from retail outlets on a weekly basis
- Inventory at retailers distribution centres on a real–time basis
- Pre-determined seasonal factors
- Promotional activity schedules (manufacturer's and competitors)
- Pre-determined promotional impact factors (manufacturer's and competitors)

The reliability of promotional activity schedules and the actual quality of the pre-determined seasonal factors and promotional impact factors depend on the level of collaboration between the certain echelons of the system. Taking these factors into account the forecast module first decomposes recent POS data, removing seasonal deviations and promotional impacts. Thereafter a regression analysis combined with time series forecast (double exponential smoothing) determine long term, mid-term and short term trends. These trends are then combined with forthcoming average demand and finally adjusted by expected forthcoming seasonal deviations and promotional activity impacts. This forecast procedure results in very reliable demand prediction in case all of the above mentioned information is available from all echelons. This is nevertheless only the case if all members of the supply chain system provide these data completely, accurately and on time. These issues are investigated in Chapter 5 in detail. Within the worst case (no collaboration and no market intelligence at all) scenario the "forecast" will only be based on default demand from average historic figures and bi-annual market trend updates. In between these best and worst case settings there are many feasible scenarios which will be further investigated within Chapters 5 and 7.

Priority ranking system

The order fulfilment priority ranking module attempts to optimise the flow of goods in case of stock shortages and is of importance at two points within the framework:

- Order fulfilment/replenishment (loading stage) by the manufacturer
- Order fulfilment/replenishment (loading stage) by the retailers' DC

The amount of product that is assigned to competing incoming order requests depends on several factors:

1. Amount of product available
2. Combined order request quantities
3. Minimum load level (fill rate) setting
4. Inventory level at subsequent supply chain stage (in case of VMI/CPFR)
5. Predicted forthcoming demand (in case of CPFR)
6. Past order quantities (default order amount)
7. Prioritisation policies

Taking these factors into account, a large number of possible product allocation procedures can be defined. Overall the most likely procedure can be laid out in the following order:

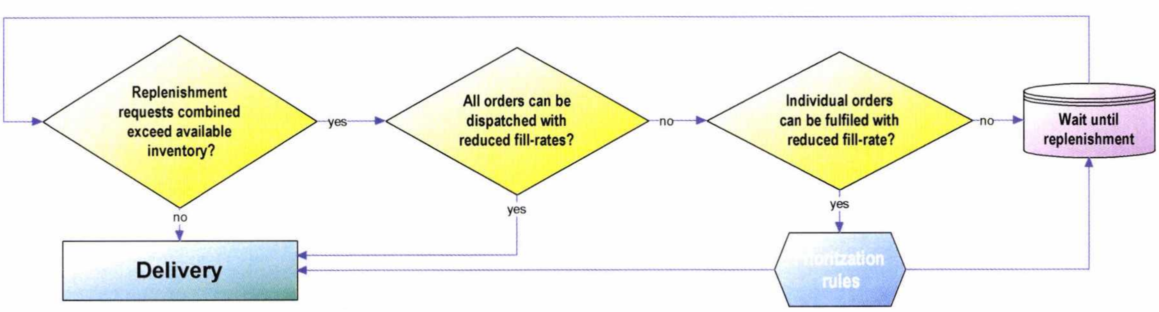


Figure 4.12: Order fulfilment process decision flow

1. Replenishment requests combined exceed available inventory, if yes
2. Check if all orders can be dispatched with reduced (minimum) fill-rate, if no
3. Check if individual orders can be dispatched with reduced (minimum) fill-rate, if yes
4. Define priorities amongst these orders and fulfil according to ranking

Examples for priority rules applicable within step 4:

- Customer 3 ahead of customer 2 ahead of customer 1 ahead of customer 4
- CPFR replenished customers before VMI before ROP
- Prefer customer who is most likely to run out of stock at DC stage

- Prefer customer who is most likely to run out of stock at retail outlet stage
- First come first served
- Random
- Small orders first, large orders later
- Large orders first, small orders later

etc.

There are many more combinations of individual settings. In Chapter 8 we give additional information about the functioning of this decision module. We also have a detailed look at which type and level of impact individual settings have on the entire system.

4.5.4 Model output - Performance metrics

As already outlined in Chapter 2, performance measures are categorised into three groups – planning accuracy, distribution effectiveness & efficiency and customer service performance. Within each of these groups we defined a broad range of performance indicators that can potentially contribute to address the project objectives. Investigations within later chapters will utilise these metrics but will only include a certain choice of the ones presented here. To account for reasons of confidentiality most metrics are expressed as percentages of a certain default state.

Metrics within Group 1: Planning accuracy

Manufacturer's average inventory – this performance indicator accounts for the level of recorded inventory at the manufacturer's ready-made-goods storage facility. The measure is taken as an average over the entire simulation time-span (3 years). The output should give information about the necessary storage capacity that has to be allocated to a particular product. Overall it is desirable to diminish the average inventory held by the manufacturer due to storage facility limits, inventory holding cost and possible expiration of products. On the other hand a low inventory level will decrease the degree of responsiveness to unexpected demand changes and thus impact delivery flexibility.
Retailers' average DC inventory - this figure is similar to the previous one since it describes the amount of inventory held on average by the distribution centres of either a single retailer or all retailers combined. As mentioned before it is desirable to keep this figure as low as possible which should result in cost advantages but also increases the risk of possible delivery bottlenecks.
Retailers' average outlet inventory – once again this figure is similar to the other inventory metrics as it describes the amount of inventory held on average by the retail outlets of either a single retailer or all retailers combined.
Excessive Inventory – measures the percentage of time during which inventory held by the manufacturer exceeded a critical upper limit which is set to 200% of the targeted average inventory level. This metric should reveal additional information about possible problems arising from the actual implemented inventory policy.
Production overutilisation – this figure states the percentage of time during which production facilities operated at their maximum capacity. This should give additional information about capacity restrictions. Extensive times of maximum capacity utilisation indicate facility or planning shortcomings since within such times there is no slack of excess capacity to tackle additional demand or accommodate machine breakdowns. Furthermore, the assembly of other products might be impaired if excessive resources are occupied by a particular process.

Production underutilisation – states the percentage of time with particular low usage of available production facilities. This lower limit depends on the individual manufacturer's circumstances. It is commonly close to 70% of the standard capacity. In cases of extensive machine underutilisation there will be additional cost in case workforce cannot be adjusted flexibly enough.
Average weekly production output – describes the level of production output in relation to a certain standard output level. The standard output level is commonly determined by mean past output figures.
Production volatility – expresses the percentage of average deviation between actual production and standard production output. The stated figure is an absolute value combining negative and positive divergence.
Production forecast accuracy - this measure captures the average gap in forecast that drives production planning. As such it combines deviations arising from differences in forecasted and actual demand. This metric is also a measure for the quality of the implemented forecasting system in general as the common demand forecast within a CPFR system drives numerous activities within the supply chain framework.

Measures within Group 1 only applicable within perishable goods environments:

Percentage of expired products – this figure states the ratio between all products that were removed due to expiry reasons and the total number of produced items. A high percentage of expired products is clearly a sign of inefficient planning and operating of a supply chain since they incur substantial cost and diminish customer service.
Origin of obsolete products – reports the distribution of the overall waste according to place of recording. Depending on the individual setting, products can be declared obsolete at either the manufacturer's storage, distribution centre or at the retail outlets. The actual quantity and distribution of expired items directly depends on the overall expiration policy. This policy defines the age at which a product is taken out of the stream of goods at a particular stage of the supply chain.
Product age – indicates the average age in days of the products at the moment of sale. This can reveal valuable information about the impact of e.g. inventory dispatch policies.

Metrics within Group 2: Distribution effectiveness and efficiency

All the following key performance indicators are recorded for individual customers as well as at a global level:

Number of delivery tours needed **(Manufacturer to DC)** – expresses the number of tours necessary to supply the distribution centres (DC) of the customers. This figure is expressed as a percentage compared to a theoretical level which is determined during distribution planning. The reference case is commonly determined by a general replenishment agreement (e.g. once a week leading to 52 deliveries per year).
Number of delivery tours needed **(DC to retail-outlets)** - accounts for the same as above but relates to the replenishment process in between retailers' distribution centres and retail outlets.
Non-delayed deliveries by Manufacturer – this measure captures the overall percentage of deliveries from manufacturer to retailers' distribution centres that were carried out from available stock straight away.
Non-delayed deliveries by retailers' Distribution Centres – accounts for the same as above but relating to the replenishment process in between retailers' distribution centres and retail outlets.

Critical delays by Manufacturer – stands for the percentage of deliveries that are postponed by the manufacturer and finally carried out with a substantial delay that made the delivery exceed critical order lead time. These cases must be seen as severe interruptions of order-delivery procedure and are thus the reason for major inconveniencies.
Critical delays by Distribution Centres – accounts for the same as above but relates to the replenishment process in between retailers' distribution centres and retail outlets.
Manufacturer's fill rate – measures the load level (fill rate) that deliveries obtained on average. Thus it captures the proportion of the initially requested amount that is actually delivered. This measure should optimally be 100%.
Retailers' Distribution Centre fill rate – accounts for the same as above but for the replenishment process in between retailers' distribution centres and retail outlets.
Percentage of perfect deliveries – captures the proportion of on time-in full deliveries that were not critically delayed and achieved a fill rate of 100% (measured either in between Manufacturer and DC or DC and retail outlets).
Order lead-time by manufacturer – expresses the time in between placing an order and actual replenishment at the retailer's distribution centre.
Delivery volatility by manufacturer – determines the deviation of the actual delivered quantities from the average value. The average value is commonly set by dividing the annual ordered quantity by the number of delivery tours.

Metrics within Group 3: Customer service performance

Overall Service Level Gap – this metric accumulates the individual service level gap figures of the four customers and is usually the most important performance metric within the forthcoming analyses. This measure accounts for any occurring gap in supply on store level and thus lost sales and customer/consumer goodwill which has to be seen as the ultimate failure within a supply chain. All service level gaps should optimally be zero but are commonly in between 1% and 10% for most of the investigated scenarios which is equivalent to 90% - 99% actual service level. The reason why service level is predominantly taken as a variable performance metric instead of inventory which is used in most other logistics research is due to the supply chain frameworks of the involved SME companies which evolve around lean inventory policies due to storage capacity constraints, perishable goods or substantial holding cost.
Individual retailer's service level gap – accounts for the same as the global figure outlined above but for a single retailer only.
Typical Service Level Gap – expresses the average gap in supply at store level for just the weeks in which demand cannot be fully met by available inventory. This measure thus gives further insight as to how severe supply gaps are once they should occur (measured either on a global level or for each individual retailer).
Largest gap in supply – states the service level gap for the single worst week of supply of a particular customer (individual outcome) or from any of the customers (global outcome).
Weeks of perfect supply – states the percentage of weeks within the total investigation timeframe where demand could be fulfilled to 100%. This is either taken for each customer individually or as an average from individual figures from each of the four customers.

Additional control measures:

The following values are also recorded and part of every output report since they represent significant figures within the reporting system.

Overall demand – states the total quantity of requested items by the consumers within the entire supply system.
Individual retailers' demand – expresses the total quantity of requested items by the consumers of a particular retailer.
Overall production – accounts for the total number of produced items by the manufacturer within the main phase of the simulation run.

4.6 Validation and Verification

An important aspect of a simulation modelling project is to determine if the model and its results are reasonable. However, we do not expect the model to be a precise replicate of the real life system because of implied simplification. According to Pidd (2003) a model is not even meant to be completely accurate, but a simplified means for understanding and exploring reality. Within the framework of validating and verifying a model the aim is to ensure that the model is sufficiently accurate and this accuracy is with reference to the purpose for which the model is to be used. To ensure that this accuracy is indeed sufficient, this section refers to several validation and verification techniques and demonstrates their consideration within the project.

4.6.1 Model validation

The ultimate goal of model validation is to make the model useful in the sense that the model addresses the right problem, provides accurate information about the system being modelled, and to make the model actually being used. According to Sargent (1994) there are three basic decision-making approaches used in determining that a simulation model is valid. Each of them requires verification and validation to be carried out by the modeller as part of the model development process.
The most common approach is about the model developer to judge individually on the model being valid. This decision is thus a subjective one based on various tests and evaluations conducted throughout the model development process.
The second approach is called independent verification and validation, IV&V. Here a qualified outside party decides about validity. The evaluation used in IV&V can be as simple as reviewing the verification and validation performed by the model developer according to the previously described approach. On the other hand it can also involve a complete independent verification and validation effort which would be very costly and time consuming.
The third validation approach is about using a scoring model (Balci, 1989) to decide about model validity. Scores are assigned subjectively to various aspects of the validation procedures. Altogether a simulation model is considered valid if its overall and category scores are greater than a particular passing mark.
Due to the limited resources within the process of conducting this research, validation was mostly carried out focusing on the first approach. Thus the main responsibility for appropriate modelling including various tests and evaluations conducted throughout the model development process remained with the modeller. Nevertheless, there was substantial support from external experts that contributed valuable knowledge within several vital steps of the modelling process. To cope with increasing complexity, the model has been developed in a way to first test system dynamics on a very simple version which was afterwards extended adding additional complexity in form of feature-modules. Accordingly, new implemented modules were frequently analysed for their valid output before and after their implementation to account for a certain level of global validity. A

helpful tool within the model development and validation process was the use of visual interactive simulation packages. By using such, it is possible to take advantage of the graphical interface when verifying a model. Improving the appearance of the simulation model to make the graphics more informative not only aids the verification process but also helps other people to understand the model. Following that idea the model was occasionally discussed for its appropriateness with market insiders from the participating companies to avoid miscomprehension and reveal possible weaknesses within the design. Additionally, actual market data and intelligence that was provided by the companies turned out to be extremely helpful to verify the model output. The obtained results were most of the times reasonably close to actual market figures which supported the trust in the simulation for investigation scenarios that reached beyond the actual market framework and thus could not just as easily be verified with actual data. For these cases verification of the simulation output had to be rather based on common sense. Altogether the kind of procedure employed for validation purposes roughly follow the outline of Sargent (1994). The main techniques employed are as follows.

Animation

Here the goal is to demonstrate the operational behaviour graphically as the model moves through time. This has been done to a wide extent with the help of animation facilities provided by the Simul8 software package. The entire considered supply chain framework is graphically presented as it is run. The model layout follows the market outline identified within conceptual modelling stage. Most crucial activities i.e. loading, transporting, storage, expiration of products, delays or purchasing are visually displayed as the model runs. This supports an instant familiarity of outside experts with the implemented processes which could not have been achieved if the model was based on spreadsheet or pure programming interfaces. For a visual display of the model see Figure 4.10 which shows the graphical interface of the model but obviously does not account for the underlying animation.

Comparison to older models

The goal within this step is to compare various output figures with results of existing, validated models. This has been considered in the form of comparing output between complex and underlying simplistic models. Throughout the progression of the modelling process which added more and more detail to the initial system, a simplified version of the model was set up and updated simultaneously. The main use of this basic model was to test various assumptions that could not be evaluated fast enough or were difficult to isolate within the complex model. This simplified version helped to find and test interrelationships between certain variables and to find root causes of certain behaviour.

Degenerate Tests

Here the idea is to remove parts of the model or to set up variables in a rather unusual manner to observe if the model behaves rationally. Following this outline, the model has been tested for consistency if various modules were disconnected or removed. These include e.g. individual retail outlets, distribution centres, transportation, suppliers or whole customers. Furthermore various activities or control parameters were set to either very large numbers or very low as zero to see if the model behaved as expected.

Face Validity

This technique is about asking people knowledgeable about the (or similar) systems whether the model behaves reasonably. Within the modelling process and after the model was set up various people involved in the project (including practitioners as well as academics) evaluated the model for its appropriateness to tackle the project objectives. Although there was a wide range of opinions about the level of applicability and possible changes and improvements, the general outline and potential usefulness was not questioned.

Extreme Conditions Tests

This is to check if model structure and output are plausible for any extreme and unlikely parameter setting. There has been a substantial effort put into testing the model behaviour within unlikely scenarios. Such scenarios included supply disruptions for certain periods, machine breakdowns, extremely high or low demand, extensive demand volatility, extremely high promotional impacts, excessive or reduced capacities (production, transportation or inventory), highly perishable goods, extreme demand diversity amongst customers, very long or short replenishment cycles, extensive production planning horizon etc. All those changes have been implemented and contributed to verification, validation and increased understanding of the processes within the supply chain framework.

Fixed Values

This validation concept evolves around fixed values being used for all input and internal variables to compare model outcome against pre-calculated results. This proved to be very useful to compare the model outcome with actual figures obtained from various stages of the system. By using this method we evaluated output measures for their suitability by comparing them with past records. Output figures investigated included service levels, inventory levels or production output.

Historical Data Validation

Here historical data is used to build and set up the model and to test it afterwards if it behaves as anticipated. Historical records have been the main basis of constructing and setting up the model. Especially the demand modelling part would not have been possible without relying on historic figures including sales records, out of stock incidents, inventory and order records etc. Appropriate modelling of actual historic demand to test what effect certain parameter changes had on the system throughout the investigated period (2001-2004) is one of the fundamental objectives of the research project. This way we have evaluated the suitability of promotional impact analysis, seasonal deviations and market trends.

Parameter-Variability (Sensitivity Analysis)

The idea here is to change values of input and internal parameters of a model to evaluate the effect upon the model behaviour and its output. Concluded interrelationships between certain factors should occur in the model as well as in reality. Parameters that are found to cause significant changes in the model's behaviour should be obtained to a higher degree of accuracy than less important factors. Amongst the variety of information that was implemented in the model there are certain parameters which are surely more influential and crucial for the overall outcome than others. Such identified parameters of high importance are manufacturer's ready made goods average inventory level, inventory adjustment policy (triggers and actions), order schedules and order fulfilment priorities. These factors have experienced particular attention within conceptual modelling as mentioned above and will be within the main interest of investigation within the following chapters.

Predictive Validation

Here the model is used to create a forecast of the system behaviour and later on forecasts are compared with real world figures. This has only been done to a limited extent since not many proposed changes have actually been implemented in the real system. Some of the exceptions include e.g. the perishable goods expiration schedule within supply chain framework 2 which has been successfully adjusted in practice following the outcome of the simulation analysis. Furthermore inventory policy adjustments have been tested by the manufacturer within supply chain framework 1 and the experienced impact supported the suggestions made as a result of the simulation analysis.

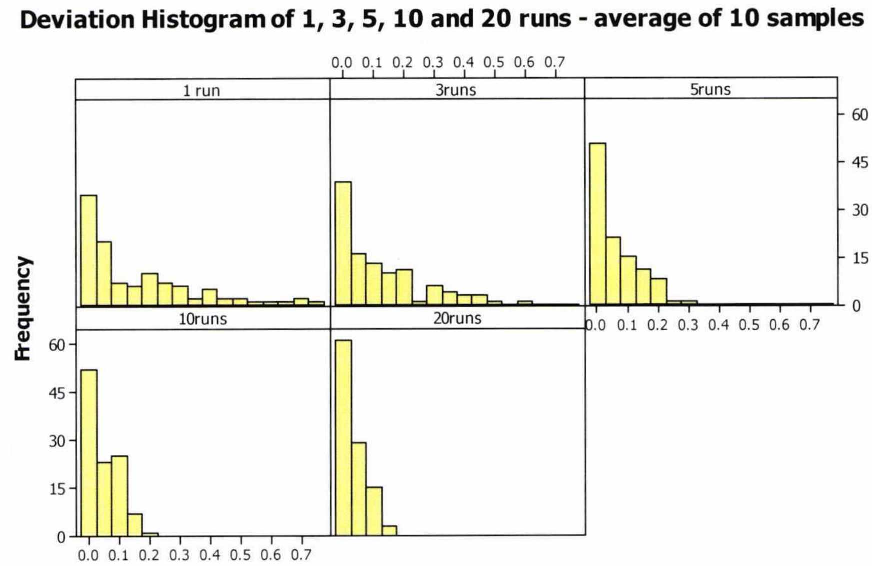
Operational validity

Operational or internal validity is about whether the model output is accurate enough for its purpose. It is commonly achieved via running several replications of a stochastic model in order to determine the level of internal stochastic variability. In general there are two ways to estimate output parameters within a simulation model:

1. Make n independent runs and use average values for the parameters.
2. Make one run, split it into n subruns, and use averages over subruns.

The first method is easier to deal with (individual results will be uncorrelated), but the second method will be better if the warm-up period is long compared to the results collection period.
Considering the model framework of this analysis it seems to be more straightforward to use independent runs instead of subruns. We can obtain multiple run results easily via the "trials" facility within Simul8. Considering the number of runs necessary, we have to ensure that models with very variable output data require more replications than those with a more stable output. Law and McComas (1990) rule of thumb recommends that a minimum of 3-5 replications are performed. This number should represent a minimum regarding necessary repetitions but substantial output variation may require additional runs. To investigate the impact of improved accuracy as a result of increased repetitions we ran three typical simulation scenarios one hundred times to obtain sufficiently reliable reference values. Due to a standard single run-time of about three minutes, this takes about five hours simulation time. Considering that the wide range of investigations presented within the following chapters require hundreds of individual scenario settings it becomes obvious that running as many as one hundred replications is not an option. The question then arises how many runs are sufficient to obtain reliable results.
To get a better idea about this problem, we sampled various sets of 1, 3, 5, 10 and 20 individual runs out of the 100 runs obtained and calculated deviations from reference performance measure values (these were taken from average scores of all 100 runs). Overall we investigated three different scenarios including one typical setting for each framework. The evaluation is based on 109 performance output values. The following diagrams represent the spread of deviations of model output variables according to the number of simulation runs they were obtained from.

Scenario 1



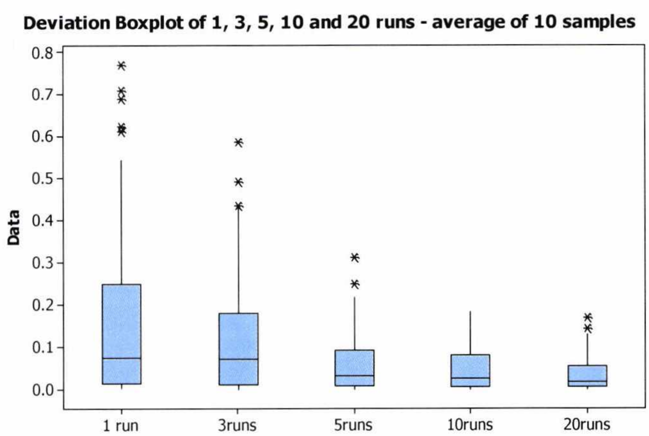
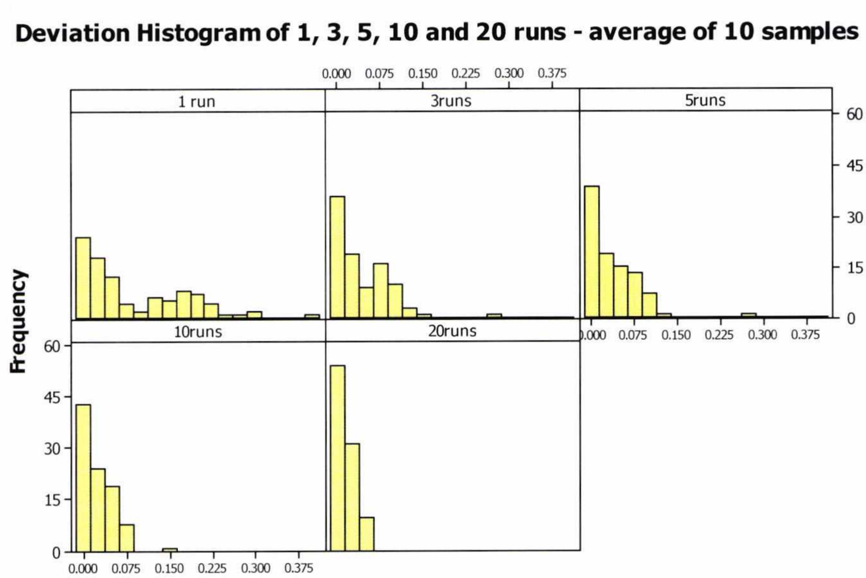


Figure 4.13: Deviation histogram and boxplot for each sample size – Scenario 1 taken from SC-FW 1

Scenario 2



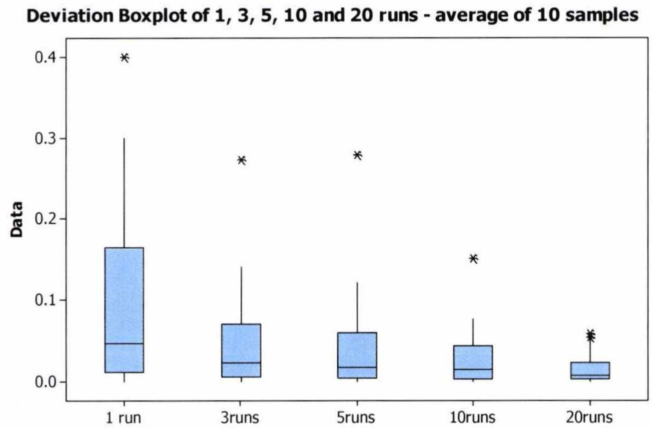


Figure 4.14: Deviation histogram and boxplot for each sample size – Scenario 2 taken from SC-FW 2

Scenario 3

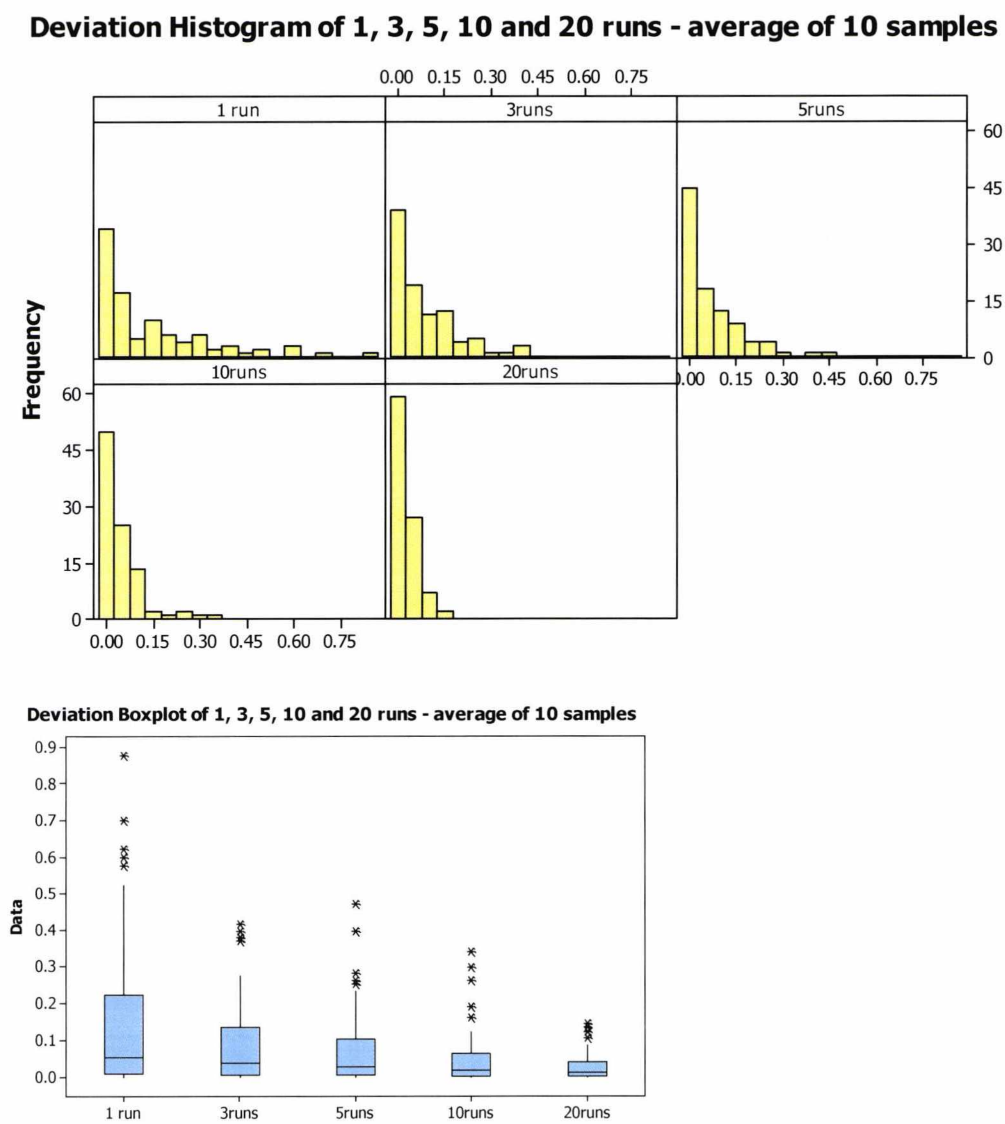


Figure 4.15: Deviation histogram and boxplot for each sample size – Scenario 3 taken from SC-FW 3

As we can see from the diagrams there is a clear increase in output accuracy in case of multiple replications. The outcome of the considered cases above further support the recommendation of Law and McComas (1990) suggesting a minimum of 3 to 5 replications. Altogether, a minimum of five runs should result in sufficiently accurate output within the considered simulations that need a significant time for completion. As long as computing power or time are no critical issues, using 10 or 20 replications is more advisable since accuracy can be further improved substantially. Due to extensive running time of most of the simulation scenarios that are investigated later on, the default number of replications is set to 10. This should result in sufficiently reliable outcome that is not significantly influenced by the implemented model variability.

Solution validation – comparison with the real system

Ultimately within solution validation we investigate how the model behaves under the same conditions as the default real world system. Therefore, we compare the output of the model with data and information collected beforehand. These two resulting scores should be sufficiently similar or a sound reason has to be found why they are not. The problem within this step of validation might be the possible inaccuracy of real world data, thus instead of simply comparing the stated scores we should try to evaluate the outcome for its feasibility. To be able to interpret the results one has to consider that the market data/information were either obtained from historic records or follow the estimate of subject matter experts or practitioners. As mentioned earlier, the simulation model was set up to sufficiently reflect the identified processes within the conceptual model on one hand and to account for the observed market intelligence on the other. Since the obtained reference data are by no means free of errors, deviations should be acceptable to some degree since the actual simulation model aims at nothing more than to reasonably represent the actual system and not necessarily to precisely map every detail of it.

Model output to reference comparison Supply Chain Framework 1

Framework parameters: fixed order date, flexible quantity delivery schedule

Key performance indicators	Simulation results	Observed data/ estimates
Service level gap overall	4.4%	5-6%
Service level gap C1	1%	<1%
Service level gap C2	1%	<1%
Service level gap C3	11%	~10%
Service level gap C4	7%	~5-10%
Max duration of Out of Stock at retail outlets	>1week	>1week
Fill rate Manuf-retailer DC	87%	~80-90%
Fill rate Retailer DC-outlets	98%	97%
Number of tours to replenish retailer DCs	98%	100%
Ready made goods inventory level at manufacturer	10 DD*	10-15 DD*
Excessive inventory at manufacturer	4%	almost never
Production output	812000	~800000
Production planning forecast error	8%	10-15%
Non-delayed deliveries Manuf-retailer DC	59%	~2 in 3 orders
Critically delayed deliveries Manuf-retailer DC	9%	~1 in 10 orders
Delayed deliveries retail DC-retail outlets	7%	5-10%
Consumer demand during the investigation period	846500	851000

*DD – Days' Demand

Table 4.3: Key performance indicator comparison simulation vs. reference for SC-FW1

Model output to reference comparison Supply Chain Framework 2

Framework parameters: flexible order date and quantity delivery schedule, no collaboration

Key performance indicators	Simulation results	Observed data/ estimates
Service level gap overall	3.7%	4-5%
Service level gap C1	3.9%	~4-5%
Service level gap C2	3.6%	~3-4%
Service level gap C3	3.5%	~4-5%
Service level gap C4	4.1%	~5%
Max duration of Out of Stock at retail outlets	0.5 weeks	<1 week
Fill rate Manuf-retailer DC	74%	~70-80%
Fill rate Retailer DC-outlets	97%	~95-100%
Number of tours to replenish retailer DCs	131%	125%
Ready made goods inventory level at manufacturer	8 DD	7-10 DD
Excessive inventory at manufacturer	3%	almost never
Production output	162000	160000
Production planning forecast error	9%	~10-20%
Non-delayed deliveries Manuf-retailer DC	12%	~1 in 3 orders
Critically delayed deliveries Manuf-retailer DC	78%	~1 in 2 orders
Delayed deliveries retail DC-retail outlets	8%	9%
Critically delayed deliveries retail DC-retail outlets	2%	4%
Consumer demand during the investigation period	168000	170000

Table 4.4: Key performance indicator comparison simulation vs. reference for S- FW2

Model output to reference comparison Framework 3

Framework parameters: flexible order date and quantity delivery schedule, no collaboration

Key performance indicators	Simulation results	Observed data/ estimates
Service level gap overall	1.9%	2-3%
Service level gap C1	0.2%	<1%
Service level gap C2	3.4%	3-4%
Service level gap C3	2.9%	3-4%
Service level gap C4	0.8%	<1%
Max duration of Out of Stock at retail outlets	0.4 weeks	<0.5 weeks
Fill rate Manuf-retailer DC	89%	90%
Fill rate Retailer DC-outlets	99%	~99%
Number of tours to replenish retailer DCs	110%	~110-120%
Ready made goods inventory level at manufacturer	12 DD	11-14 DD
Excessive inventory at manufacturer	12%	15%
Production output	537200	~540000
Production planning forecast error	15%	21%
Non-delayed deliveries Manuf-retailer DC	60%	~2 in 3 orders
Critically delayed deliveries Manuf-retailer DC	11%	~1 in 10 orders
Delayed deliveries retail DC-retail outlets	2%	no data
Consumer demand during the investigation period	548300	549200

Table 4.5: Key performance indicator comparison simulation vs. reference for SC-FW3

Looking at the figures obtained from the simulation outcome we can see most of them being sufficiently close to the pre-obtained benchmark scores. This was accomplished by experimenting with the various model parameters in order to obtain suitable values to reach the desired output. Multiple runs assured that output figures were stable enough to achieve sufficient confidence limits. The presented benchmarking metrics represent the most important performance measures within the forthcoming analyses and should thus be capable to assure a reliable investigation output. There are altogether a few cases where reference scores seem to differ substantially from the model output (e.g. production planning forecast errors and delivery delay figures in supply chain framework 2). These cases have been individually evaluated with the conclusion that deviations seem to be due to implicit simplifications within the modelling process but do not constitute general methodological shortcomings. The planning forecast error for example is different due to missing human interference. The lower delivery delay figures obtained by the model compared to real life figures can be explained by an idealistic system assumption of no breakdowns or human error which is of course different in real life. Considering the amount of predetermined framework assumptions and substantially reduced complexity, the model still seems to successfully reflect the operational flow of the individual systems. Within reference scenario investigation in Chapter 6 there will be additional explanation of the individual scores stated above, each default supply chain frameworks' performance background and further details comparing the actual situation with the results of the simulation outcome.

4.6.2 Model verification

Model verification focuses on testing whether the conceptual model has been satisfactorily turned into a computer model. There are two main approaches to conduct verification: static and dynamic testing.

Static testing

Within static testing, techniques such as a *structured walk-through* aim to examine the correctness of the structured properties of the programme. The modeller thus needs to walk through the implemented code to ensure that data has been entered correctly and appropriately. Within our simulation this involves mainly verification of the implemented Visual Logic code. Overall, the amount of implemented logic is quite substantial since the scale and scope of the model necessarily demand incorporating a vast amount of programming code that establishes the model-underlying logic and steers strategic and operational behaviour of the various model-entities. Altogether the code expands over 60 printed pages (see Appendix III), so to help ensuring the programming code runs properly, program design and development procedures found in the field of Software Engineering were employed within the developing and implementing phase of the modelling process. Some examples for this kind of verification techniques are top-down design, bottom-up, structured programming and program modularity. Within top-down design we first make a simplified overall model of the system and test it. When it works, simplified versions of parts of the system are replaced with more complex and realistic sub-models. Following a bottom-up approach on the other hand implementation starts with testing individual parts of the model before combining them. Overall, we used a combined approach integrating elements of all four aforementioned verification techniques. In general a rather complex simulation model including hundreds or even thousands of lines of code needs to be debugged in modules or sub-programmes. It would without a doubt be poor programming practice to attempt writing the entire code before attempting any debugging. Once such a large, untested programme is finally run, it almost certainly will not run as expected and determining the location of the errors will be extremely difficult. To prevent this from happening, the basic logic routines need to be written and debugged first. Then additional subroutines or additional level of detail must be added and debugged successively, until a model is developed that satisfactorily represents the system under study. Following this logic, we initially created a simplified overall version of the system. Afterwards new features were implemented in a simple form and tested extensively. Within this stage only one new feature is added to the system at a time to avoid possible interdependencies. In that way we established various reference schemes that recorded individual impact of each feature module and could be used for comparison later on. Once these individual modules operated sufficiently correct we ran them simultaneously. Within this stage we compared model output with the reference designs obtained earlier to reveal possible inaccuracies or any kind of abnormal behaviour. If the so enhanced system operates satisfactory, we replaced the simplified feature-modules with more complex and realistic sub-models. Finally the underlying system itself could be extended to reach the scope and scale of the conceptual model.

Dynamic testing

Within dynamic testing, the computerized model is executed under different conditions and the resulting values are used to determine if the computer programme and its implementation are correct. The techniques commonly used in dynamic testing are traces, investigations of input-output relations, internal consistency checks and reprogramming critical components to determine if the same results are obtained (Sargent, 2000). Throughout the modelling process we applied dynamic testing mainly in the form of consistency checks using extreme values to observe the resulting behaviour. Apart from that we used traces, in the form of step by step evaluation of any ongoing change within the system. The ability to investigate a system stepwise with even the possibility to go backwards in time is a particular strength of modern discrete event simulation packages. This allows to monitor any minor change within the system that can be tracked to see if it is operating as intended. In performing such a trace it is desirable to evaluate each possible logical path and the way the system handles extreme conditions. To account for such situations, special input data was prepared for the model.

4.6.3 The challenges of verification and validation

As already mentioned above, validation and verification are meant to ensure that the used model is wholly adequate and appropriate for the task for which it is intended. However, this simple idea can be immensely hard to fulfil in practice. To begin with, within modelling we assume that problems we work on are independent of the modeller, outside observers or inside experts that contribute knowledge towards the final model. However, a model will always reflect the individual views about what should be included in the model, how and to what extent and thus never be an accurate representation of reality. A simulation model of a complex system can thus only be an approximation to the actual system, regardless of how much effort is put into developing it. Since absolute validation is barely possible the goal is to find a trade-off point between effort put in to further validate a model and the actual accuracy gain resulting from this validation. Extensive effort put into validity of a model beyond a certain point will surely be expensive and time consuming but might not actually increase the value of the model itself. Simulation models in general are better in comparing alternatives than determining absolute answers. It might thus be a good idea to develop and validate a model up to the point that allows a reasonable comparison between two or more alternatives but at the same time to accept the fact that it might not be possible to determine the exact outcome of either alternative. A simulation model should thus be validated relative to those performance indicators that will actually be used for decision making whilst other measures may not be important. A common mistake in simulation modelling is also to make the model overly complex in an attempt to incorporate as much realism as possible. Such models will be costly to develop, slow running, hard to control and thus prone to errors whilst they might not contribute any additional valuable information to address the defined objectives. On the other hand it is all too easy to oversimplify which results in a model providing insufficient detail to handle the full complexity of the simulated system. Common further issues applicable within the framework of this research project are messy real world data and information provided from various sources, insufficient time to verify and validate every single assumption and to some part the non-availability of comparison data due to non existence of the system that is aimed to be implemented. The overall aim thus had to be to ensure that as much of the model is verified and validated that is reasonably feasible to the modeller. Following the outline of Robinson (2003), it is not actually possible to prove a model is valid but what matters more is the confidence that can be placed on it. Overall the goal of verification and validation needs to be to foster this confidence to convince clients to the point where they are willing to use it as a tool for decision making. Considering the fact that the developed simulation model has actively been involved in tactical and strategic decision making within three supply chain frameworks, this goal has certainly been reached.

5. Data preparation, forecast evaluation and implementation

This chapter aims to reveal a variety of insights about practical implementation issues that arise within the process of analysing real life sales data, developing forecasting models and methodology and implement these into simulation models. The process that will be explained is about analysing raw sales data with the aim to utilise them in a supply chain simulation model and to drive a demand and order forecast that can be used within the model. Particular emphasis will be laid on the process of data preparation and analysis, choice of forecast techniques and forecast implementation. Preliminary, the following analysis underlines the need for thorough data analysis prior to implementation into any kind of forecasting or simulation system to identify the right influential factors that will distinguish random fluctuations from a true demand signal. We demonstrate that saved effort within this preliminary phase cannot be made up for at later stages since even the best forecasting technique cannot patch up mistakes that are done within the data preparation phase. In a second step, the analysed data are used to test a variety of common forecasting techniques to evaluate their capabilities, suitability and ease of implementation. To support this target, several forecast accuracy measures are evaluated for their appropriateness and novel approaches are introduced using "weighted" factors. In the final step the gained knowledge is used for implementing suitable techniques within a simplified version of the previously introduced discrete event simulation model which will underline the success or misperception during the preliminary considerations.

5.1 Preliminary considerations

Without any doubt, forecasting within the last decades has been consistently recognised as an essential instrument for business planning and management (e.g. Sanders and Manrodt, 1994 or Makridakis and Wheelwright, 1977). A good forecasting system does much more than just to prepare demand predictions. Depending on the system it can additionally help in generating optimal plans for distribution, manufacturing, logistics, sales, finance and marketing (Jain, 2003). Regardless of whether a particular company is a supplier, retailer, manufacturer, wholesaler or some other kind of service provider associated with whatever industry, effective demand forecasting helps organisations to successfully identify market opportunities, achieve high service levels, satisfy their customers, cut down on unnecessary inventory, avoid product obsolescence, enhance channel relationships and schedule production effectively to achieve overall competitive advantages and to run a business profitably (Galfond, Ronayne and Winkler, 1996). To continuously improve their forecasting methods, companies took advantage of a variety of electronic equipment and information technology that emerged within the last decades. Forecasting systems have moved from large mainframe workstations to standard PC's and thus are accessible by the entire management not just by specialists. Furthermore, modern forecasting systems are not limited to a single forecasting approach anymore but can choose and compare the outcome and accuracy of a variety of methods (Mentzer and Kent, 1999).
The use of scanning technology to obtain point of sale (POS) data made demand data available for further analyses instantly and without any timeless delays. Electronic Data Interchange (EDI) is used to transmit detailed sales information throughout various marketing channels to product distributors and manufacturers (Mentzer and Kahn, 1997). The internet has made it possible to retrieve data from any part of the globe easily, quickly, accurately and inexpensively (Jain, 2003). Finally, the introduction of computer simulation that uses these data to realistically model entire supply chains and thus make it

possible to reveal cause and effect relationships as well as testing of what-if scenarios within the entire business environment have further improved the possibilities of data analysis for management (Pidd, 2004).
Nevertheless, all these advantages and process automation developments have led to a gap in understanding of the relationships between systems and techniques used for forecasting, and the behavioural factors associated with the management of forecasting in organizations (Winklhofer *et al.*, 1996). Out of these developments, a wide variety of forecasting techniques were developed within academic circles and incorporated in more or less proprietary software packages but practical understanding of the developed methods suffered. Since some degree of forecasting is nowadays daily business of all levels of management within a majority of companies, a gap is widening between using and understanding particular techniques and approaches (Moon, 2003). A variety of studies including Fildes and Hastings (1994) and Mentzer (1999), have come to the conclusion that successful implementation of forecasting systems in the managerial decision making process within a company involves more than just the introduction of more sophisticated forecasting techniques and tools. What is rather necessary is an increased level of understanding how these forecasts are generated and how new methods and tools can particularly support better decision making. Most forecasting related literature seems to focus on how to best improve and possibly combine existing models on a rather theoretical level. This opens a gap between the academic theorists that try to achieve better results within specialised fields of application and managers that do not have the theoretical insights and just look for some simpler guides and case studies of how to take advantage of these developments within the last ten years.
Forecasting as practiced in business is still a young function. According to Jain (2003), only 55% of surveyed companies across all industries have hired one or more full-time forecasting experts. Furthermore, 70% of the companies that have actually introduced some kind of systematic forecasting system have done so within the last seven years. Thus businesses are looking for guidelines and directions either for starting this function for the first time or for improving it. A special emphasis within this investigation is to be laid on companies that do not belong to the avant-garde of businesses that are blessed with vast resources. The focus of the analysis is – in line with that of the entire thesis – on SME companies that just cannot afford to hire forecasting experts or maintain specialised forecasting departments nor do they have the resources to perform extended research and testing activities. On the other hand they also want to take advantage of new, fashionable business tools like data mining, simulation and extensive forecasting techniques but on a much simpler and customised level than the major players.
To serve the above spirit, analytical tools and methods have been chosen to represent the level of understanding that can be expected from typical sales analysts within these small or medium sized companies. Too deep technical detail is avoided to serve the purpose of understanding rather than an exhaustive overview of latest dynamic forecasting approaches. ARIMA[1] methods in particular were limited to ARIMA(0,1,1) and ARIMA(0,2,2) approaches since auto-regression proved to be of very limited additional value regarding the forecast quality of the particular two data-sets applied since market

[1] The acronym ARIMA stands for "Auto-Regressive Integrated Moving Average", ARIMA models are, in theory, the most general class of models for forecasting a time series which can be stationarized by transformations such as differencing and logging.
Time-Series Forecasting approaches like random-walk and random-trend models, autoregressive models, and exponential smoothing models (i.e., exponential weighted moving averages) are all special cases of ARIMA models. A non-seasonal ARIMA model is classified as an "ARIMA(p,d,q)" model, where:

- p is the number of autoregressive terms,
- d is the number of non-seasonal differences, and
- q is the number of lagged forecast errors in the prediction equation (Nau, 2004)

conditions proved to be rather stable. To serve the purpose of simplicity and lower the computational and implementation effort, dynamic regression was avoided and annual market trends based on static regression were incorporated instead.
Nevertheless, the analysis follows typical crucial points within the process of understanding, analysing, implementing and testing of a demand forecasting system. It has been obtained in cooperation with two SME companies that prior to this analysis based their sales forecast mainly on past experience and a pen and paper based "feeling for the market" in order to set long term production and delivery horizons. The analysis underlying processes of applying spreadsheet based data-decomposition, forecast quality measurement evaluation, forecast method comparison and testing via simulation were appreciated as a helpful approach to consider changing market conditions and to evaluate certain what-if scenarios.

Methodology

The investigation approach will begin with a data analysis part, continuing further with an examination of forecast determinants to lay the groundwork for evaluation and comparison of several forecasting techniques. On the basis of this we will apply data and selected techniques within a simulation approach to draw final conclusions about importance, suitability, problems and possible improvements of the whole analysis.

The data analysis will use classical time series decomposition techniques (Winston, 1997) which are standard procedures for removing trends out of raw data to reveal a true underlying signal. Sources that will be used to ensure an appropriate analysis are:

- Weekly sales data for a particular period, region, retailer and products obtained from two supply chain frameworks
- Promotional activity schedule data for the particular period, as well as historical promotion-impact data
- Historical seasonal factor data that goes beyond the period under consideration
- Further framework related information provided by both companies

The forecast evaluation will be based on this data-decomposition. The analysis will evaluate several scenarios to make judgements about forecast accuracy measures as well as forecast quality. These judgments will rely on a spreadsheet-based analysis of the underlying data. The software used for that purpose will be MS Excel 2003. Within this analysis, scenario-optimization will be carried out using the *Premium Solver Platform Version 5.5* of Frontline Systems that enables to solve even complex non-linear optimisation problems extremely fast and reliably using state of the art heuristic solution methods (Frontline Systems, 2005). An especially important feature is the variable multi-start option that approaches problem-sets globally and reveals several areas of local optima within the solution space as well as very good global optimum solutions which will be highly appreciated as further investigations will show. The simulation analysis is carried out using Simul8. The actual supply chain simulation model is the same as it was developed and introduced in Chapter 4. Although it is designed to investigate the impact of collaboration, it is capable to support the here considered analyses albeit after some further simplification.

5.2 Data Analysis and Preparation

The following section will introduce the sales data that are used to serve the investigation. Furthermore the raw data are broken down into several components to derive evident influential factors. This procedure aims to reveal a true demand signal aside from possible factors of influence that can be used for the later forecasting stage to achieve reliable prediction models.

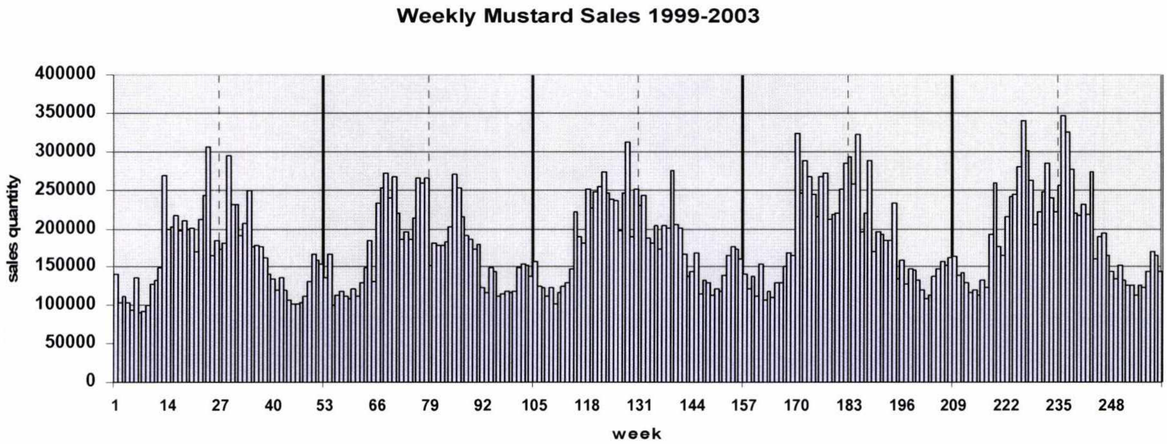
5.2.1 Preparation of the Data – Decomposition & Detrending

The analysis is based on data taken from two of the three supply chain frameworks introduced in Chapter 4. As a result of this, sales characteristics (promotional activities, sales impact, distribution schemes etc.) follow the previous outline.
In order to obtain a clear picture and true behaviour of the investigated sales-data, raw data have to be broken down into their components. Commonly these components are a *trend factor, a cyclical factor, a seasonal factor and an irregular factor* (Winston, 1997). A time series of data is built up of several of these components that have to be corrected to reveal a "true" signal. This signal can then be used together with the obtained factors to predict future behaviour.

De-Promotionalizing

Since both companies rely solely on two types of promotional activities, knowledge of previous and upcoming activity schedules should enable us to correct the given data to obtain a rather unflawed picture.

According to promotion schedules provided by the companies, the raw data is adjusted taking the average impact figures outlined in section 4.1.



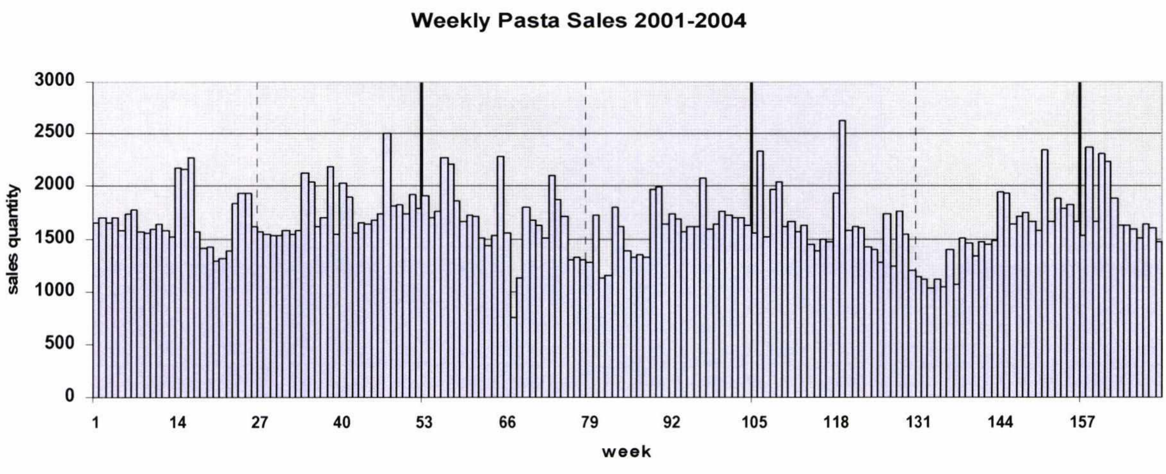
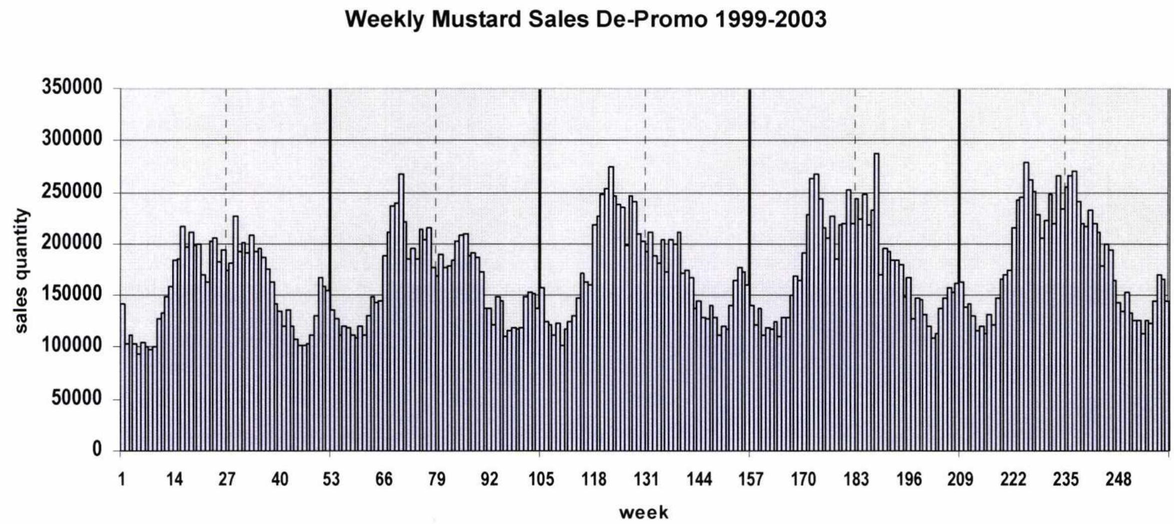


Figure 5.1: Weekly Sales unadjusted - Mustard and Pasta

The two data series above are clearly flawed by particular foreseeable events (promotions) and do thus not represent a clear image of the true demand trend structure.



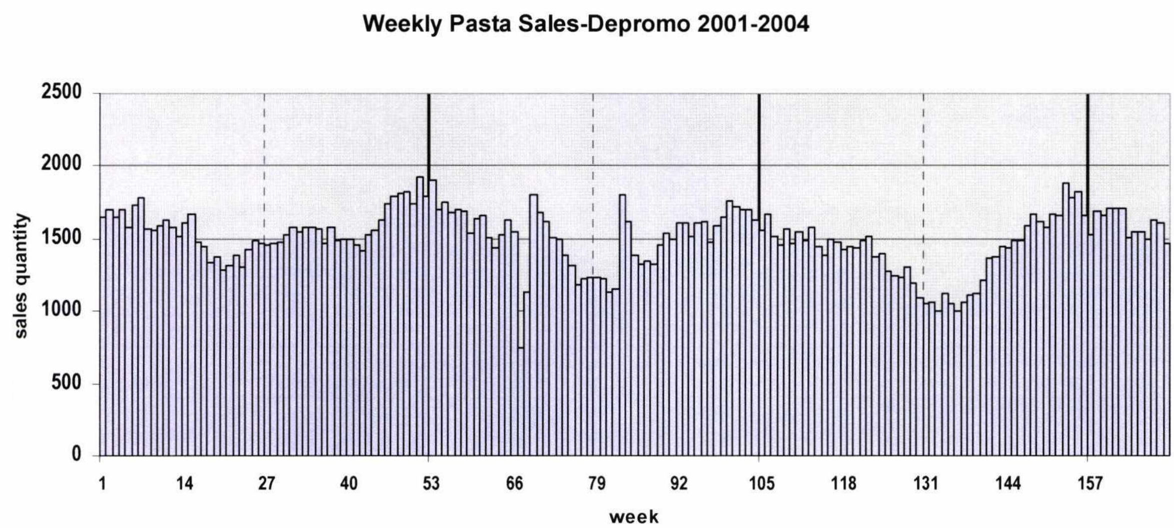


Figure 5.2: Weekly sales without promotional activity influence – Mustard and Pasta

As a result of the de-promotion adjustments, the graphs look smoother and show a much steadier behaviour. Following this step, the data can be used for further decomposition.

De-Seasonalizing

The goal here is to obtain seasonal factors from historic data that explain the deviations within a year as good as possible to adjust forecasts to match these seasonalities.
As can be seen from the graphs above, both products have quite steady and characteristic sales records that seem quite stable over successive years. Most characteristic for both are strong seasonalities. For pasta the sales are remarkably higher in winter whilst the mustard sells much better in summer. This does not come at a surprise since according to past sales experience pasta consumption and thus sales depend on season and outside temperature. Particularly in summer, sales seem to drop with hot weather and rise with cooler periods. This behaviour can be seen at several points within the pasta sales graph. To highlight the parts with this unusual behaviour, the seasonal factors have to be calculated and taken into the graph.

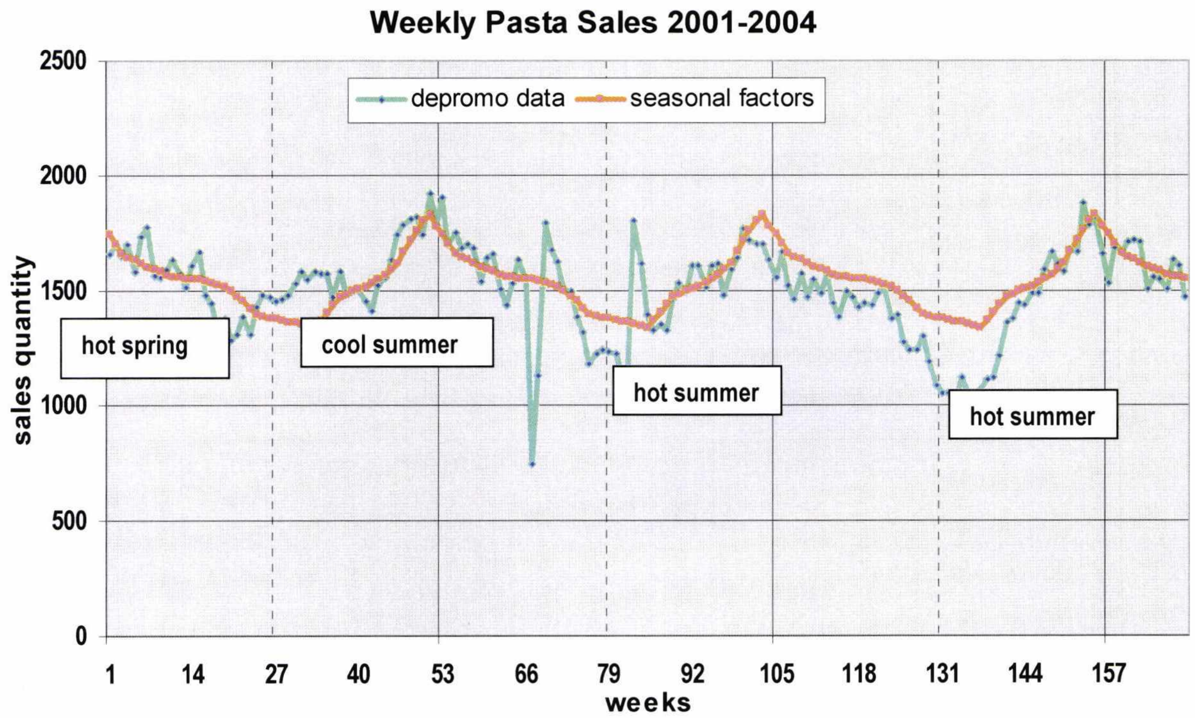


Figure 5.3: Seasonal pattern and weather influences on Pasta sales

After matching unusual demand deviation with weather and temperature statistics for the particular period and region, the predicted weather dependency can be at least partly acknowledged.

Mustard sales should be weather-influenced as well since according to the company's market research about 50% of summer sales of the investigated product are connected to BBQ usage and thus weather dependent consumption.

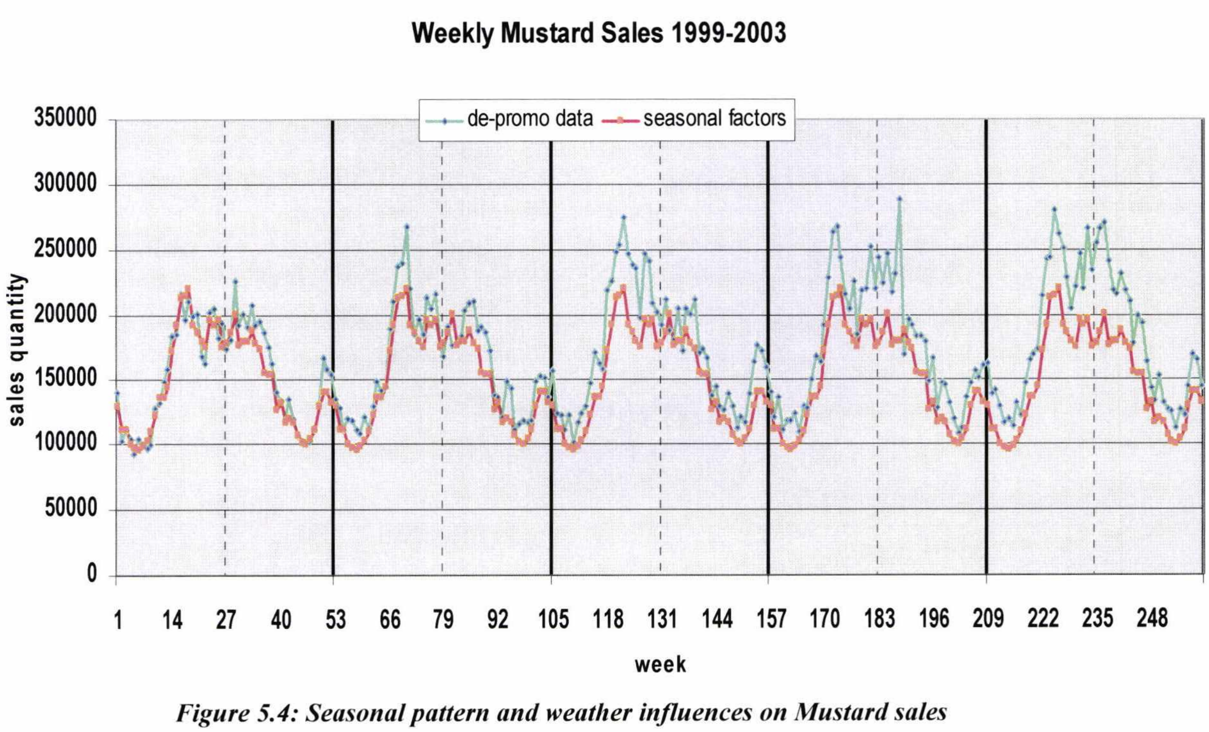


Figure 5.4: Seasonal pattern and weather influences on Mustard sales

Apparently the mustard is not that much influenced by unusual weather conditions but some slight deviations can be stated. Nevertheless there seems to be an underlying upwards trend due to increased market share which has to be removed to obtain a clearer picture.

Market trends and cyclical components

The market trends that influence the data should mainly consist of a global market trend, specifically if the market for the particular kind of product is expanding or contracting. The other part of the market-trend analysis is the development of market share for the particular product or company. Fortunately the market conditions for both products are rather stable. Both are food products which can be counted as standard, basic food items that should not be part of short term fashion trends or follow a particular life-cycle. A cyclical economic up or down-turn influence should be negligible as well since it is either covered by the other factors already or is not of much influence for basic food consumption. Investigations will thus focus on market-share and total market trend.

Pasta

The total sales figures of pasta for the entire market reveal a considerable increase over the considered forecasting period. Between 2000 and 2003 total annual sales increased from 259.560 tons to 279.478 tons, which is an increase of 7.7%. The total market sales increased therefore by approximately 2.5% per annum within these years (Nielsen, 2003).
At the same time the nationwide market share of this brand diminished from 7.8% in 2000 down to 7.0% in 2003, thus a decrease of 11% within four years (Nielsen, 2003). Taking these numbers into account we probably can expect a slightly diminishing sales trend since the overall expansion of the market does not make up the loss of market share. Aside this slight deviation, the development of the market for the particular pasta-product can be rather classified as mature and stable. Particular global sales trends must not be overemphasized within the forecasts.

Mustard

Compared to the pasta, a slightly different picture arises when having a look at the mustard sales. Unfortunately there was no market data available that could underline the development of the total market for this special kind of mustard but considering the nature of the product it can be assumed that it is fairly stable. The market share of the product is known nevertheless and it seems to follow a clear uptrend. The nationwide market share rose from 8.2% in 1999 to 9.9% in 2003, thus an increase of 21%. Considering this remarkable growth, any kind of production and delivery forecast should take this uptrend into account to obtain a reasonably good prediction for the future. After the discovery of certain movements within the market, a regression analysis is run to reveal these long-term trends and remove them from the underlying data.[2]
Having taken out promotional effects, seasonal effects and long term trends we obtain a much better picture of the data.

[2] For reasons of simplicity at this stage only a simple linear regression over the entire period of investigation was run.

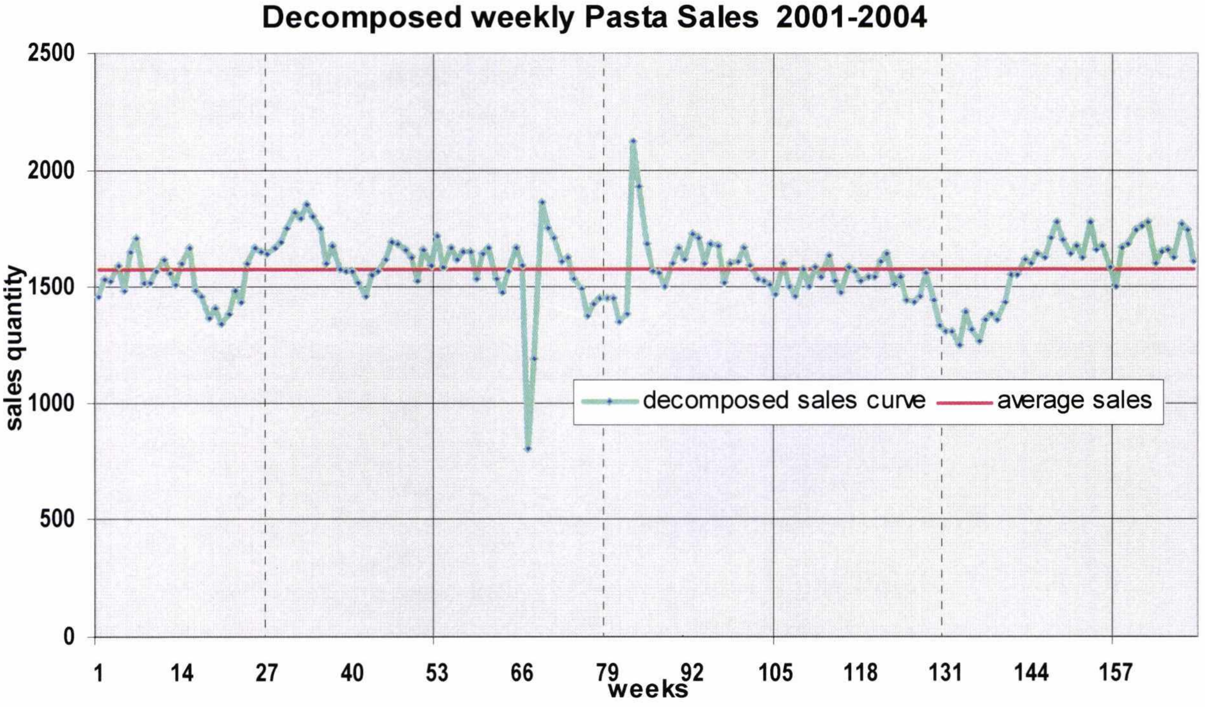


Figure 5.5: Pasta sales data after full decomposition

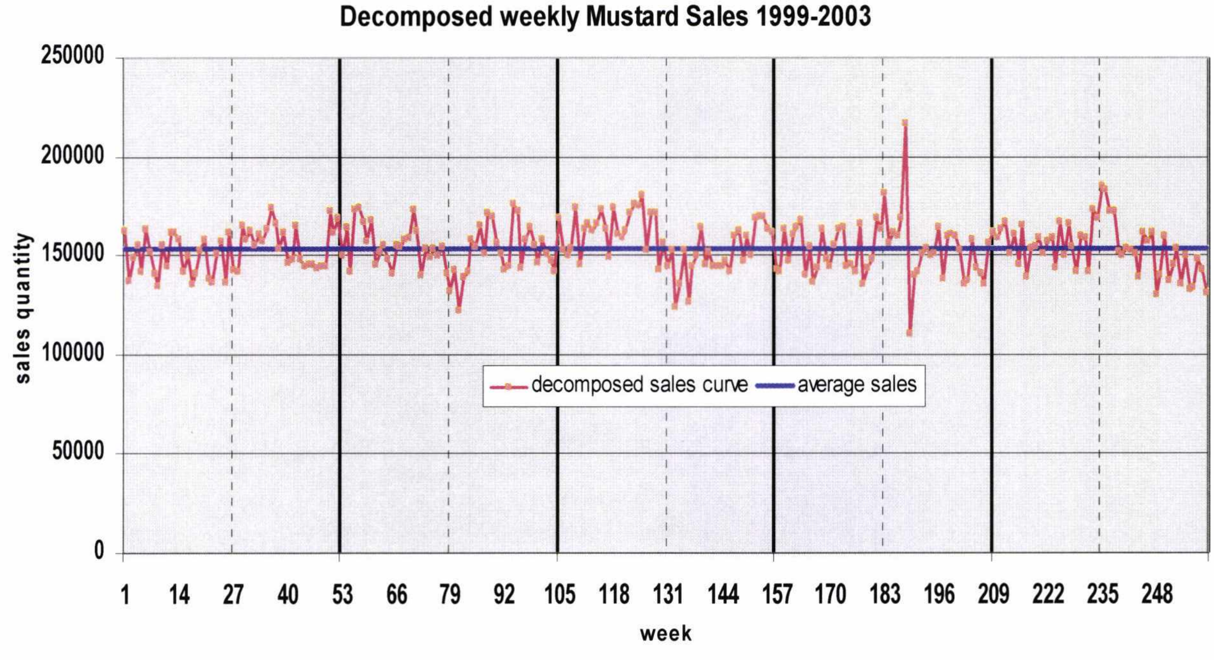


Figure 5.6: Mustard sales data after full decomposition

Within the two graphs above, decomposed sales curves move quite closely around the total average. The straight average sales line represents the case of no noise or the non existence of any kind of irregular factor. If in reality these lines would move straight there would not be much need for difficult forecasting techniques. In reality the decomposed curve still shows more or less remarkable deviations from the average sales line. These deviations can be seen as a degree of instability for the particular market and company. Strong temporary deviations are most often due to some kind of critical incident or disturbance. These are most often unpredictable but coping with these extreme situations is also a quality measure for a good forecasting system.

Exceptional Events – Irregular component

Aside from promotions, seasonalities and market trends the considered period seems to have seen further unexpected incidents that influenced sales more or less significantly. One of these is the weather and temperature dependency outlined before. Other unusual incidents can be identified as the flooding natural disaster that struck the region in August 2002 and in case of the pasta – a salmonella scandal within a competitor's pasta assortment in April 2002. The curve deviations for these incidents can be used to create some kind of event library that can serve as an underlying pattern for future forecast adjustments. After the phase of decomposition it is thus highly recommended to try to explain as much of the deviations as possible to reveal possible patterns.

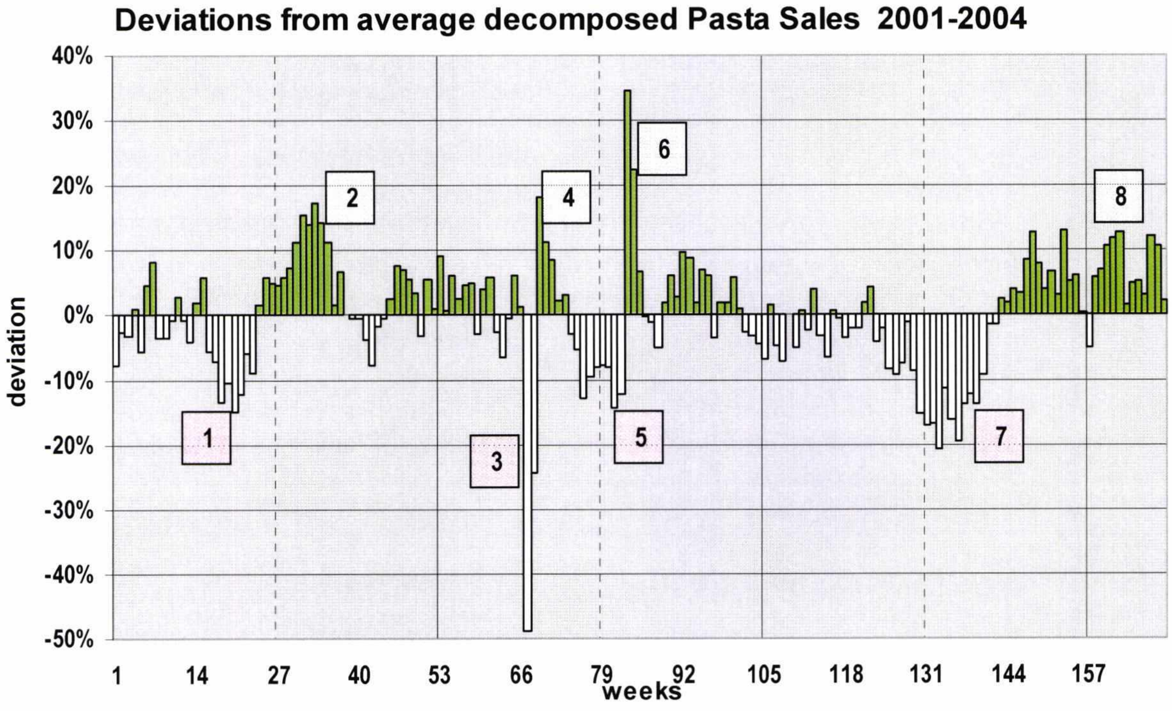


Figure 5.7: Exceptional sales deviations Pasta

- Deviation set 1 could be identified as hot spring period within the year 2001. For the particular region temperatures for late April, May and June were 8 degrees above normal (Statistisches Jahrbuch Stadt Leipzig, 1999-2003).
- Set 2 could be identified as unusually cool summer. Temperatures within July and August were remarkably below the long term average.
- Sets 3 and 4 can be explained with a salmonella incident that occurred in April 2002 that shortly affected all pasta that contained egg as an ingredient.
- Set 5 is again due to a hot summer.
- Set 6 can be reasoned with "panic" sales connected with the major flood incident that struck particularly this region in August 2002.
- Set 7 is due to the extremely hot "Century-Summer" 2003.
- Set 8 could not be identified that clearly but could have to do with the introduction of new package designs and thus increased market share in the very end of the investigation period.

Apart from the outlined explainable variations there is always some kind of fluctuation within the data that cannot be justified. These minor deviations are referred to as noise.

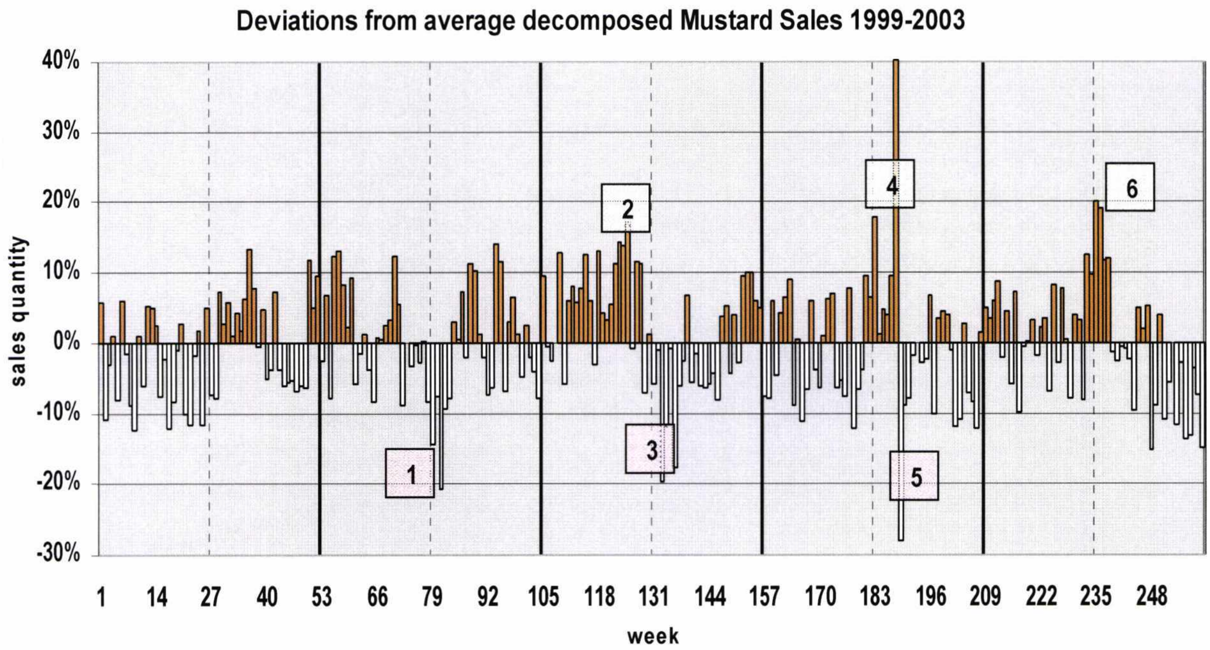


Figure 5.8: Exceptional sales deviations Mustard

Things are slightly more difficult to reason for the mustard sales. There seems to be much more "noise" that cannot be justified. Deviation sets 1 and 3 could be connected to rather cool summers in 2000 and 2001. Set 2 with the exceptionally hot spring in 2001 and 4 & 5 with the flooding. Set 6 could be due to a very hot summer in 2003 again. Aside from that and according to company-internal sources there is an unusual peak in demand depending on the asparagus season start within March/April/May since this mustard is frequently used as ingredient for a special sauce that is very popular to be combined with asparagus. Nevertheless it becomes obvious that identification of particular events is often a matter of chance that depends on how stable other influential factors are that could usually flaw a clear observation of particular effects.

5.2.2 Concluding comments

Considering the forthcoming forecast investigations, managing unexpected incidents and short term trends is a major part of a forecast's prediction quality. Since most often such events are not foreseeable and thus cannot be incorporated into production and delivery schedules, they must remain in the data sets during further investigations. Decomposition is thus most useful to analyse historic sales data to find demand pattern under certain circumstances that can be used if a similar incident should happen in the future.

It is therefore important when creating a simulation model not just to take historic demand figures to validate the model but also to cope with certain abnormal behaviour to be able to judge about the analysis outcome. Interdependencies between echelons within a supply chain simulation or cause and effect of delivery failures within delivery scheduling are examples that need scenario analyses to be able to judge what has to be changed to improve the system in case of failure. It is the flexibility that defines applicability in real-life. At the end of the day a good system analysis tool such as simulation has to cope with unforeseen incidents since it is such a useful tool as it does not depend that much on constraining conditions. Thus a thorough investigation of all underlying data prior to implementation is essential for any model validation process.

5.3 Evaluating Forecasting Techniques and Accuracy Measures

After section 5.2 introduced the method of data-decomposition, the pre-processed data is now used to evaluate several forecasting techniques for their suitability, success and ease of implementation.
To serve the purpose of completeness but still keep the necessary effort manageable, the investigation procedure will select several common techniques and compare them with each other as well as with another custom forecasting method that is used by the sales department of one of the investigated manufacturers. In particular we will have a look at moving average based forecasting techniques, exponential smoothing approaches, adaptive forecasting techniques, seasonal factor forecasting, regression forecasting and compare these standard approaches with a simple Excel-based system that is used by various practitioners ("BUCK's approach"). Within further analyses a particular focus will be on how well the forecast matches the requirements within a real life (or simulation) business framework rather than at a theoretical level.

5.3.1 Brief outline of certain techniques and types of forecasting

Within this initial step we will briefly introduce common techniques and types of forecasting as well as discuss their appropriateness within chosen frameworks. At the end we will discuss certain targets and implementation issues for the forthcoming simulation analyses.

Extrapolation forecasting vs. causal forecasting of future sales

Within the whole framework of possible forecasting approaches starting from either statistical or judgmental approaches and going deeper into univariate or multivariate modelling, there are mainly two important types of forecasting methods that are of major concern for sales and demand prediction considering implementation into self-guiding simulation models. These are extrapolation and causal forecasting models.

Within **extrapolation forecasting** (also known as time series forecasting) past patterns and trends are assumed to continue in future months. Pure extrapolation of time series assumes that all we need to know is contained in the historical values of the series that is being forecasted. Thus, solely past sales data of the particular product are used to generate forecasts of future sales. Extrapolating methods do not take into account what caused past data. They just assume that more or less recent trends will continue in the future (Winston, 1997).

Causal forecasting methods on the other hand try to forecast future values of a variable by using past data to estimate a relationship between one or more independent and one dependent variable. For the particular case the dependent variable will always be the sales quantity respectively the demand. Possible independent variables are price, advertisement, seasonal factors or competition. Causal forecasting is mostly used in scenarios where demand or sales patterns vary significantly with planned or unplanned events, it aims to find underlying influencers of the sales quantity to determine some kind of relationship between the underlying and the output variable to describe and predict future behaviour. Common types of causal forecasting are regression and correlation-analyses (Pindyck, 1998).

The weakness of causal forecasting lies in interpretation of the outcome; it can be quite problematic to identify the right amount of independent variables that reliably support a future prediction. Moreover it is generally difficult to combine the identified influencing variables and form some kind of short term prediction. Overall, it results in suggestions rather than a clear trend projection of what to expect from business in the short term future. Nevertheless its strengths lie in situations with clear correlations to just predict the outcome of one variable that is influenced by one main determinant. It is an essential tool to identify underlying influencers of the observed and forecasted output variable. These identified influencers can then be taken out of the data and reveal a true signal for time series based forecasting techniques. Causal forecasting techniques used for short-term demand prediction are thus particularly necessary within the process of data-decomposition.

Besides these two methods mentioned above, we can also classify *Life-Cycle* Techniques that use demand-curves or profiles to forecast into the future and additionally *Judgemental*-approaches that solicit opinions from stakeholders such as customers, all sorts of market influencers, gurus and the like to judge about the future (Lapide, 2002).

Types of Forecasts

The appropriateness of either one or a combination of the four main techniques mentioned above depends on the actual forecast purpose and horizon.

Generally we can distinguish three main types of forecasts commonly used in companies to support a variety of planning activities (Lapide, 2002):

1. *Operational forecasting* – for this type of forecast the emphasis lays on short-term scheduling of operations in such areas as supply quantities, production-level, inventory management, transportation and delivery schedules. The time horizon is usually within several days or weeks. This is the classical field for time-series based forecasting techniques since the short timeframe should imply no major external influencers and thus provide the stable environment that is needed for classical extrapolation forecasting.

2. *Tactical Forecasting* – supports tactical planning such as sales, marketing, brand-management, master-production schedule, distribution requirements and labour planning. The time horizon is certainly longer, usually several months or quarters even up to a couple of years. Therefore times-series based forecasting techniques will be useful to a certain extent as well but a major role will be taken by causal and judgemental techniques.

3. *Strategic Forecasting* – supports strategic planning for long term business planning and investment decisions as well as capital planning. Forecasts are thus generated over a much longer period of time, typically years or even decades. This is clearly the area for causal, life-cycle and judgemental forecasting techniques. Due to a vast amount of uncertain variables within the business framework, extrapolation forecasting would be of no use whatsoever.

Implementation Issues

The focus within the forthcoming investigations, particularly within the simulation analysis is to optimise production levels, delivery schedules, inventory capacities and reach a targeted service-level within the supply chain of a chosen company. The techniques of particular interest will thus rather be extrapolation or time-series methods. Nevertheless from the above proceedings it becomes obvious that a plausible forecast of future sales requires a combined approach taking advantage of time-series based forecasting as the main type of interest but also causal and judgemental types of techniques within preliminary considerations like the data preparation phase. For the case of the pasta and mustard sales data, it would make no sense to simply take the raw data and apply a time series forecasting method to it. An essential initial step is always to isolate an appropriate amount of factors that influenced these past sales patterns and will thus influence future sales accordingly. In general these are factors like market trends, price changes, promotional activities, seasonal factors or competitor's activities. These factors have to be tested for correlation and thus either proven to be of no significant effect or have to be taken out of the raw data according to correlation models found within the causal forecasting preparation phase. In the previously introduced pasta and mustard sales-example, factors that were identified to have significant influence were promotional activities, seasonal effects and weather conditions. Promotional activities from competitors, price changes or other possible major influencers proved to be of no significant influence or at least not within the period of investigation. The following proceedings will thus visualise the importance of each of the identified influencing factors towards the final forecast quality. Later on several extrapolation forecast techniques will be evaluated for their appropriateness and prediction quality. These appraisals nevertheless need forecast quality measures to be able to quantify the accuracy of the forecast and judge about practical use. Thus, such measures will be discussed preliminary.

5.3.2 Introducing Forecast Quality Measures

Due to the large scope of the field of forecasting, the sheer amount of models and techniques and their relevance to an enormous variety of business applications, there are also a large number of forecast quality or forecast accuracy measures defined.
To be able to make reasonable judgements about the forthcoming applied forecasts we have to define certain measures to evaluate their accuracy. These measures will define the optimal settings of the forecast methods' determinants and thus will decide upon the characteristics a particular forecast method takes. One general issue is that demand forecasts have to deal with balancing short term and long term accuracy. Long term forecast accuracy is rather important for strategic decision making like investment decisions or product introductions or alterations. Long term forecasts are thus often tackled by a combination of judgemental and statistical forecasting approaches. At an operational level or within tactical planning short term forecasts are usually much more important. Since forecasts considered hereafter mostly deal with these kinds of decisions further analysis will focus on short term accuracy to a greater extent.
Within the simulation model that was outlined in Chapter 4, forecast techniques will be mainly used to predict the upcoming demand within the forthcoming four weeks and thus determine the production level for the company or determine replenishment points and quantities. Altogether, this clearly speaks in favour of a more short term oriented forecast optimisation approach. The two prediction quality measures that will be taken for evaluation here will be MAPE (Mean Absolute Percentage Error) as the most widely used measure of forecast accuracy and RMSE (Root Mean Squared Error) as a further

commonly used measure (Winston, 1997). Whilst MAPE is mostly used within the majority of applications due to its simplicity and robustness, RMSE is particularly interesting to avoid a few but rather severe deviations within the forecast due to its quadratic nature.

A shortcoming of both methods results from the fact that they always incorporate all sets of data. In real life forecast parameters are adjusted in order to achieve the absolute best outcome. Nevertheless, since demand forecasting takes a long period into consideration there will always be events that can be marked exceptionally or emergencies. Demand behaviour during these incidents is usually too exceptional for a standard forecast to tackle it. Such scenarios will always depend on manual adjustments from skilled supervisors. Nobody would support the idea to just let the internal IT forecasting software optimise production and delivery schedules instantly responding to an event of emergency like September 11th 2001 or the Elbe-Flooding in Eastern Germany 2002.

Nevertheless these figures (deviations in demand either extremely high or extremely low) will remain in the data and standard forecasting accuracy measures will treat these particular extreme error levels like any other. Thus the forecasting parameters will most likely solely focus on minimisation of error levels for the few extreme incidents since these have an enormous weight within the total sum of errors due to their extreme nature.

What is thus needed is an accuracy measure that optimises forecasting parameters only for the 95-99% of "normal" cases. Therefore we will introduce another forecasting quality measure named *Percentile* that optimises for a >95% percentile of error scores. The score that will be displayed in tables of further investigation will represent the 95% percentile score, meaning that 95% of the cases have a deviation below that score. Hence optimisation of forecast parameters will focus only on the "normal" 95% of the cases and ignore the extreme deviations.

Another idea within forecasting quality measurement that could be considered is the heavier weighting of underproduction compared to overproduction errors. Generally within production scheduling it is considered much worse if the forecasted and thus produced quantity should be too low than if it should be too high. Optimal production and delivery schedules always target to get along with the lowest possible level of safety stock and inventory. Thus an underproduction resulting from too low forecasts constitutes a much bigger problem than a slight overestimation of demand and thus some excess inventory that can be accommodated within the following weeks' production plans.

Hence some kind of forecast quality measure should be considered that puts heavier weights on negative errors (forecast lower than actual demand) and thus supports a parameter setting that tends to focus primarily on avoidance of underproduction but still has total error minimization as main target. To achieve this effect within the following proceedings, negative forecast deviations (underproduction) are weighted with a certain factor (e.g. 2) to increase their impact within the total optimisation model.

5.3.3 Impact of different Forecasting Accuracy Measures

After implementing several forecasting techniques into a spreadsheet to reasonably predict near-future sales, each forecast's parameters were optimised to achieve the best possible result according to the six different forecasting accuracy measures defined above.

Namely these were MAPE, RMSE and the Percentile approach either weighted to emphasize overproduction rather than underproduction or with no particular preference.

The impact of these six measures was evaluated within three different forecasting technique scenarios, namely Linear Exponential Smoothing (Holt's method), Double Exponential Smoothing and a custom forecast method. This custom method is based on a "traditional" excel forecasting approach used by one of the manufacturers. It will be laid

out in more detail later. So far it just has to be mentioned that it does not use any adjustable parameters and thus cannot be optimised according to different accuracy measures. It will nevertheless serve as a reference.
Each particular forecast technique tried to predict sales as good as possible within a three weeks timeframe. This is due to the fact that within the simulation model discussed in Chapter 4, production planning has to be determined according to the demand within the following four weeks since items produced within each particular day of the actual week should reach the retail outlets within a 4 to 35 days timeframe.
The sales data have been decomposed to avoid influence from promotional activities, seasonalities and global long term trends. Those were removed from the data prior to forecasting and re-instated afterwards. The investigation is run only for one of the supply chain frameworks since this is the same case that will also serve for the forecast implementation investigation later on in this chapter.

Forecast accuracy measure evaluation for Linear Exponential Smoothing scenario

Non-weighted approach LES

Parameter Settings	MAPE-Score	RMSE-Score	Percentile-Score	Alpha-Parameter	Beta-Parameter	Initial Trend Parameter
Optimal MAPE	15.62%	360.14	609.20	0.515	0	0
Optimal RMSE	16.04%	344.80	583.28	0.244	0	1.19
Optimal Percentile	16.39%	349.05	555.79	0.211	0.0076	1.8

Table 5.1: Results for non-weighted Linear Exponential Smoothing

The alpha, beta and initial trend parameters presented in the table are running and starting parameters of the particular forecast method. They will be further outlined in section 5.3.4. For more details about forecasting parameters see Winston (1997). From the table we can see that each accuracy measure sets the forecasting algorithm (LES) up with different parameters to obtain an optimal fit. Optimal MAPE is achieved with a rather high alpha value of 0.515 thus including historic values to the same amount as very recent data. Optimal RMSE and Percentile conditions have lower alpha values and thus preferably include historic figures more than recent trends.

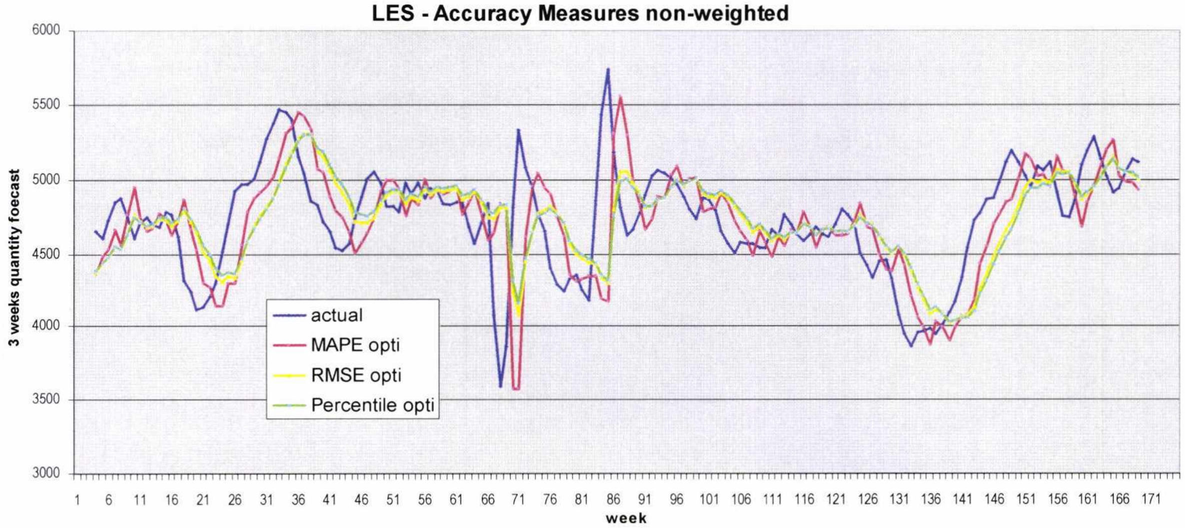


Figure 5.9: Four different forecast accuracy measures tested using LES

Looking at the actual graph we can identify that RMSE and Percentile optimised forecasts behave almost identically. From a pure eyeball test MAPE optimisation gives the best fit since it follows the closest when it comes to sudden trend changes.

Weighted approach to support over- rather than under-production LES

Parameter Settings	MAPE-Score	RMSE-Score	Percentile-Score	Alpha-Parameter	Beta-Parameter	Initial Trend Parameter
W Optimal MAPE	21.98%	556.42	808.60	0.535	0	14.43
W Optimal RMSE	24.65%	497.88	805.45	0.148	0	9.72
W Optimal Percentile	24.52%	502.96	751.01	0.1918	0.0033	15.7

Table 5.2: Results for weighted Linear Exponential Smoothing

The weighted approach where negative forecast deviations are weighted with a certain factor (2 for the above case) reveals some considerable changes in parameter settings. The absolute error-figures increase which does not come as a surprise since the error level is increased by a factor of 2 for each negative deviation. All three accuracy measures now reach their optimum by taking an initial trend parameter into account which was previously not the case. The historic vs. recent data combination (alpha-value) stays approximately the same except for the RMSE which reaches now optimality with taking historic figures much more into account than recent data.

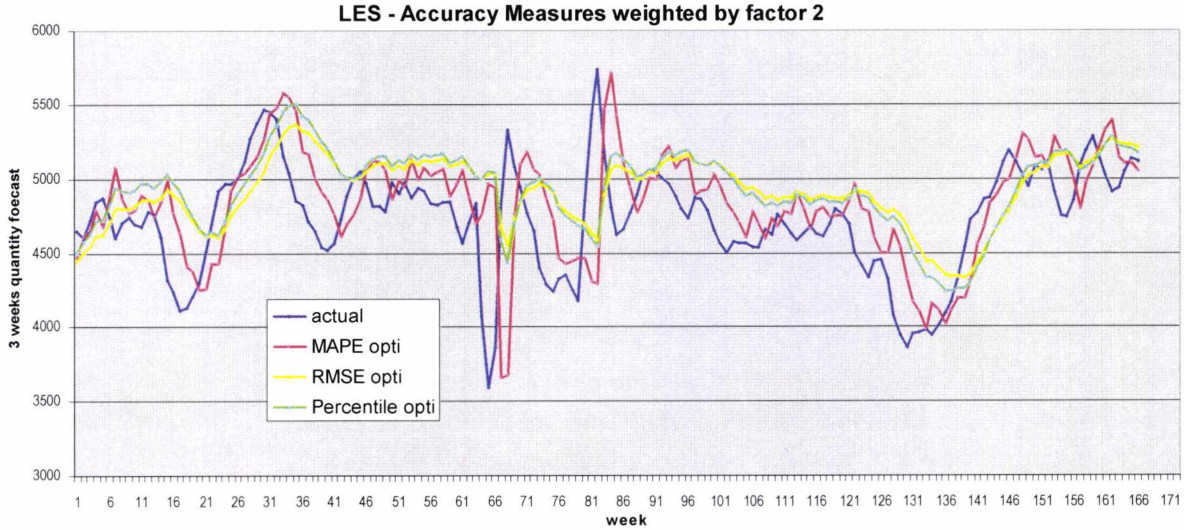


Figure 5.10: Four different forecast accuracy measures tested-weighted deviations

The graph shows a clear difference from the non-weighted approach. Demand anticipation is increased throughout the whole period, thus underproduction should better be avoided. The success of this will be checked later within the simulation implementation part. The favourite accuracy measure would most likely be again the MAPE approach since even though it is up-levelled it is still quite close to the actual curve and behaves better in critical "increasing demand" situations as within weeks 16 to 30 and 136 to 150.

Forecast accuracy measure evaluation for Double Exponential Smoothing scenario

Non-weighted approach DES

Parameter Settings	MAPE-Score	RMSE-Score	Percentile-Score	Alpha-Parameter	Initial Smooth S_1	Initial Smooth S_2
Optimal MAPE	16.96%	372.64	665.88	0.099	1553.0	1567.0
Optimal RMSE	17.38%	363.44	742.28	0.000	1500.4	1432.2
Optimal Percentile	17.39%	378.2	633.97	0.117	1425.0	1456.0

Table 5.3: Results for non-weighted Double Exponential Smoothing

The accuracy measure comparison for the Double Exponential Smoothing algorithm reveals some quite interesting outcome. MAPE and Percentile approach prefer historic data to a much wider extent than recent data. Exceptional is the case for RMSE since here the optimal fit is apparently reached if there are no recent data taken into account at all and just a straight forecast line that stays unchanged during the whole 3.5 years of investigation framework. In this case, S_1 and S_2 are just starting values and influence the forecast outcome only to a minor extent except for cases where alpha is zero.

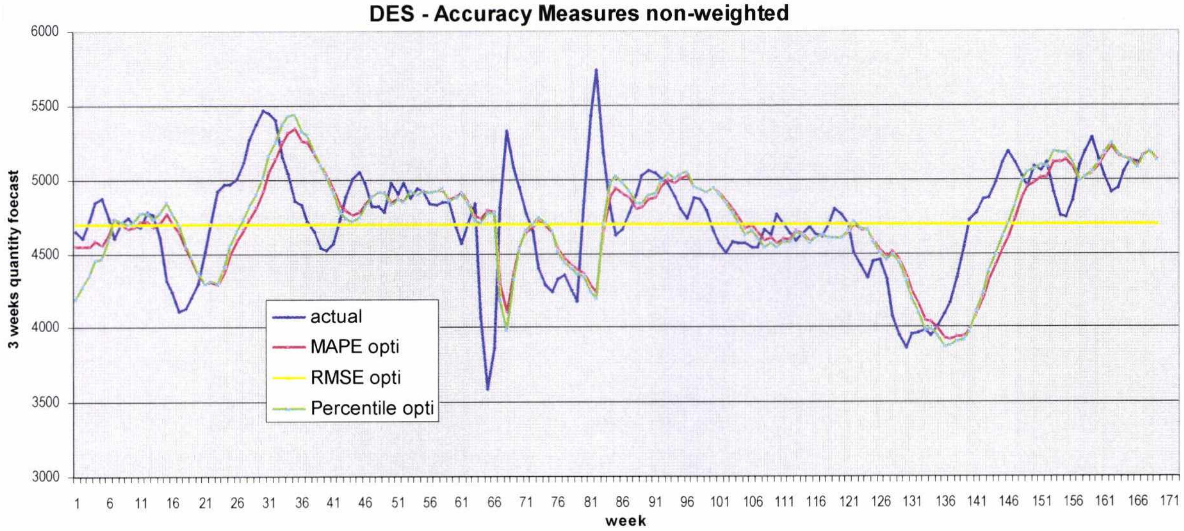


Figure 5.11: Four different forecast accuracy measures tested using DES

The graph uncovers the outcome of the individual forecast parameter settings. Generally it is not a too good fit from either of the scenarios.

Weighted approach to support over- rather than under-production DES

Parameter Settings	MAPE-Score	RMSE-Score	Percentile-Score	Alpha-Parameter	Initial Smooth S_1	Initial Smooth S_2
Optimal MAPE	22.69%	473.29	980.41	0.000	1618.0	1611.0
Optimal RMSE	22.85%	471.06	959.25	0.000	1588.7	1541.4
Optimal Percentile	24.96%	498.74	901.69	0.006	1616.0	1541.0

Table 5.4: Results for weighted Double Exponential Smoothing

The extra weight put on negative deviations apparently increases the tendency that all algorithms move their optimality towards a straight line. Only the Percentile approach still has a minor recent trend value within its optimal setting.

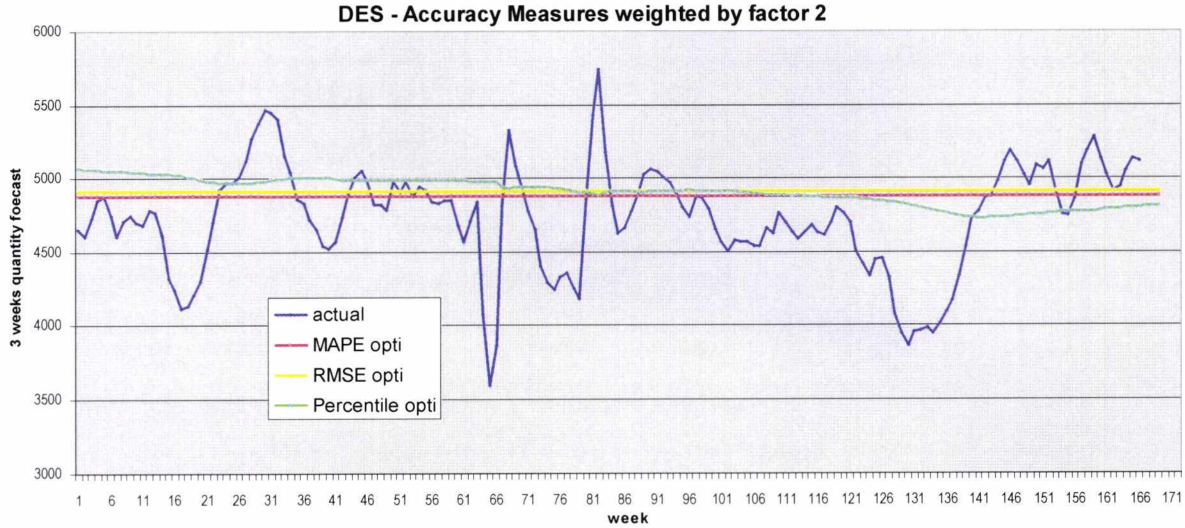


Figure 5.12: Four accuracy measures tested using DES - weighted deviations

The graph visualises this rather strange scenario. All three forecasts achieve the "optimal fit" with a straight line approximation. The possible success of this will be evaluated later.

Forecast accuracy measure evaluation for the custom forecast scenario

Parameter Settings	MAPE-Score	RMSE-Score	Percentile-Score	Weighted MAPE	Weighted RMSE	Weighted Percentile
Single Setting	15.09%	387.88	775.95	22.79%	638.32	1016.92

Table 5.5: Results for BUCK's custom forecast method

The third forecasting method does not have adjustable parameters and thus has only one setting with one particular outcome for each of the accuracy measures.

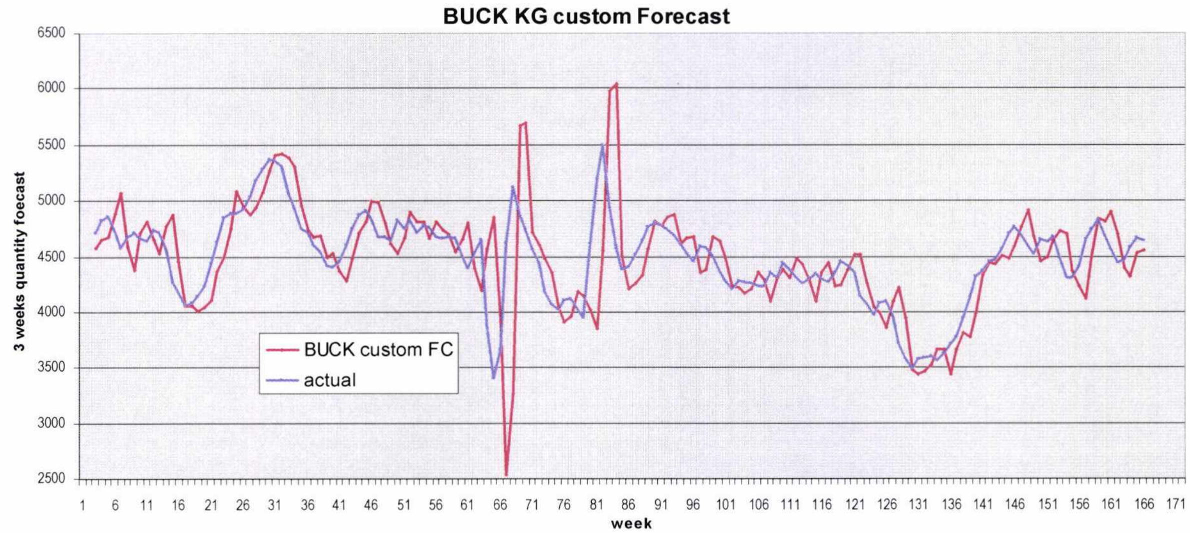


Figure 5.13: Forecast fit-curve using custom forecast method

This custom non-standard forecast reveals a surprisingly good fit to the particular market developments. This will be further discussed within the forecast method comparison framework.

Concluding Comments

Put in a nutshell we can see that parameters of particular forecasting techniques vary quite remarkably when they are optimised for several accuracy measures. This leads to sometimes completely different forecast behaviour as in the case of Double Exponential Smoothing where MAPE and Percentile revealed a normal time shifted curve whilst RMSE optimisation resulted in a straight line forecast. It has to be therefore evaluated quite thoroughly which measure of forecast quality will be chosen. The best recommendation is thus to use several measures and make a decision according to their outcome and to an eyeball test on a graph. None of the three investigated measures have been proven to be all superior or all inferior to the other. Even though it is rather easy to calculate, the Mean Absolute Percentage Error procedure seems to obtain the best result for the particular investigated scenarios according to personal judgements and eye-ball test on the graphs.
The weighting approach results in slightly different outcome than the non-weighted scenario which was expected. The success of this particular approach will be evaluated later within the simulation implementation part.

5.3.4 Evaluation of Forecasting Techniques

After having put serious emphasis on accuracy measures we will now use the obtained knowledge to evaluate the actual underlying forecasting techniques themselves. The methods under consideration will be taken from the three major approaches within extrapolation forecasting. These are moving average forecasting, exponential smoothing and adaptive forecasting techniques. The goal is to identify several promising approaches that will afterwards be checked for their suitability and success after implementation into a simulation model.

Moving Average Forecasting Techniques

This kind of forecasting technique seeks to smooth out past data by averaging the last several periods and projecting that view forward. The only adjustable parameters here are to either smooth the signal once or twice or to adjust the number of periods used for smoothing. The calculative effort is rather low and the implementation within Simulation Software reasonably easy since it does not necessarily depend on spreadsheet capabilities[3].
A weakness of moving averages commonly is that they lag behind recent trend developments. For production forecasting they should thus only be used for smoothing shorter periods.
The first method that tested with the data is **Double Moving Average**. This method smoothes out past data by applying Moving Average twice, smoothing the already smoothed series. We use 3-weeks moving average since it suits the underlying data best and matches also the forecast horizon of the companies.
The second method is a **custom method used by one of the companies**. It is a combination from moving average and trend implication. The data basis part particularly is calculated as a 3-point moving average, additionally a demand trend prediction for x_{t+1} is made taking $T(t+1) = \frac{1}{f} * \frac{x_t}{x_{t-2}}$, where t is the period and f is a certain factor that determines to what extent the recent trend is projected forward. An f-value of 1 would take recent trends and amplify them even more whilst an f-value of 10 would mainly give a normal moving average result. Common values taken for *f* are 4 or 6.

Exponential Smoothing Techniques

Techniques that feature this approach largely overcome the limitations of moving averages or percentage change models, mainly the time-lag. They do this automatically by weighting past data with weights that decrease exponentially with time, the more recent the data value, the greater its weighting.
Nevertheless the calculation effort increases remarkably compared to simple moving averages since exponential smoothing techniques always rely on a couple of parameters that cannot just be set but have to be optimised manually prior to forecasting using historic data or even have to be updated during the forecasting procedure. The goal is to set parameters in a way to obtain the best possible fit. This is traditionally done using trial and error beforehand or better by applying optimisation models that mainly use heuristics to approach these rather complex non-linear problem sets. Depending on the optimisation tool applied near optimal solutions can be found within reasonable time. Nevertheless, global search procedures have to be used to obtain a reasonably good outcome, thus local optimum approaches like standard solver in MS Excel are not of sufficient quality. Within the forthcoming investigations the *Premium Solver Platform* of Frontline Systems is applied to obtain good or even near optimal solutions.

[3] Speaking of "spreadsheet capabilities" within the forthcoming analyses basically means the possibility to store a rather large amount of data in a spreadsheet table and perform simple arithmetics within it which is necessary to perform the particular time series forecast. The more complex a forecast method is the more in-between calculations and running variables it needs and thus the necessity for integrated spreadsheet facilities within the simulation software increases.

From the wide choice of applied methods the investigation will focus on Standard Double Exponential Smoothing (DES), Holt's DES approach and Muir's DES approach (for further details about the chosen methods see Winston (1997)).
Standard Double Exponential Smoothing (DES) is a very wide-spread and common extrapolation forecasting technique. It basically applies simple exponential smoothing twice. This is useful where the historic data series is not stationary and thus contains some kind of trend. Parameters to set are mainly an alpha-value that sets a trade-off between historic and recent data, and the initial starting values for the two smoothing procedures.
Holt's DES approach (HDES) is also known as linear exponential smoothing and is similar to regular Exponential Smoothing. This technique uses not just one but two different smoothing constants to be applied for the first and second smoothing process. It needs thus two smoothing parameters as well as a basis and trend starting value.
Muir's DES approach represents a modification to Holt's method. It adjusts the growth rate for periods beyond t+1 in a way that $T_{t+x}=T_{t+1}(1/\alpha+x-1)$. This is supposed to achieve a better fit for forecast scenarios that go beyond one period in advance. Since it is only a calculative adjustment, no extra parameters are needed.

Adaptive Forecasting Techniques

These are methods which adapt themselves to the pattern of the data with which they are dealing. The idea behind these methods is that the weightings (alpha and beta parameters) used in the particular techniques adjust as new data accrues. This is contrary to the techniques above since they rely on fixed parameters that have to be adjusted prior to the analysis or could be updated within but only by the forecaster not by the algorithm itself.
The algorithm that has been chosen from this field of techniques is **Trigg and Leach's Method** which is quite close to standard exponential smoothing techniques but with self-adjusting parameters. Here the trade-off value alpha that decides between historic (alpha near to zero) and recent (alpha near to one) data's influence for the actual predicted value is adjusted and updated by the algorithm for each period. This makes the model very responsive to sudden changes in the data and commonly represents a considerable improvement over standard exponential smoothing.

Regression Analysis

Besides the above single time-series forecasting approaches there is also the possibility to combine time-series models with regression analysis. Modern regression methods, such as generalized additive models, multivariate adaptive regression splines, and regression trees, have one clear advantage: They can be used without specifying a functional form in advance. These data-adaptive, computer-intensive methods usually offer a more flexible approach to modelling for more complex scenarios than traditional statistical methods (Ryan, 1997). However, within more or less stationary demand forecasts that are not dependent on some kind of cyclical market trend or life-cycle shape demand structures these kinds of forecast approaches are neither appropriate nor exceptionally successful. Moreover they demand very significant computational efforts that are usually not appropriate for more complex supply-chain simulation models that include individual forecast systems for numerous entities. Furthermore, after several test-runs these techniques did not reveal improvements in forecast quality whatsoever and rather placed themselves in the lower end of all considered techniques.
It must nevertheless be mentioned that this kind of techniques are very useful for analyses that feature complex demand systems as mentioned above; systems that do not just depend on seasonal, promotional and market trend factors. As soon as there are life-cycle approaches or heavy dependencies on competitor activities or fashion/life-style trends that create clearly visible shapes within demand structures that cannot be explained with

seasonalities, regression models are the way to go. Since this investigation aims to demonstrate and evaluate forecast implementation issues from raw-data up to adaptation into software simulation models for the chosen two products' market conditions, detailed investigation of more complex conditions and different products has been abandoned for the sake of comprehensibility.

Performance of forecast-techniques within case analysis

Within the investigation stage the introduced techniques were evaluated using the decomposed data from pasta and mustard as introduced earlier. Each forecast scenario was run with optimised parameters that followed the recommendations of the Forecast Accuracy Measure investigation. The quality of each forecast was evaluated using these accuracy measures and an eyeball observation identifying possible critical points within the time series forecasting graphs. The analysis revealed certain strengths and weaknesses and according to that some forecast methods could be recommended for application within the simulation model which will be used later on to reveal the practical achievements and suitability of the chosen techniques.

	Pasta												Mustard												
	min MAPE						min RMSE						min MAPE						min RMSE						
	non-weighted			weighted			non-weighted			weighted			non-weighted			weighted			non-weighted			weighted			
	Score	Graph	total	Score	Graph	total	Score	Graph	total	Score	Graph	total	Score	Graph	total	Score	Graph	total	Score	Graph	total	Score	Graph	total	Total
Double Moving Average	6	3	9	6	4	10	6	4	10	5	4	9	3	4	7	4	4	8	5	4	9	5	4	9	71
BUCK MA+Trend	1	2	3	2	3	5	4	3	7	4	3	7	3	3	6	4	3	7	5	3	8	6	3	9	52
Double Expon.Smoothing	4	4	8	2	3	5	3	4	7	1	4	5	1	3	4	1	3	4	1	3	4	1	3	4	41
Holt's DES	3	1	4	1	1	2	2	2	4	2	3	5	2	2	4	2	1	3	3	3	6	2	2	4	32
Muir's DES	3	1	4	1	1	2	2	3	5	1	3	4	2	2	4	2	1	3	3	3	6	2	2	4	32
Trigg&Leach's Adaptive	2	1	3	3	2	5	1	3	4	3	3	6	2	1	3	2	3	5	2	3	5	3	3	6	37
		12			14			19			20			15			15			19			17		

Table 5.6: Ranked results from all eight investigated scenarios

The above table gives the ranked results from all eight scenarios of investigation. The numbers represent a result ranking with 1 being the best and 6 the worst. For each scenario there are points given for the error minimisation *score* and an eyeball-quality test of goodness of fit comparing each *graph* with the actual demand. As can be seen from the table, investigations of this wide range of forecasting methods combined with the several accuracy measure approaches revealed quite some interesting insights. Altogether there was not one over-dominant winner but several methods showed strengths within particular scenarios.

The ***simple double moving average*** did fail to accomplish the set targets. The ease of calculation and implementation do not make up for the lag in accuracy. This method scored the worst or second worst results in every scenario. The trend-line was evidently always some steps behind the actual signal and matched it sometimes only for reasons of chance. If one keeps in mind that we dealt with demand signals that were completely decomposed and can be assumed as rather stationary and uncomplicated except for some unusual incidents then this method cannot be recommended for demand forecasting purposes whatsoever.
Regarding implementation - the only reasonable recommendation for this method can be given for simulation packages with limited data-storage capabilities due to somewhat lower computational effort – DES needs fewer "in between" steps to achieve the final outcome compared to the other smoothing average based techniques that were evaluated.

The custom method proved to be somewhat effective but within certain limits. This rather simple, moving average based method has particular strengths for scenarios that are completely decomposed so that there is no global trend. Given these circumstances the method sticks to the actual signal very closely and can thus be suggested as a very good indicator of trend changes. Its weaknesses lie in the high volatility and thus steady up and down of recommendations. Furthermore it essentially needs supervision to be able to adjust parameters in extreme situations like the salmonella or flooding incidents.
Due to its strengths and shortcomings this method can be recommended for combined approaches where a second forecast is taken as a reference and total deviation is limited. For these cases implementation into simulation models would be interesting.

The ***basic Double Exponential Smoothing*** technique revealed some light and shadow as well. On one hand it obtained the best *score*-value in 5 out of 8 scenarios which is quite remarkable. On the other hand it achieved all these "victories" by applying a straight trend line approach. For rather volatile data structures that include several extreme incidents it is understandable that a straight line approach sometimes is superior to an ever changing signal-chasing strategy. Nevertheless for forecasting within a simulation model that is supposed to fulfil demand as accurately as possible, minimize inventory and maximize service levels a straight line approach might not be the way to go. Even so we have to consider that we deal with decomposed data and thus "staying calm in the storm" might sometimes be a rewarding strategy. Hence DES straight-line approaches will be evaluated within the simulation implementation stage later on to seek out clarity about these questions.

Holt's and Muir's methods behave quite similar within most of the investigated scenarios and perform very well in almost every setting. Moreover they do not show the "straightening" tendency of most of the other approaches within the weighted scenarios. They further achieved particular recommendations for the case of pasta-optiMAPE (non-weighted and weighted) and mustard-optiMAPE (weighted) since they showed forecasting behaviour that is very much appreciated especially within supply-chain forecasting: follow demand peaks as close as possible but do not over exaggerate them since they are mostly very temporary. Similarly, they never over-emphasize demand downturns to not miss a sudden upturn once demand increases again.
The implementation of these techniques requires somewhat more effort and advanced data storage and spreadsheet calculation capabilities within the simulation software package. Nevertheless, given the right parameter settings these two methods achieved the best overall score and get our recommendation.

Finally, ***Trigg and Leach's method*** achieves remarkable results that are often very similar and on several occasions even better than Holt's and Muir's methods. On the negative side there is a tendency for straightening within the weighted approaches. Furthermore the computational effort is remarkably higher than with the previous two methods. Particularly for complex supply chain computer simulation models that commonly need numerous individual forecasts within each echelon, this method with all its running variables may be rather too complex to implement as that the sometimes superior results would justify that.

Outcome for the forecast quality measures

When having a look at the accuracy measures, considering the accumulated goodness of fit (*graph*-result) for each scenario, MAPE seems to be clearly superior over RMSE. It plainly wins both cases (non-weighted as well as weighted) for the Pasta as well as the Mustard scenario.

On the other hand it is not possible to make a clear statement about the superiority of either weighted or non-weighted approach. Overall the non-weighted case prevails in 2 scenarios over the weighted case, with 1 case on par and 1 behind. Thus the previously newly introduced weighted approach that is supposed to prevent underproduction seems to be at least worth considering.

5.3.5 Importance of several decomposition factors within forecasting systems

The following section will analyse in some more detail the importance of decomposition factors towards the forecasting quality – theoretically and after implementation. Whenever a demand-forecasting system based on historic sales data that is projected ahead is supposed to be implemented into a computer simulation – several factors have to be known to make reasonable judgements about the outcome. The investigation will evaluate the impact of ignoring demand influences caused by promotional activities, seasonal factors and general market trends. Each scenario will assume knowledge of the other factors and just analyse the isolated influence of one particular factor.

Influence of Promotional Activity Data

From the actual decomposition proceedings earlier on, we could get an idea already about the importance of additional sales data information. As soon as the investigated product is promoted by whatever means, product distribution processes will dramatically change depending on the promotion-impact. For some particular products promotional activities can cause short-term demand increases of up to 400%[4] within the particular demand channel. If promotional activities are either combined within one demand channel or are effective within the same period in several channels – production and delivery capacity will reach bottleneck status and thus forecasts are needed to predict these happenings and trigger necessary buffer production already in advance to avoid drops in service level.
Nevertheless within most investigations demand data is taken without underlying knowledge about how it had been affected by promotional activities. Thus forecasts that do not take into account what has caused certain (short or long term) swings in demand are most likely highly inaccurate and do not represent a real-life scenario that is necessary for a simulation model to achieve useful practical recommendations. To demonstrate these effects, forecasts are run for the Mustard and Pasta scenario once with knowledge about underlying promotions and once without.

PASTA-MAPE	Optimal MAPE With knowledge about Promotions	Optimal MAPE Without knowledge about Promotions	Increased Error Level
Double Moving Average	18.90%	38.77%	**+105%**
BUCK MA+Trend	16.29%	35.26%	**+116%**
Double Expon. Smoothing	18.77%	26.32%	**+40%**
Holt's DES	16.87%	28.07%	**+66%**
Trigg and Leach's Adaptive	16.65%	28.48%	**+71%**

PASTA-RMSE	Optimal RMSE With knowledge about Promotions	Optimal RMSE Without knowledge about Promotions	Increased Error Level
Double Moving Average	412.19	849.86	**+106%**
BUCK MA+Trend	402.81	808.79	**+101%**
Double Expon. Smoothing	388.40	571.10	**+47%**
Holt's DES	366.01	618.14	**+69%**
Trigg and Leach's Adaptive	359.59	619.98	**+72%**

Table 5.7: Impact of promotional activity analysis on forecast accuracy using MAPE and RMSE accuracy measures within the pasta setting

[4] 400% for example for Pampers diapers taken from Proctor and Gamble Corp. Data (Hambuch, 2004)

The above tables show that for the case of unknown promotional schedule and historical impact estimation, forecasts are all much inferior independent of applied forecasting method or accuracy measure. Deviations reach from +40% up to +116% increased error level. To put it another way – even the worst forecasting technique with knowledge of the promotional schedule produces better forecasts than the best technique without knowledge. The forecasting approach that seems to be least affected by the absence of promotion data is basic Double Exponential Smoothing. It loses "only" approximately 40% of accuracy. The two graphs below show the forecast lines for optimal MAPE according to Trigg & Leach respectively BUCK's method. It can easily be seen that knowledge of promotional schedule and impact estimation give a totally different quality of forecast.

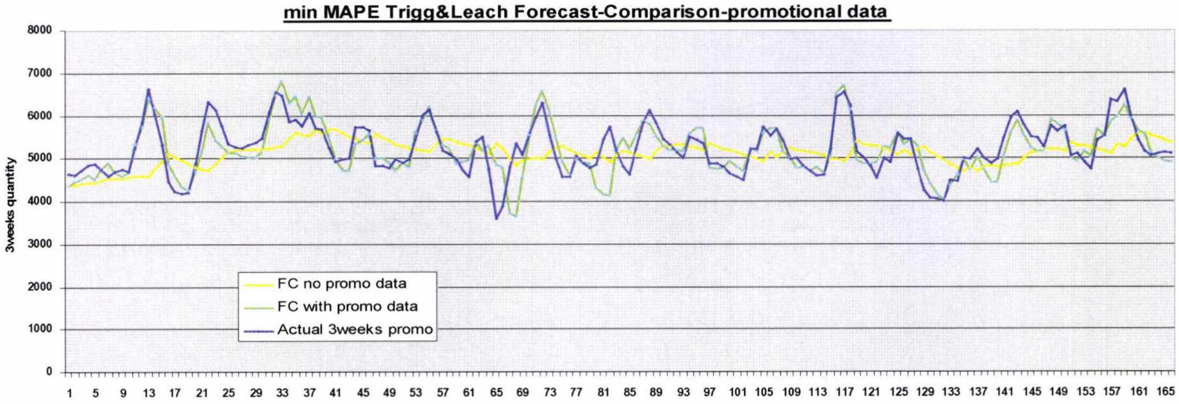


Figure 5.14: Impact of promotional activites on forecast accuracy – Trigg&Leach

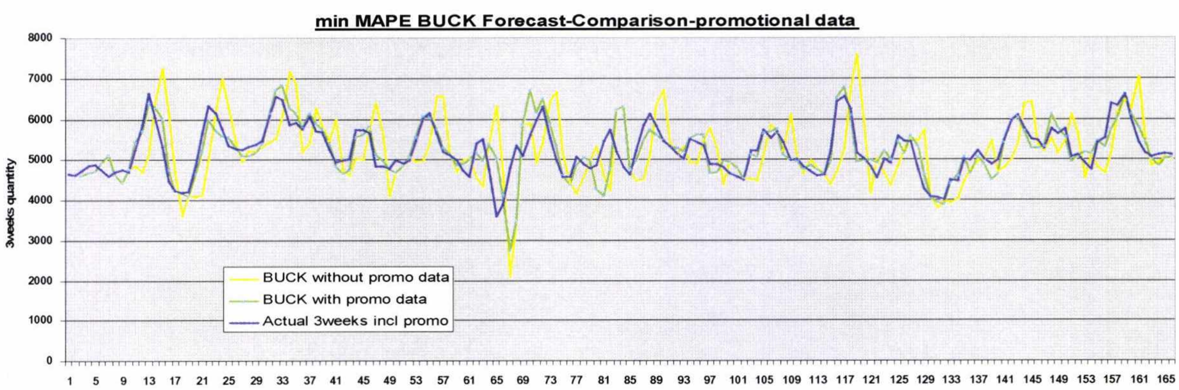


Figure 5.15: Impact of promotional activites on forecast accuracy – BUCK's method

Mustard – Scenario

MUSTARD-MAPE	Optimal MAPE With knowledge about Promotions	Optimal MAPE Without knowledge about Promotions	Increased Error Level
Double Moving Average	16.50%	32.47%	**+97%**
BUCK MA+Trend	16.30%	34.53%	**+112%**
Double Expon. Smoothing	13.98%	24.51%	**+75%**
Holt's DES	14.88%	24.86%	+67%
Trigg and Leach's Adaptive	14.53%	24.86%	**+71%**

MUSTARD-RMSE	Optimal RMSE With knowledge about Promotions	Optimal RMSE Without knowledge about Promotions	Increased Error Level
Double Moving Average	32274	70216	**+118%**
BUCK MA+Trend	32822	75121	**+129%**
Double Expon. Smoothing	27523	51490	**+87%**
Holt's DES	28896	51496	+78%
Trigg and Leach's Adaptive	28114	51496	**+83%**

Table 5.8: Impact of promotional activity analysis on forecast accuracy using MAPE and RMSE accuracy measures within the mustard setting

A pretty similar picture arises taking the mustard data at hand. Forecasts without any promotional activity data lose significantly. Particularly BUCK's method seems to depend heavily on promotion schedules and impact data to perform reasonably. The minimum loss in accuracy seems to be with Holt's method. It "only" loses around 70% of accuracy. If there can be any recommendation for a particular method in case there is no promotional data regarding schedule and impact available then it must be for basic DES method. It performs best in all four scenarios given no promotional details. The two graphs below show the forecast lines for optimal MAPE according to basic DES respectively Holt's method. It can easily be seen that knowledge of promotional schedule and impact estimation give again a totally different quality of forecast.

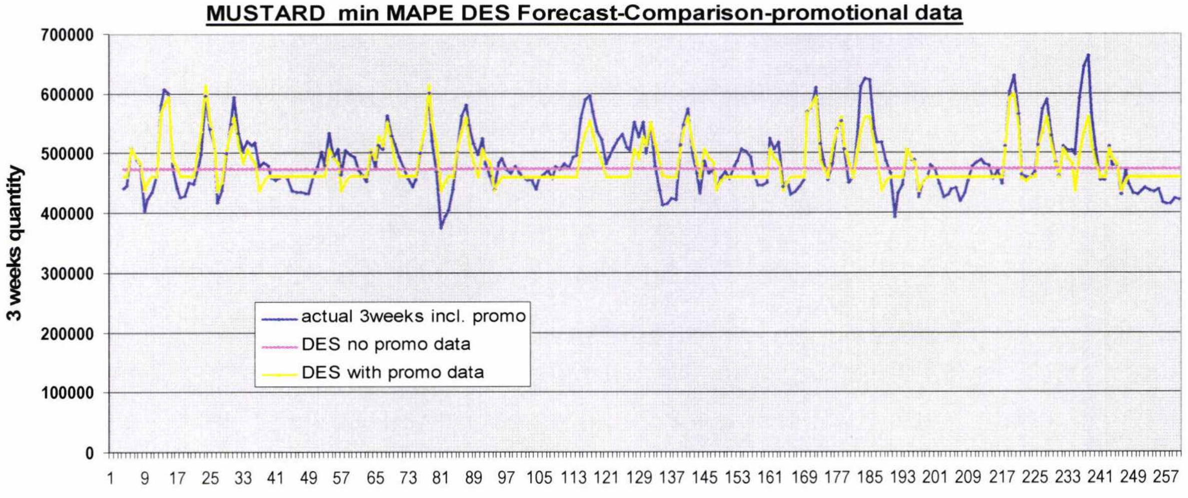


Figure 5.15: Impact of promotional activites on forecast accuracy – DES

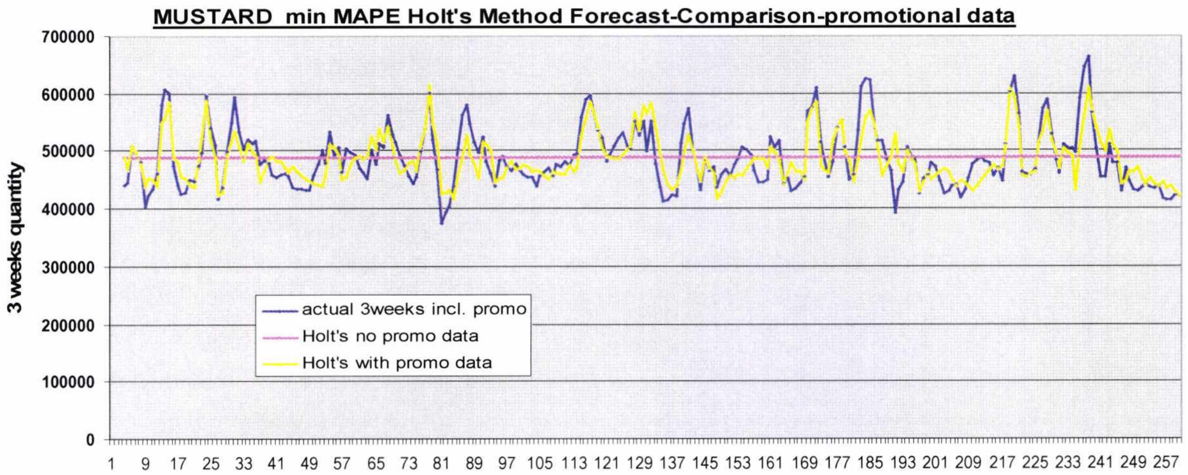


Figure 5.16: Impact of promotional activites on forecast accuracy – Holt's method

Influence of Seasonal Factors

Seasonal factors as another vital part within trend-decomposition can have an extremely important impact within a forecasting system. This actually depends on the degree and steadiness of seasonalities within demand behaviour for the particular product of investigation. For items with strong seasonalities like many food or non-food assortments it is thus essential to investigate the data for these seasonalities prior to implementation.

A basic impact analysis of seasonal factors for the Mustard and Pasta sales data has been conducted above already. Another reason why we will not carry out an even more detailed investigation of influence at this point is because seasonality data is not that crucial as promotional data in the sense that seasonal factors can be generated simply from the obtained data if necessary. Thus if a forecasting system depends only on raw data given from any source, the investigator can obtain seasonal factors by himself prior to forecasting or using a forecasting technique like Winter's method which accounts for seasonalities as well as special seasonality adjusted versions of Holt's and Muir's approaches.

Influence of general market data

The third factor that shall be investigated for possible importance within raw-data decomposition is knowledge of particular market data. This can include market share data of the particular company, market data of possible competitors and total market volume data.

Market Volume Data

Knowledge about this factor would be highly appreciated if the product/company under investigation sells their products within steadily growing or shrinking markets. Data can thus be analysed to obtain a long term trend that is taken into consideration whilst choosing a particular forecasting methodology.

Market Share Data for the investigated product/company

These data again would be very useful in case of strong market share growth or decay. Again this information can be used to adjust forecast systems to obtain more accurate measures about future tendencies apart from short term trends, seasonalities, promotions etc.

Competitors' Data

Finally information about competitors may be valuable as well since they may include knowledge about new product introductions, assortment extensions or contraction, delays or other incidents that can somehow be included into a forecasting system to include opportunities and threats in a probabilistic fashion.

Concluding Comments

Altogether it has to be concluded that the importance of preliminary information about promotion schedules and sales impact cannot be emphasized enough. Looking at the numbers makes it quite obvious that the difference such knowledge makes is absolutely vital for a profound forecasting approach.
Apart from that it is the only one of the three discussed factors above that solely has to rely on additional information and cannot be obtained from the actual sales data. Seasonal factors as well as general market trends can be obtained from frequently updated raw data of the particular period of investigation. This might not be as precise as within the decomposition discussed earlier that uses not just the actual data to obtain seasonal factors but also previous historic data, nevertheless deviations should not be too extensive if data is available for several years.
The same holds true for market data. The more and better data about market volume, market share and competitors are available the better factors can be taken into account and the better a true trend signal can be revealed. However, it is possible to obtain some rough idea about the market trends when doing a simple linear regression analysis of the sales data over the length of the period. This only reveals a general trend without any information about the root-cause. Nonetheless it can be a sufficient basis for trend-decomposing. Thus additional market data is welcomed but not absolutely vital for an analysis.

5.4 Forecast Implementation into Simulation Models

Having carried out a detailed examination of the underlying data that served the investigation, an analysis of selected forecast accuracy measures and finally an evaluation of numerous forecasting techniques, we now test the applicability of the previous considerations for implementation into an actual simulation model. Practical issues such as ease of implementation will be considered as well as a thorough output analysis. In the following section, possible strategies to evaluate certain implementation scenarios are discussed, results evaluated and finally recommendations are derived to summarise common issues regarding implementing demand forecasting within simulations models.

5.4.1 Simulation Model Setup

The actual simulation model that serves the investigation will be the same as described in Chapter 4 based on the Simul8 Professional 2006 Simulation Software Package from Simul8 Cooperation. For the purpose of the forecast investigation within this section, the complexity of the model is reduced to just one retail outlet distribution channel per customer. The simulation model setup that will be used to evaluate the forecasting methods will focus on simulating conditions that exist within an advanced CPFR approach. Thus, all echelons will depend on a common forecast that is determined by seasonal factors, promotional activity information, market trend data, POS data and information about inventory at the retailer, distributor and manufacturer level. The forecasting methods presented earlier in this chapter will be used to create a master forecast that serves suppliers to determine delivery schedules for raw materials, the manufacturer to determine the optimal production level for the following week and to deliver the right amount at the right time to the distributor to match forthcoming demand. Furthermore it determines the time and quantity of deliveries from the distributor to the several retailers. Overall, the analysis within this section will focus on strengths and weaknesses of individual forecast methods, demonstrating which approach can handle the given situation best.

5.4.2 Evaluation Strategies

The actual evaluation and conclusions about successful application of certain forecast scenarios will be made taking a variety of output factors of the simulation model into account. As already mentioned before, commonly most critical aspects within supply chains are inventory levels and customer service level. These will thus be taken as key performance indicators. Apart from inventory levels for the manufacturer, the distribution centres and the retailers, the investigation will take the number, length and the impact of supply gaps at retail echelons into consideration. Another factor that will be accounted for is the particular production rate that is set at the beginning of each week. Interesting observations can be made regarding maximum, minimum and average weekly production levels since they will reveal some information about the usage of existing capacity.

A further focus of attention is to check each particular approach for its ease of implementation. Some techniques may achieve superior outcome but may be very complicated to calculate (e.g. regression approaches).

5.4.3 Scenario Outcome Evaluation

For reasons of simplicity and to isolate specific variables of influence, the supply chain model is reduced to only one particular product out. The quantity is extrapolated to reach full truck load conditions for transportation. Absolute numbers e.g. inventory levels will seem rather low but one has to keep in mind that we deal with one particular assortment-product only for a choice of customers within a particular sales region – it is thus rather advisable to focus on relative differences than on absolute figures. All stated scores have been obtained taking the average from 20 individual runs.

Reference Scenario – expected demand set to total average demand

This scenario is used as a reference for further investigations. It shows the outcome of the simulation for the case that the expected weekly demand for the whole period is set to the average total demand. Thus the production rate stays the same throughout the entire timeframe.
As can be seen from the graph below, production rate does not stay absolutely constant since the model is set to behave in a certain manner to increase production rate temporarily independent from the expected demand in case the designated safety stock runs low. On the other hand production rate drops in case the safety stock exceeds a certain limit.

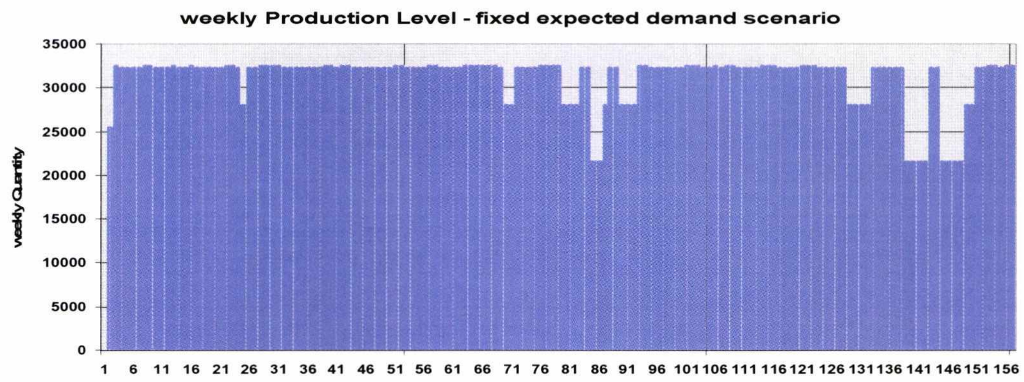


Figure 5.17: Timeline of weekly production output

From the graph we see that the production rate stays mainly constant throughout the three years timeframe the model runs. Drops in production are due to excessive safety stocks that accumulated when demand is much lower than default production level.

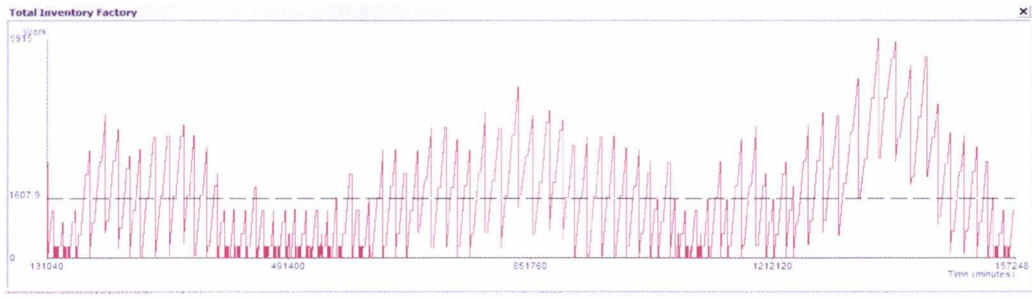


Figure 5.18: Timeline of inventory accumulating at the manufacturer echelon

The second graph shows the development of the inventory level at the manufacturer's stage throughout the simulation period. It can be seen that excess inventory is piling up at times with demand below average. The maximum inventory level is as high as 5900 cartons (118000 items) which we will be able to judge about later. This figure is not only important for pure comparison; it also determines how much storage space has to be allocated to a particular item from the assortment. Since warehousing space is always a scarce resource, the goal must be not only to minimize the average but also the maximum inventory level. The key output figures are summarized in Table 5.9. This initial tableau will serve as a reference for further scenarios. Due to the lack of comparison we cannot conclude much at the moment. Nevertheless it should be safe to say that this scenario is characterised by some serious shortages. Thus the number for unsatisfied demand is expected to be high. We will be able to judge about the level of inventories later.

Investigated Variable	Quantity
Total Items produced	4.458.440
Manufacturer: Average inventory	32.780
Distribution Centre: Average inventory	19.990
Retailer: Average Inventory	16.272
Unsatisfied demand	144.527
Total demand	4.758.043 [5]
Service Level	96.96%

Table 5.9: Output variables for the reverence scenario

2^{nd} Scenario – Forecast by Seasonal and Promotional Factors only

In this scenario we will introduce seasonal and promotional factors that serve as some sort of forecast to estimate forthcoming demand. Nevertheless the scenario does not feature any real forecasting technique that would detect long term or short term trends which are independent of normal seasonalities. The production rate schedule changes quite remarkably which does not surprise. Production level is now adjusted to an individual 3-week "forecast" according to seasonal factors and promotional schedules. Production range is between 17600 and 43500 units per week which is much more volatile than in the reference scenario. In general the model has been set up in a way to allow an absolute maximum weekly production output of 45000 units which is 50% above the normal output. This value is quite realistic since it can be achieved with nightshifts and weekend-production. Nevertheless a very high output (in this case up to +44% over standard output) might cause problems if the maximum weekly output capacity cannot be reached due to staff shortage or machine maintenance or if so only at significant extra cost.
The majority (80% of the scores) lie within 25050 and 37850 units per week and thus within a range between -17% to +25% deviation from the standard production level (30200 items per week). The development of the manufacturer's inventory within the particular period seems rather stable compared to the previous approach. There are nevertheless some signs of shortages and moreover several periods with remarkable excess inventory. Maximum inventory level reaches 4760 cartons which is lower than before but still rather high. From table 5.10 we can see that the most remarkable change compared to the initial scenario is a significant drop of unsatisfied demand. Inventory levels slightly increased most likely due to fewer shortages.

Seasonal+Promotional Factors Forecast	Quantity	Change
Total Items produced	4.486.960	+0.6%
Manufacturer: Average inventory	35.820	+9.3%
Distribution Centre: Average inventory	22.520	+12.7%
Retailer: Average Inventory	17.310	+6.4%
Unsatisfied demand	**61.241**	**-57.6%**
Total demand	4.772.757	+0.2%
Service Level	**98.69%**	**+1.78%**

Table 5.10: Output variables for the seasonal & promotional factors forecast scenario

3^{rd} Scenario - BUCK's custom forecast method

This method achieved already some remarkable results within the theoretical forecasting evaluation stage. Considering its rather basic nature of combining a 3-point moving

[5] The reason why total demand is higher than total items produced is due to the warm-up period transition where items that were produced within the warm-up period will not be accounted for as items produced but constitute part of the demand within the result collection phase.

average with a rather simple trend factor approach it reveals quite astonishingly good results. The production level schedule is again slightly different from the scenarios before. Apparently incorporated seasonalities influence the setting quite strongly and the unusually low demand within the 2003 summer is mirrored in a low production rate as well. Production range is between 14100 and 42300 units per week. Thus once again capacity restrictions and additional cost for extra shifts etc. could become an issue. The majority (80% of the scores) lie within a deviation range between -17% to +27% from the standard production level (30200 items per week). The manufacturer's inventory shows quite a homogeneous development over the whole timeframe. There are some minor signs of excess inventory but altogether very marginal. Maximum inventory level reaches 4015 cartons, which is much lower than in the previous scenarios.
The data in Table 5.11 finally acknowledges the good impression gained already before. BUCK's forecast almost matches the basic global goal of 99% service level and achieves very good result for the individual inventory levels as well, particularly the manufacturer's inventory as the most important one. This is a remarkable improvement compared to the seasonal and promotional factor only approach. Altogether it is a very remarkable performance that could not have been expected.

BUCK's custom forecast	Quantity	Change
Total Items produced	4502640	+0.9%
Manufacturer: Average inventory	31028	-5.3%
DC: Average inventory	21940	+9.8%
Retailer: Average Inventory	16416	+0.9%
Unsatisfied demand	**51632**	**-64.3%**
Total demand	4750109	-0.2%
Service Level	**98.89%**	**+1.99%**

Table 5.11: Results for BUCK's forecast scenario

4th Scenario - Holt's DES forecast method

The fourth scenario has been conducted using Holt's DES Method that proved to be very effective within the forecasting technique evaluation earlier. This turned out to be true for the actual simulation outcome as well. Nevertheless there seemed to be a problem with the used forecast parameters. The theoretical, Excel based evaluation suggested a setting of 0.515 for the most important alpha-value to minimize the total deviation. Nevertheless the simulation showed a rather disappointing outcome when using this setting. Even though inventory levels can be considered rather low, the total outcome was not remarkably better than within the previous, less promising approaches. Unsatisfied demand outcome as the most important reliability measure in particular did not reach the expected target of more than 99%. Since the forecasting technique revealed its strength within previous investigations, a suspicion arose that it might be the parameter settings that led to this inferior result. Thus we tried to find good locally-optimal parameter sets that lay somewhere distant from the global optimum used. The *Premium Solver Platform* of Frontline Systems allows obtaining several globally suboptimal but locally optimal parameter settings that lead to a total error level very close to the globally optimal solution. Hence, Holt's method is tested with two more parameter settings that are fairly different from the global MAPE minimizing setting. One setting featured an alpha value of 0.41 and another one an alpha value of 0.89. These values were selected according to recommendations given by the premium solver platform. The first proved to be inferior to the previous solution whilst the second turned out to be very effective. The production level schedule changed again compared to the previous scenarios. The level is now adjusted according to Holt's DES predictions and takes seasonal and promotional factors into account as well. Production range is in between 14300 and 42500 units per week. Most of the scores (80%) lie in a deviation range between -19% to +26% from the standard production level. The development of the manufacturer's inventory within the particular period turns out to be much more stable especially compared to the first two approaches. There is almost no sign of shortages or excess inventory whatsoever. Maximum inventory level went further down to a record low of 3868 cartons which is a remarkably good value and speaks in favour of the approach. As we see from Table 5.12 all the inventory levels are lowered compared to the initial parameter setting and unsatisfied demand respectively service level is much better than in any scenario before. Finally we also reach the targeted service level of above 99%.

Holt's DES alpha=0.89	Quantity	Change
Total Items produced	4499340	+0.9%
Manufacturer: Average inventory	31176	-4.9%
DC Average inventory	21976	+9.9%
Retailer: Average Inventory	16560	+1.8%
Unsatisfied demand	42746	-70.4%
Total demand	4761954	+0.1%
Service Level	99.08%	+2.19%

Table 5.12: Output variables for Holt's DES forecast scenario

5th Scenario – Basic Double Exponential Smoothing

The final method under investigation will be the basic double exponential smoothing approach. As it could be seen already before, this method behaves very differently under certain conditions and various parameter settings. In general it tends towards straight line approaches which should result in an outcome rather similar to the seasonal and promotional factor forecast within scenario 2. It will therefore be necessary to test this method for several parameter settings to obtain an overall view of its behaviour.
After evaluating several other Frontline-Solver generated candidate parameter settings that are spread throughout the entire possible range for alpha, it becomes obvious that once again the overall global error-minimization parameter setting does not result in the optimal solution for the simulation model. One of the sub-optima achieves much better outcome than the theoretically found globally "best" solution.

Basic DESmoothing	Alpha=0	Alpha=0.1	Alpha=0.3	Alpha=0.5	Alpha=0.35	Change
Total Items produced	4468860	4425060	4452960	4444960	**4460440**	+0.1%
Manufacturer: Average inv	35860	31660	30600	30620	**31310**	-4.5%
DC-Average inventory	22040	21100	21640	22560	**22386**	+12.0%
Retailer: Average Inventory	17433	16401	16401	16483	**16453**	+1.1%
Unsatisfied demand	56397	87239	68536	70706	**56790**	-60.7%
Total demand	4774007	4786529	4787826	4790033	**4776070**	+0.3%
Service Level	98.79%	98.15%	98.54%	98.49%	**98.79%**	+1.89%

Table 5.13: Results for DES method considering various alpha-forecast parameter settings

The best solution for this method is apparently found for an alpha value of 0.35 and S_1=S_2=1456 which represent starting values for each smoothing process. A straight line approach (or even with a minor global trend) does not seem to fulfil the hopes that arose when looking at the forecast deviation measures. According to the level of the straight line, such an approach will either cause severe gaps in demand supply and thus unacceptably low service level, or it is placed high enough to fulfil the service level constraint but then it results in a very high level of excess inventory as it can be seen from the first column of the above table (alpha=0). Comparing the above cases, the scenario for alpha=0.35 provides the best combination of high service level combined with low inventory levels and will thus be taken as reference setting for this scenario. The production level schedule turns out to be somehow similar to the previous scenario. Production range is in between 13100 and 42500 units per week. The majority (80% of the scores) lie within a deviation range between -18% to +31% from the standard production level. Thus the production schedule is slightly more volatile than in previous scenarios and capacity restrictions respectively additional cost will be an issue. Production in general is less smooth and there are numerous production level-jumps. The development of the manufacturer's inventory within the particular period was less stable compared to Holt's approach. There are some signs of short-term shortages. Excess inventory does not seem to be a major concern. Maximum inventory level was 3905 cartons which is a rather good value but slightly higher than for Holt's method. Put in a nutshell, the optimum setting for the Double Exponential Smoothing approach achieves quite respectable results but cannot beat Holt's DES approach.

6th Scenario - Combining Methods – a novel approach

To finish the section of scenario evaluations a somewhat novel approach will be examined for its efficiency. This scenario will evaluate a combined approach consisting of several forecasting techniques that are calculated simultaneously and evaluated each week for their previous and actual accuracy. Finally a decision is made each week upon which method is employed for the actual period's forecast. Thus the used forecast technique will most likely change several times throughout the simulation run.
The implemented techniques were Holt's DES approach (Scenario 4), BUCK's method (Scenario 3) and the basic Seasonal & Promotional factor forecast (Scenario 2). It is important to state that the application of three simultaneous techniques requires more effort for implementation and computation and can thus only be recommended for rather smaller problem sets that do not need too many individual forecasts. After running the simulation several times the output revealed following usage distribution:

Total Periods(weeks)	157	
Holt's Method used (alpha=0.515)	78	49%
BUCK's Method used	51	33%
Simple SF+PF approach used	28	18%

Apparently all three methods have been used to a certain extent which is quite surprising especially in the case of the simple SF/PF approach since it usually obtains inferior predictions compared to the other two methods as can be seen from the previous investigations. A possible explanation could be the behaviour during the exceptional incidents within the year 2002.
The investigation revealed that when using Holt's method setup with alpha=0.89 which was the previously found best setting for the simulation implication (Scenario 4), the service level outcome was inferior to the original Holt scenario. On the positive side the approach achieved the lowest inventory level of all scenarios. Service level as most important decision variable improved remarkably after taking the originally found optimal parameter setting (i.e. optimal setting found in section 5.3) of alpha=0.515. With this setting the combined approach achieved the best service level figure from all scenarios. On the other hand inventory levels increased slightly and fell behind the achieved results of Scenario 4. The production level distribution seems much more volatile than before which might have to do with the constant switches in forecasting methods. Production range is

between 14000 and 42300 units per week. Most scores (80%) lie within a deviation range between -19% to +26% from the standard production level. Development of manufacturer's inventory is again fairly stable. Shortages have been avoided as much as possible; some minor signs of excess inventory still exist. Maximum inventory level was 4042 cartons which is a rather good value but surely higher compared to solely Holt's approach within scenario 4.

Combined Approach	Alpha=0.89	Alpha=0.515	Change to initial	Change to Holt's
Total Items produced	4504357	**4517337**	+1.1%	+0.04%
Manufacturer: Average inv	29934	**32242**	-1.6%	+3.42%
DC: Average inventory	21186	**22316**	+11.6%	+1.55%
Retailer: Average Inventory	16433	**16908**	+3.9%	+2.10%
Unsatisfied demand	52804	**41959**	-71.0%	-1.84%
Total demand	4732299	**4714278**	-0.9%	-0.93%
Service Level	98.87%	**99.09%**	+2.20%	+0.01%

Table 5.14: Results for combined methods scenario

Overall, scenario 4 gives a slightly better impression considering manufacturer's inventory. Altogether it can be stated that combining several methods is an interesting approach since it achieves results that are similar to the best single method's outcome but on the other hand it offers some protection against unpredictable behaviour during unexpected events. Deviations during these times are remarkably decreased when a more trend focused method is combined with a more steady, moving average based method that provides some kind of safe haven in case of extreme incidents like the salmonella and flooding mentioned before. Nevertheless there was also some disappointment that Holt's DES single method approach could not be improved further using a combination of methods. Theoretically a combination of methods should be superior, it just depends on the decision criteria which method to choose for a particular period. Further investigations should thus be carried out in future-looking for improved decision criteria methods.

Ease of implementation and robustness

A final remark within the forecast-scenario evaluation will consider rather practical issues when implementing certain techniques into simulation models. Generally all the above considered techniques can be implemented quite neatly; it is just a matter of effort and computational power. Ideally, the software package offers Visual Basic type programming interfaces that allow carrying out even complicated computations. Nevertheless techniques that need historic data for more than a few periods necessarily need spreadsheet facilities to operate properly. Simul8 is very suitable for these cases since it has these spreadsheets facilities implemented and does not need necessarily external programs like MS Excel. If these internal spreadsheet facilities are missing, linking external programs is essential which can work sufficiently convenient in many cases. Nevertheless, it has been our experience that the more data is actually transferred and the more extensive calculations are requested externally the slower the model runs and the more vulnerable to breakdowns it gets. For rather simple investigations it is thus recommended to use methods that base on simple calculations like moving averages. BUCK's method is a good example for this kind of techniques since it combines less complex calculations with an acceptably good outcome.

If there is a need for a more thorough analysis and computational power is not a bottleneck, regression or self-adaptive parameter methods like Trigg and Leach become an option. Nevertheless it must not be forgotten that the more complex the models become the more susceptible they are towards breakdowns or unexpected behaviour. Debugging a

forecasting part of a supply chain simulation that features 3 variables per forecast is certainly much easier than one with 14. In the end it depends on the complexity of the model. Just to give some example: The above mentioned model considering all available demand channels would need 19 instances of individual forecasts to predict demand behaviour of all particular entities. Trigg and Leach's forecasting method needs 14 running variables that have to be stored and updated at each iteration. If one would take this method for all 19 sub-forecasts one would end up with 14*19=266 new calculations each time the forecast is run. Additionally there is the problem of storing run-time variables and forecast records in some kind of spreadsheet format for later analysis. It is thus advisable to check data prior to implementation for forecast accuracy with a certain choice of techniques. If a less complex method should reveal similar outcomes it could be reasonable to give up 0.3% accuracy but still have a manageable simulation model.
Some problems also arise with methods that overemphasize recent trends in case of very unusual demand behaviour like in the Salmonella and flooding incidents mentioned before. Forecasts often do not show sensible behaviour in these situations. This can result in unreasonably high or low production recommendations, which have to be taken care of by the simulation model for example by defining sensible upper and lower limits. BUCK's method and basic Double Exponential Smoothing have been found especially vulnerable to this kind of behaviour.

5.4.4 Recommendations

From the above considered models, Holt's DES approach seems to be the most promising. It is the only one of the single method approaches that achieved a service level above 99% whilst keeping inventory levels reasonably low. Another positive fact was the low maximum inventory needed since this figure is important for capacity planning of storage facilities within each echelon of the supply chain. Comparing Scenario 1 with the others also highlights the importance to obtain good measures of seasonal and promotional behaviour. Particularly for products in rather stable market conditions – good seasonal and promotional predictions are the most important tasks to do. This can be seen from the outcome of scenario 2 – without any real forecasting technique applied 98.7% service level and acceptable inventory levels were reached already. This result could be only slightly improved by some of the "real" forecasting scenarios, of which some even achieved worse outcome.
In general it can be stated that some of the findings from the theoretical spreadsheet based investigation could be acknowledged but some had to be altered. On the positive side all chosen techniques obtained reasonable results. Especially Holt's method behaved very promising within earlier investigations and proved to be the most effective method after implementation. Moreover BUCK's method turned out to be quite effective as it has already been speculated before. On the negative side none of the prior-optimized parameter settings proved to be optimal after implementation. Thus the extensive time spent to find minimum MAPE-parameter settings was more or less futile. Minimum absolute error level does apparently not guarantee reasonable outcome after implementation. Consequently distinct measures have to be developed to check the forecast quality a particular method can achieve within a simulation model. Theoretical, prior-implementation analyses can only give hints about suitability of a technique but cannot replace actual testing within the simulation model.
A possible way to achieve better fits could be a distinct quality measure that checks for particular long term underestimation of real demand. Thus it would not be the absolute error that counts but a cumulated negative deviation error for a certain number of successive periods that are causing supply gaps in the final stage of the supply chain.

Forecast parameters would then be adjusted to avoid particularly these successive negative deviations. Another method that has been proven to be effective within this investigation is generating several sets of parameters, preferably scattered over the whole range of possible parameter settings. These sets represent local minima regarding absolute forecast deviation. Several of these sets are then chosen and evaluated after implementation into the actual simulation model. This requires either a lot of trial and error playing within Excel or a more sophisticated solver approach like the *Premium Solver Platform* of Frontline Systems that was used within this investigation.

5.5 Conclusion and Suggestions

The preceding investigation demonstrated quite neatly preliminary considerations, necessary steps, opportunities and threats within a forecast evaluation and implementation process into simulation models.
Initially we showed that there is a crucial need for thorough data analysis prior to the simulation implementation phase. Certain steps are necessary to build a foundation that is reliable and can be trusted later on. A simulation model is often a very complex and fragile entity thus it needs a strong underlying base regarding the data it uses. A forecast is only as good as its underlying data and a simulation model that relies on the robustness of a forecast approach must thus also rely on preceding data analysis steps being carried out comprehensively and exhaustively.
The first part of the theoretical forecast evaluation revealed interesting approaches towards accuracy measurement with the introduction of the percentile and weighted approaches which cannot commonly be found in textbooks. The obtained results and recommendations were proven to be interesting since in many cases optimal parameter settings within the simulation stage were actually closer to forecasting parameter settings suggested by the weighted approach than the ones that achieved minimal error levels without weighting. Within this context further investigations should be run that also consider different weights aside from the factor 2 that was used here. Furthermore, the several forecast parameter settings obtained from using percentile and weighted approaches served as valuable investigation settings within the simulation phase. They thus helped to find scenarios with better service level and lower inventory.
The theoretical forecasting method evaluation revealed some strong points regarding the suitability of particular methods for implementation. The analysis clearly revealed some more or less suitable candidates for implementation later on. From the variety of methods investigated, Holt's and Muir's methods could be recommended in most of the cases and turned out to achieve the best results after implementation later on as well. Attention was given to robustness of the approaches as in raising awareness of certain parameter settings that made most of the techniques tend towards straight line approaches. Since this kind of behaviour would be comparable to implementing simply seasonal factor and promotional impact adjusted prediction, one has to take care to avoid this kind of behaviour in choosing for example different parameter settings. Altogether this part of the investigation obtained valuable insights and recommendations for what to expect and what to watch out for within the stage of implementation.
Another outcome was the level of importance promotional activity data can have within sales-forecasting. Since this knowledge cannot just be drawn from the actual data-set like seasonal factors or global trends, it has to be obtained beforehand and investigations revealed the high level of significance. Without information about schedule and impact of promotional activities even the best forecast performs much worse than the most inferior forecast approach that can rely on this information. Thus any sales forecast that attempts to correctly predict future demand based on a non-depromotionalized set of data is doomed from the very beginning.

6. Reference scenarios and homogeneous solution context

The following four chapters constitute the main part of the thesis investigation and contribution. Within this chapter we will first introduce the reference scenarios, outline the main problems within each and compare initial simulation outcomes with information obtained from the companies. Thereafter we demonstrate the possible effects and improvements within a homogeneous improvement framework. This implies that there will be no distinction in between customers such as various adjustments being carried out for all of them equally and simultaneously. This investigation approach can be considered as the widespread standard procedure for supply chain collaboration research since it applies global changes to an existing supply chain setup and evaluates the global performance impact of the applied adjustments.

6.1 The reference scenarios – problem outline, solution thoughts

The companies within the investigation have a very diverse set of products and supply chain characteristics. Each of the companies has to struggle with individual problem scenarios which nevertheless fit altogether in a very similar framework. This section will present the default setups of the investigated products of each individual company and outline certain characteristics while identifying apparent problems and possible solutions.

6.1.1 Default setup, problem outline and solution considerations for Manufacturer 1

Default setup

Chapter 4 described already the chosen products, market framework and production/delivery setup parameters. The product group that was investigated out of the portfolio of manufacturer 1 was spicy mustard as their top selling product within the entire assortment. Within the original distribution outline, all four customers are replenished via a non-collaborative fixed-date, fixed-interval and flexible quantity ROP approach. Thus the reordering occurs at particular pre-defined weekdays whilst the quantity is set up by each retail-company according to forecasted demand within the forthcoming inter-replenishment period. The default reorder interval for all four customers is two weeks. Hence, the following order timetable arises: Customer 1 reorders each Friday of an even week, Customer 2 reorders each Tuesday of an even week and Customers 3 & 4 order each Monday of every odd week. The ordered quantities are defined according to anticipated demand within the two-week inter-replenishment period obtained via an internal demand forecast and adjusted by the actual stock level at the distribution centres at the time of ordering to avoid overstocking but retain a certain level of safety-stock as well.
The traditional inventory policy of manufacturer 1 is to keep somewhat extensive stock for class A inventory items. The investigated product group in particular has an average stock level of 10-15 days of standard demand.

Problem outline

The main areas of concern within the traditional distribution framework of this product group are:

- low service level as about 5-6% of sales are lost due to non-availability at retail outlets

- out of stock incidents distributed unevenly - customers 1 and 2 have very high service levels whilst customers 3 and 4 suffer substantially
- upon occurrence, supply gaps at retail-outlets are very severe, in some cases stock-outs last for more than one week
- extensive non-critical and critical delivery delays between manufacturer and retailer-DCs as only about 2 out of 3 order requests can be carried out from available manufacturer-stock straight away and 1 out of 10 orders is substantially delayed and thus exceeds typical order lead time substantially
- about 6% of deliveries between DCs and retail outlets are delayed due to insufficient inventory
- inventory facilities are insufficient to keep the traditional stock policies and accommodate further expansion of the product assortment

Solution considerations

The majority of the above problems are presumed to be caused by the virtually simultaneous delivery requests of retail-customers 1, 3 and 4 which combine about 70% of overall demand. Possible solutions include:

- rescheduling delivery as to avoid 70% of overall demand to be requested at virtually the same time within the two-week delivery interval
- transition to flexible delivery triggered by DC inventory reaching a reorder-level instead of fixed order dates
- collaboration to anticipate demand better and to identify which customer needs goods most urgently to minimize overall service level gaps

Regarding the insufficient inventory facilities the company estimates to reduce average inventory of class A products by 25% to free up enough space to be able to cope with forthcoming assortment expansion.
Considering the already weak delivery performance, transition to flexible replenishment and collaboration are assumed to be the only possible ways to be able to significantly reduce inventory down to the intended level whilst at least maintaining actual delivery performance.

6.1.2 Default setup, problem outline and solution considerations for Manufacturer 2

Default setup

The particular product group investigated here was a certain kind of pasta. The default distribution framework evolves around a non-collaborative flexible order-date, target interval and flexible quantity ROP approach. Thus reordering is not bound to particular points in time but is triggered by DC inventory reaching a predefined lower-limit. The actual reorder barrier is variable and is set up according to forecasted demand. Altogether reorder intervals are agreed to be about two weeks whilst the order-quantity is determined by each retail-company according to estimated demand within the forthcoming two weeks inter-replenishment period.
Due to the flexible nature of the reordering process the necessary safety stock at DCs can be lower compared to the fixed order date framework since an urgent reorder request must not be delayed to match the pre-agreed order date but can be placed at any time.

The traditional inventory policy of manufacturer 2 is to keep stocks for class A inventory items rather low due to limited storage space and a wide assortment. The investigated product group in particular has an average stock level of 7-10 days of standard demand.

Problem outline

The main areas of concern within the default distribution framework of this product group are:

- rather low service level as about 4% of sales are lost due to non-availability at retail outlets, this is before accounting for inefficient store ordering
- extensive non-critical and critical delivery delays between manufacturer and retailer-DCs as only about 1 out of 3 order requests can be carried out from available manufacturers-stock straight away and 5 out of 10 orders are substantially delayed and thus exceed typical order lead time substantially
- about 7% of deliveries between DCs and retail outlets are somewhat delayed whilst 3-4% are postponed beyond a critical level and thus lead directly to end-consumer service level gaps
- the number of delivery tours needed to supply the distribution centres are 25% higher than expected due insufficient stock and resulting low fill-rates

Solution considerations

The above problems are mainly due to the very low inventory held at manufacturers DC. This is due to insufficient facilities that cannot cope with the assortment expansion the company initiated lately. Possible solutions include:

- average inventory held should be increased but it is very difficult to implement and very costly since storage area cannot be extended
- collaboration to anticipate demand better and to identify which customer needs goods most urgently to minimize overall service level gaps and improve delivery accuracy

Considering the limited storage facilities collaboration should be the only option that can substantially improve performance figures. Nevertheless, it has to be questioned if collaboration alone can substantially improve the severe shortcomings.

6.1.3 Default setup, problem outline and solution considerations for Manufacturer 3

Default setup

The product group recommended by the manufacturer for investigation is pickled gherkins. Similar to the products investigated for manufacturer 2 the default distribution framework evolves around a non-collaborative flexible order-date, target interval and flexible quantity ROP approach. Thus reordering is not bound to particular points in time but is triggered by DC inventory reaching a predefined lower-limit. The actual reorder barrier is variable and is set up according to forecasted demand. Default reorder intervals are either one or two weeks depending on customer. Whilst the two dominant customers receive delivery each week, the less important ones are commonly re-supplied every second week. The actual order-quantity is determined by each retail-company according to estimated demand within the particular forthcoming inter-replenishment period.

The traditional inventory policy of manufacturer 3 is to keep somewhat extensive stock for class A inventory items. The investigated product group in particular has an average stock level of 2 to 3 weeks of standard demand.

Problem outline

The main areas of concern within the production/distribution framework of this product group are:

- service level altogether on an average level (2-3% gap) but unevenly distributed as the small customers have virtually no out of stock incidents (gap <1%) while the major customers suffer rather more severely (3-4% gap)
- demand forecast accuracy is very low (around 20% average deviation) considering the rather unchallenging demand structure of the product
- times of excessive inventory (weeks with average inventory of 25 days or more) are unreasonably high (15%) and need to be reduced to lower inventory holding cost
- number of delivery tours needed to supply the distribution centres are 10-20% higher than expected due to insufficient loading
- extensive non-critical and critical delivery delays between manufacturer and retailer-DCs as only about 2 out of 3 order requests can be carried out from available manufacturers-stock straight away and 1 out of 10 orders is substantially delayed and thus exceeds typical order lead time substantially
- inventory facilities are insufficient to keep the traditional stock policies and accommodate further expansion of the product assortment

Solution considerations

A large number of the outlined problems is caused by a combination of insufficient demand forecast and inventory capacity problems. The lack of knowledge about forthcoming promotions is one of the major issues together with an overall growing demand and severe seasonal demand deviations. Any form of additional demand transparency and collaboration should thus be highly beneficial to tackle the above problems. Apart from improving the issues mentioned before, the manufacturer is planning to extend the assortment to respond to diverse customer requests. This will require substantial additional inventory capacity which is meant to be provided without physical extension of existing storage and loading facilities. The company estimates that average inventory of class A items needs to be reduced by 30% to accommodate future assortment expansion and market growth.
Altogether we can state that in case inventory remains constant collaboration should help to improve demand forecasts and reduce delays. If average held inventory needs to be reduced by as much as 30% as outlined within the mid-term strategy plan of the company, intense collaboration is considered to be essential to retain competitive performance.

6.1.4 Simulation outcome of the reference scenarios

In Table 6.1 the results of the simulation runs for each of the reference scenarios are presented. This will give more information about level of performance prior to any applied changes within the distribution frameworks of the three manufacturers. Moreover we are able to verify if the above stated practical problems raised by the involved companies, are reflected in the performance metrics outcome obtained from the simulation.

	Product distribution layout	Manufacturer 1 Mustard fixed date ROP	Manufacturer 2 Pasta flexible date ROP	Manufacturer 3 pickled gherkins Flexible date ROP	Units/explanation
global	overall SL gap	4.4%	3.7%	1.9%	% of total demand
	average SL gap-size	23%	12%	6%	% of week-demand
	largest overall SL gap	100%	51%	41%	% of week-demand
	excessive inventory	4%	3%	12%	% of days with inv>200%avrg
	demand forecast accuracy	8%	8%	15%	% of deviation from sales
	actual inv/target stock	130%	100%	140%	% of target inventory
Manufact urer to DC	DC deliveries	98%	131%	110%	% of anticipated no of tours
	delivery delayed	41%	88%	40%	% of deliveries delayed
	critically delayed	9%	78%	11%	% of deliveries delayed >2days
	delivery fill-rate	87%	74%	89%	% of ordered quantity
DC to retail	retail deliveries	98%	99%	100%	% of anticipated no of tours
	delivery delayed	7%	8%	2%	% of deliveries delayed
	critically delayed	2%	2%	0%	% of deliveries delayed >2days
	delivery fill-rate	98%	97%	99%	% of ordered quantity
individual	SL gap Customer1	1%	4%	0%	% of total demand
	SL gap Customer2	1%	4%	3%	% of total demand
	SL gap Customer3	11%	4%	3%	% of total demand
	SL gap Customer4	7%	4%	1%	% of total demand

Table 6.1: Results of the reference scenarios

The key performance indicators in the table represent average results from 10 simulation runs of each modelled scenario. The red highlighted numbers indicate the main figures of interest following the company's key performance targets. We can see that the practical scenario problems stated previously are represented quite well by the simulation model outcomes. The obtained results are certainly not identical with the actual observed figures but are within a reasonable range of variation. Altogether the model seems to be capable to serve as a basis for investigating various parameter adjustments to observe the impact on the performance measures of interest.

6.1.5 Additional concerns arising out of the supply chain distribution context

Among the proposed improvement suggestions, increased collaboration is the predominant one to improve most of the identified performance problems. Within this framework it is nevertheless questionable if delivery policies are changeable for all the customers and to such a wide extent as proposed by CPFR which demands a joint forecast system that needs a high degree of maintenance and initiation investments not to mention trust and willingness to collaborate to such a wide extent.

Considering these points, it is not just interesting to reveal what a full collaborative delivery framework is capable of but it is essentially necessary to also evaluate a wide range of heterogeneous setups that represent reality much better than the rather unpractical homogenous frameworks.

Hence, the analysis needs on one hand to reveal the outcome of an optimal case that assumes all participants to collaborate at a very sophisticated level, instating a fully working collaborative planning, forecasting and replenishment system to give a vision what is possible. On the other hand a variety of heterogeneous scenarios needs to be investigated to give more real life recommendations featuring collaboration either **i)** only to a limited scope (only some of the customers collaborate with the manufacturer) or **ii)** only to a limited scale (customers may instate only more basic VMI, or even only individual collaboration modules instead of a full-featured CPFR solution). Preliminary to evaluating such heterogeneous frameworks we will have a look at the somewhat less complex homogenous supply chain improvement context.

6.2 Homogeneous solution context

Within this section we investigate the performance impact of a jointly enhanced supply chain. In particular we consider what level of improvement can be achieved by either engaging all retail-customers in Vendor Managed Inventory schemes or establishing Collaborative Planning Forecasting and Replenishment. In addition we also evaluate the impact of varying inventory levels to obtain a broader idea what effect this causes on the system. Furthermore we investigate stock policy changes as this was particularly requested by the manufacturers supporting the research.

6.2.1 Solutions for the Supply Chain framework of Manufacturer 1

Fixed manufacturer inventory level

Due to the default replenishment framework of manufacturer 1 there are four proposed improvement scenarios, namely fixed ROP at different weekdays, flexible ROP, VMI and CPFR.

		fixed ROP	fixed ROP	flexible ROP	VMI	CPFR	
	distribution dates	F/Tu/m/m	F/F/f/f	variable	variable	variable	Units/explanation
global	overall SL gap	4.4%	2.2%	0.4%	0.2%	0.2%	% of total demand
global	average SL gap-size	23%	17%	7%	4%	4%	% of week-demand
global	largest overall SL gap	100%	64%	29%	15%	15%	% of week-demand
global	perfect weeks	81%	88%	94%	95%	96%	% of all weeks
global	inventory level	100%	100%	100%	100%	100%	% of initial inventory
global	excessive inventory	4%	10%	9%	8%	9%	% of days with inv>200%avrg
global	total DC inventory	100%	98%	116%	103%	109%	% of initial inventory
global	forecast deviation	8%	8%	8%	6%	5%	% of deviation from sales
Manufacturer to DC	DC deliveries	98%	100%	113%	118%	113%	% of anticipated no of tours
Manufacturer to DC	delivery delayed	41%	18%	39%	26%	19%	% of deliveries delayed
Manufacturer to DC	critically delayed	9%	9%	13%	3%	1%	% of deliveries delayed >2days
Manufacturer to DC	delivery fill-rate	87%	88%	89%	92%	94%	% of ordered quantity
Manufacturer to DC	perfect deliveries	41%	32%	49%	58%	62%	% of all deliveries
DC to retail	retail deliveries	98%	100%	101%	101%	100%	% of anticipated no of tours
DC to retail	delivery delayed	7%	5%	1%	1%	1%	% of deliveries delayed
DC to retail	critically delayed	2%	1%	0%	0%	0%	% of deliveries delayed >2days
DC to retail	delivery fill-rate	98%	98%	99%	99%	99%	% of ordered quantity
Individual	SL gap Customer1	1%	3%	1%	0%	0%	% of total demand
Individual	SL gap Customer2	1%	3%	0%	0%	0%	% of total demand
Individual	SL gap Customer3	11%	1%	0%	0%	0%	% of total demand
Individual	SL gap Customer4	7%	2%	0%	0%	0%	% of total demand

Table 6.2: Results for various levels of collaboration assuming unchanged inventory levels

As we see from Table 6.2 there is a variety of possibilities to tackle the shortcomings of the initial fixed ROP scenario. Initially we rescheduled the delivery dates within the fixed date delivery framework. This results in orders being expected only on Fridays with customers 1 and 2 ordering in even weeks and customers 3 & 4 in odd weeks (F/F/f/f). Global service-level as well as most other crucial performance metrics improve substantially. Only critically delayed deliveries between manufacturer and distribution-centres do not improve. In the second step we introduced flexible delivery which is not preset to a particular pre-agreed date. As a result of that all crucial performance measures are improved up to the proposed target level apart from manufacturer to DC delivery metrics. Engaging into collaboration via VMI or CPFR finally leads to performance outcomes that even exceeds target levels. As a result there are virtually no service level gaps or critically delayed deliveries whilst the stock levels remain constant.

Varying manufacturer inventory level

Within the following table we take a look at what happens at different levels of average inventory held by the manufacturer. This provides a better general idea about the system behaviour and to evaluate to what extent the requested inventory reduction by 20-30% can be accommodated.

		low inventory					high inventory				
		fixed ROP	fixed ROP	flex ROP	VMI	CPFR	fixed ROP	fixed ROP	flex ROP	VMI	CPFR
	distribution dates	F/Tu/m/m	F/F/f/f	variable	variable	variable	F/Tu/m/m	F/F/f/f	variable	variable	variable
global	overall SL gap	6.4%	5.0%	2.7%	1.3%	0.8%	1.9%	0.5%	0.1%	0.1%	0.1%
global	average SL gap-size	27%	20%	11%	10%	7%	17%	8%	5%	2%	2%
global	perfect weeks	77%	78%	79%	89%	91%	89%	95%	98%	97%	98%
global	largest overall SL gap	100%	62%	49%	60%	32%	100%	33%	11%	5%	6%
global	inventory level	80%	80%	70%	70%	70%	130%	130%	130%	130%	130%
global	excessive inventory	2%	4%	1%	1%	1%	12%	23%	23%	19%	19%
global	total DC inventory	85%	73%	81%	87%	92%	117%	122%	130%	113%	118%
global	forecast deviation	8%	8%	8%	7%	6%	8%	8%	8%	7%	6%
Manufacturer to DC	DC deliveries	97%	100%	126%	125%	119%	99%	100%	106%	112%	108%
Manufacturer to DC	delivery delayed	61%	39%	79%	55%	48%	21%	3%	20%	10%	6%
Manufacturer to DC	critically delayed	20%	25%	43%	14%	9%	2%	2%	3%	1%	1%
Manufacturer to DC	delivery fill-rate	84%	80%	79%	85%	86%	90%	94%	94%	96%	98%
Manufacturer to DC	perfect deliveries	28%	11%	16%	32%	33%	50%	62%	69%	77%	83%
DC to retail	retail deliveries	97%	99%	100%	101%	101%	100%	101%	101%	101%	101%
DC to retail	delivery delayed	8%	8%	6%	3%	2%	4%	2%	0%	1%	0%
DC to retail	critically delayed	3%	2%	2%	1%	0%	1%	0%	0%	0%	0%
DC to retail	delivery fill-rate	97%	96%	97%	98%	98%	98%	99%	99%	99%	100%
individual	SL gap Customer1	2%	5%	3%	1%	0%	0%	1%	0%	0%	0%
individual	SL gap Customer2	1%	7%	2%	2%	1%	0%	1%	0%	0%	0%
individual	SL gap Customer3	15%	4%	3%	1%	1%	5%	0%	0%	0%	0%
individual	SL gap Customer4	9%	4%	3%	1%	0%	3%	0%	0%	0%	0%

Table 6.3: Results for various levels of collaboration assuming altered inventory levels

When we first look at the low inventory case we can clearly see that maintaining a fixed date delivery framework does not allow us to reduce inventory in any way. Even the "optimised" altering Friday delivery schedule represented in column 2 does not perform reasonably well enough as that an inventory reduction could be considered. Adjusting the delivery system to a flexible delivery date approach results in much better outcome but yet remarkable service level gaps and poor delivery performance make it rather questionable if reducing inventory could be considered as an option. The clear winners of the low inventory scenario are the collaboration approaches since they allow for very reasonable service level figures and convincing delivery metrics. Altogether implementation of VMI or CPFR would easily enable a 30% inventory reduction with only a minor degrading of the supply chain performance. CPFR not surprisingly outperforms VMI within this setting but one could argue if the rather small advances are valuable enough to justify the additional implementation and maintenance effort.

The high inventory case presented at the right hand side of the table was carried out to observe the behaviour of the system since the manufacturer was in no way interested in extending average held inventory. However, we can see that with sufficient extra inventory (+30% in this case) even the fixed-date delivery approaches perform reasonably well. In particular the "optimised" altering Friday delivery schedule shows convincing results in case storage capacity was not an issue.

6.2.2 Solutions for the Supply Chain framework of Manufacturer 2

Investigating the delivery framework of manufacturer 2 is somewhat less complex since the company is already operating a flexible ROP delivery system. Thus fixed-date delivery scheduling does not need to be considered. Furthermore manufacturer 2 works on a low inventory policy due to insufficient storage facilities which is part of the reason for its rather inferior supply chain performance. The results in the following table are to help investigate the impact of implementing collaborative replenishment into the delivery system and additionally see the impact of a theoretical inventory increase to possibly encourage storage facility expansion.

		standard inventory			+25% inventory			+60% inventory			-15%inventory	
		flex ROP	VMI	CPFR	flex ROP	VMI	CPFR	flex ROP	VMI	CPFR	VMI	CPFR
global	overall SL gap	3.7%	2.5%	0.9%	1.1%	0.5%	0.2%	0.1%	0.1%	0.1%	6.9%	2.9%
	average SL gap-size	12%	11%	8%	8%	5%	5%	3%	3%	3%	16%	11%
	perfect weeks	71%	85%	91%	88%	93%	95%	98%	97%	97%	73%	81%
	largest overall SL gap	51%	62%	47%	31%	25%	19%	5%	6%	8%	84%	61%
	inventory level	100%	100%	100%	125%	125%	125%	160%	160%	160%	85%	85%
	excessive inventory	3%	4%	2%	10%	9%	8%	22%	20%	22%	1%	1%
	total DC inventory	100%	113%	117%	167%	149%	165%	228%	172%	178%	87%	98%
	forecast deviation	8%	6%	5%	8%	6%	6%	8%	6%	6%	6%	6%
Manufacturer to DC	DC deliveries	132%	135%	131%	122%	129%	122%	110%	119%	114%	136%	135%
	delivery delayed	88%	68%	57%	67%	42%	27%	30%	16%	14%	85%	77%
	critically delayed	78%	33%	22%	45%	10%	5%	10%	2%	2%	53%	43%
	delivery fill-rate	74%	79%	83%	81%	88%	91%	91%	95%	95%	73%	77%
	perfect deliveries	11%	21%	31%	28%	46%	56%	59%	70%	72%	8%	15%
DC to retail	retail deliveries	99%	101%	101%	101%	101%	101%	100%	101%	101%	99%	100%
	delivery delayed	8%	4%	2%	3%	1%	1%	1%	1%	1%	9%	5%
	critically delayed	3%	1%	0%	1%	0%	0%	0%	0%	0%	3%	2%
	delivery fill-rate	97%	98%	99%	99%	99%	99%	100%	99%	99%	96%	97%
Individual	SL gap Customer1	4%	1%	1%	1%	0%	0%	0%	0%	0%	4%	1%
	SL gap Customer2	4%	4%	2%	1%	1%	0%	0%	0%	0%	12%	5%
	SL gap Customer3	4%	1%	0%	1%	0%	0%	0%	0%	0%	2%	2%
	SL gap Customer4	4%	1%	0%	1%	0%	0%	0%	0%	0%	2%	2%

Table 6.4: Results for various levels of collaboration under various inventory levels

The results of the standard inventory setting make it apparent that the replenishment performance is on a rather inferior level. In particular delivery performance indicators suggest frequent and severe delivery failures. Altogether service level suffers substantially which is expressed by 4% service level gap and only 71% of the weeks have no out of stock incidents at retail outlets. The actual delivery delay figures from the simulation seem a bit high but are due to a quite tight replenishment timeframe.

The introduction of collaboration within this scenario is highly recommended and leads to substantial improvements. Within this scenario it is apparent as well that CPFR is clearly superior to VMI. All crucial performance metrics that improve already within the VMI framework, progress once more when extending the collaboration framework to a CPFR approach. Altogether the introduction of CPFR is the only possibility that allows for a replenishment performance recovery up to a satisfactory level if increasing average held inventory is not an option.

From the increased inventory scenarios we can see that inferior replenishment performance is clearly due to the low inventory held. Therefore expanding storage facilities is highly recommended. Nevertheless we can see as well that inventory held at the retailers distribution centres increases over-proportionally compared to inventory increases at manufacturer's storage. This is most likely due to the fact that within the initial scenario

DCs operate at some sort of emergency policy and ship out any available stock instantly to avoid OOS at retail outlets.

The various inventory settings demonstrate other characteristics comparing the three different replenishment approaches. Apparently service level can be achieved very conveniently by non-collaborative replenishment as long as there is sufficient stock. Delivery accuracy figures nevertheless are significantly superior within the collaboration approaches independent of the average inventory level held.

The last two columns of the table demonstrate the performance of collaborative replenishment if inventory would be even lower (-15%). We can clearly see that there is no more room for further inventory reductions since even CPFR cannot make up for this shortcoming. Nevertheless, even with average inventory reduced by further 15%, CPFR succeeds to outperform the default normal inventory ROP scenario. Another fact worth mentioning is that although introducing collaborative replenishment leads to superior overall performance, the lower part of the table reveals that customers seem to benefit in an unbalanced manner. These issues will be evaluated in detail within Chapter 7.

6.2.3 Solutions for the Supply Chain framework of Manufacturer 3

The distribution framework of manufacturer 3 is somewhat similar to the one of manufacturer 2. Thus, flexible ROP is the default delivery setup. Compared to the previous scenario, inventory is at a more elevated level but the company is strongly considering if reducing it is somehow feasible since they have detailed plans of assortment expansion ahead of them.

		standard inventory			low inventory			high inventory		
		flex ROP	VMI	CPFR	flex ROP	VMI	CPFR	flex ROP	VMI	CPFR
global	overall SL gap	1.9%	1.3%	1.1%	5.1%	2.0%	1.6%	1.6%	1.0%	0.8%
	average SL gap-size	6%	5%	4%	12%	8%	8%	6%	4%	4%
	perfect weeks	84%	87%	88%	77%	86%	85%	88%	89%	91%
	largest overall SL gap	41%	50%	38%	62%	51%	52%	35%	27%	28%
	inventory level	100%	100%	100%	70%	70%	70%	125%	125%	125%
	excessive inventory	12%	9%	8%	1%	1%	2%	21%	15%	18%
	total DC inventory	100%	94%	99%	74%	80%	84%	110%	98%	108%
	forecast deviation	15%	6%	2%	15%	6%	2%	15%	6%	2%
Manufacturer to DC	DC deliveries	110%	104%	99%	120%	110%	103%	107%	102%	97%
	delivery delayed	40%	18%	22%	68%	41%	46%	31%	13%	11%
	critically delayed	11%	2%	3%	31%	7%	10%	9%	2%	2%
	delivery fill-rate	89%	94%	93%	81%	88%	87%	91%	96%	96%
	perfect deliveries	53%	69%	66%	28%	47%	42%	63%	81%	81%
DC to retail	retail deliveries	100%	101%	101%	100%	101%	101%	101%	101%	100%
	delivery delayed	2%	1%	1%	5%	3%	2%	1%	1%	1%
	critically delayed	0%	0%	0%	1%	1%	1%	0%	0%	0%
	delivery fill-rate	99%	98%	99%	97%	97%	97%	99%	98%	99%
individual	SL gap Customer1	0%	0%	0%	0%	1%	1%	0%	0%	0%
	SL gap Customer2	3%	2%	1%	7%	3%	2%	2%	2%	1%
	SL gap Customer3	3%	1%	1%	7%	2%	1%	2%	1%	1%
	SL gap Customer4	1%	1%	0%	1%	1%	2%	0%	0%	0%

Table 6.5: Results for various levels of collaboration under various inventory levels

The simulation results demonstrate that collaboration can tackle the assumed shortcomings within replenishment performance that were described above. One major advantage seems to arise out of a much more reliable demand forecast since forecast accuracy deviation diminishes from 15% to almost 2%. Particularly distribution seems much more reliable, excessive inventory is diminished, production forecast accuracy is substantially improved and service level gaps are spread more evenly between all customers. Altogether the standard scenario with more or less sufficient stock held does not reveal the actual potential of collaborative replenishment since the flexible ROP delivery performed already reasonably well. A different picture arises when looking at the low inventory case where average stock level is reduced by 30% of the default level. This scenario complies with the mid-term strategic inventory target level of class A inventory products (few products accounting for the majority of turnover) which is supposed to be reduced to allow for forthcoming growth in demand and assortment expansion. Reduced inventory leads to major performance shortcomings in case of flexible ROP delivery. Service level in particular dropped from a 1.9% to a 5.1% gap. Delivery performance decreases significantly as well. Within this scenario we can clearly see the advantages of collaborative replenishment since although average inventory held at manufacturer is lowered to 70% of the default value, overall and individual service levels remain virtually the same in case of CPFR. Altogether performance decreases slightly even within the collaboration approaches but can still easily outperform the default inventory flexible ROP scenario. CPFR achieves somewhat better results than VMI but the advantage is not as obvious as in the supply chain framework of manufacturer 2. The high inventory case is rather of theoretical value since the company does not consider increasing the inventory capacity to weekly product sales ratio whatsoever. However, it is apparent that even though all three approaches lead to remarkably good outcomes, collaboration gives the competitive edge when it comes to even lower service level gaps or punctual delivery.

6.2.4 Concluding thoughts

Overall we can see that the strengths of collaborative replenishment approaches lay clearly within the low inventory scenarios. Taking the three example frameworks from above, collaboration is the only reasonable way to allow superior replenishment performance whilst operating very lean stock policies at manufacturer level. Taking the above outcome as a reference we can surely say that collaboration allows running a replenishment process with the same or improved performance at a substantially lower inventory level. A further strength is delivery performance between manufacturer and retailers' distribution centres. Introducing VMI or CPFR replenishment substantially increased timely delivery, fill-rates and in most cases diminished the number of necessary tours. The actual difference between VMI and CPFR is however less obvious to state. In some cases CPFR is evidently superior to VMI and has to be clearly recommended whilst in other circumstances the additional effort necessary to implement and maintain a CPFR instead of VMI system does not seem to pay off altogether.

This raises the general issue of the economical reasonability and necessary scope of engaging in collaborative replenishment which needs to be considered in more detail. Such issues of recommendable scale and scope of collaboration will thus be the main focus within the following heterogeneous improvement context analyses where various settings within the crucial low inventory frameworks are tested since they bear the most potential for efficiency increases.

7. Heterogeneous improvement context

The previous chapter revealed the remarkable improvements that could be achieved by adjusting the actual supply chain distribution system by simply altering order setups, adopting new replenishment schemes or increased collaboration. However, the analysis was limited to uniform global alterations which was a sufficient mean to demonstrate the overall potential of a proposed system adjustment but is often not very useful in practice. As discussed before, real life distribution systems are very rarely of homogeneous nature. Typically, a manufacturer has a very distinct replenishment relationship with each of its customers. The individual distribution structure or the actual level of collaboration between manufacturer and each customer widely varies due to importance of the customer, trust, business philosophy, technical resources etc. Due to that it is of high practical relevance to investigate the effect of various alterations and improvements to the replenishment system not only on a system-wide scale but also on a very individual level to evaluate specific, customised distribution setups and give practical advice to the large number of companies that are not operating within a homogeneous replenishment context. Within the following section we first investigate what impact a limited collaboration framework involving only part of the customers has on global supply chain performance. Therefore we evaluated a large number of mixed setups featuring customers being replenished via fixed ROP, flexible ROP, VMI or CPFR simultaneously. In the second part of the section we split up a CPFR approach into individual collaboration modules and analyse how important and how much necessary each of these modules is within various distribution frameworks. This was done to raise and answer questions like "How much collaboration is really necessary or really reasonable?" or "What part of a collaboration framework is most beneficial for individual customers?". Within the third part of the chapter we finally explored the effects of some customers engaging in collaboration on others that do not adjust their replenishment system. Within that framework we investigate who would benefit the most from an early adoption of collaboration and to what extent the remaining non-collaborative customers can be disadvantaged by not participating.

7.1 Performance implications within increasing scope of collaboration

Within this section we will first state again the reference scenarios that constitute the actual state of replenishment for each framework before any alterations to the system. These will serve as a basis to compare changes step by step whilst the distribution layout is adjusted and demand visibility increases through raising the number of customers that feature VMI/CPFR replenishment from 0 up to 4. Within this section we will mainly focus on global achievements of a widening collaboration framework whilst section 7.2 will evaluate various effects evolving demand transparency has on each individual customer.

7.1.1 Scenario selection and setup

To be able to evaluate how increasing the scope of collaboration affects individual performance measures on a global basis, we investigate a large set of possible scenarios. Initially we take the low inventory scenarios of each manufacturer's framework as starting point and increase collaboration step by step by engaging initially one, two, three and finally all four customers in collaborative replenishment which can be either VMI or CPFR. Frameworks 1 and 2 are investigated for the case of fixed as well as flexible delivery date setup whilst framework 3 is by default based on flexible delivery date setup. Altogether we thus have 5 default scenarios which are then altered to obtain 30 extended collaboration settings grouped into three collaboration categories. The notation schema of the scenarios within the following section uses a 4 digit code to display the actual replenishment policy in order of the customers. Within this schema F stands for a customer being replenished via fixed-date ROP, R stands for flexible-date ROP, V stands for VMI and C for CPFR. For example FFCF denotes a scenario where customers 1,2 and 4 are replenished via fixed-date ROP and customer 3 via CPFR.

7.1.2 Supply Chain Framework 1 - Fixed date ROP delivery

The first out of five investigation cases evolves from the low inventory non-collaborative fixed date replenishment system of supply chain framework 1 that was described in detail within the previous chapters. Within this initial step we observe the performance impact that is caused by any single customer being replenished collaboratively via either CPFR or VMI. For details about the individual characteristics and setup of VMI and CPFR replenishment see Chapter 4. Within this investigation context, manufacturer inventory will not be fixed to stay at a default level. The reason for that is to obtain an impression as to what extent inventory level is reduced whilst the scope of collaboration widens. The results will be comparable altogether but we have to keep in mind that several performance measures, in particular service level or delayed deliveries, would result in better outcome if inventory was adjusted to a fixed level. Since service level is the main key performance indication within the investigation we will fix inventory within scenarios later on to obtain more accurate information about the degree of service level improvement.

Low collaboration scenarios

Framework 1 - low collaboration: 3 customers fixed date ROP & 1 VMI or CPFR

		FFFF	CFFF	VFFF	FCFF	FVFF	FFCF	FFVF	FFFC	FFFV
Global	**overall SL gap**	**6.1%**	**5.1%**	**5.7%**	**6.7%**	**7.2%**	**4.5%**	**5.0%**	**5.1%**	**5.4%**
	typical SL gap	28%	26%	28%	30%	31%	29%	29%	29%	28%
	largest overall SL gap	100%	100%	100%	100%	100%	100%	100%	100%	100%
	perfect weeks	78%	80%	80%	78%	77%	84%	82%	84%	82%
	FC accuracy gap	8.2%	7.2%	7.6%	6.4%	6.7%	6.5%	6.9%	7.0%	7.3%
inventory	**Manufacturer Inventory**	**100%**	**100%**	**97%**	**105%**	**102%**	**92%**	**90%**	**95%**	**93%**
	total DC inventory	**100%**	**93%**	**92%**	**98%**	**96%**	**107%**	**101%**	**107%**	**102%**
	Excessive Inventory	1.9%	1.2%	0.9%	5.5%	4.5%	2.0%	1.7%	1.9%	1.9%
Manufacturer to DC	tours needed	97%	102%	103%	100%	101%	101%	103%	100%	101%
	delivery delayed	51%	48%	50%	46%	47%	43%	48%	43%	46%
	critically delayed	**13%**	**7%**	**8%**	**12%**	**12%**	**10%**	**13%**	**10%**	**12%**
	delivery fill-rate	86%	84%	84%	86%	86%	88%	86%	88%	87%
	perfect deliveries	35%	24%	23%	37%	35%	36%	32%	39%	35%
DC to retail	delivery delayed	7.6%	6.9%	7.0%	7.0%	7.4%	5.4%	6.4%	5.5%	5.7%
	critically delayed	2.6%	2.0%	2.0%	2.9%	3.2%	2.2%	2.7%	2.1%	2.2%

Table 7.1: Results for SC framework 1 – fixed reorder date and low level of collaboration

The results in the table show that even with one out of four customers being engaged in collaboration, we can achieve significant improvements at a global level. Most remarkable improvements are achieved within service-level, production forecast accuracy, manufacturer's inventory and critically delayed deliveries. Nevertheless considering the key performance indicators (bold numbers) it appears that engaging customer 2 into collaboration does not seem to be beneficial at all. Within this case, service level even diminishes whilst most other figures do not improve to a significant extent. Overall collaboration should therefore lead to unsatisfactory and disappointing outcome and cannot be recommended unless other framework parameters are changed simultaneously. The altogether most recommended scenario would be to engage in collaborative replenishment with customer 3. Another finding from this initial step is that most performance metrics reveal a substantially better outcome in case of CPFR compared to VMI. Nevertheless, VMI seems to have the upper hand considering inventory figures.

Medium collaboration scenarios

Framework 1 - medium collaboration: 2 customers fixed date ROP & 2 VMI or CPFR

		FFFF	CCFF	VVFF	CFCF	VFVF	CFFC	VFFV	FCCF	FVVF	FCFC	FVFV	FFCC	FFVV
Global	**overall SL gap**	**6.1%**	**5.0%**	**5.8%**	**3.6%**	**4.5%**	**3.7%**	**4.5%**	**3.9%**	**4.8%**	**4.4%**	**5.1%**	**2.7%**	**3.8%**
	typical SL gap	28%	27%	27%	31%	31%	27%	29%	31%	32%	29%	29%	16%	20%
	largest overall SL gap	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	82%	89%
	perfect weeks	78%	81%	79%	87%	85%	88%	86%	86%	83%	86%	84%	86%	84%
	FC accuracy gap	8.2%	5.9%	6.4%	6.0%	6.6%	6.3%	6.8%	5.3%	5.9%	5.7%	6.2%	5.6%	6.2%
inventory	**Manufact. Inventory**	**100%**	**101%**	**99%**	**93%**	**89%**	**93%**	**91%**	**92%**	**88%**	**92%**	**90%**	**80%**	**79%**
	total DC inventory	**100%**	**92%**	**87%**	**107%**	**101%**	**105%**	**102%**	**109%**	**102%**	**108%**	**102%**	**96%**	**91%**
	Excessive Inventory	1.9%	4.2%	4.1%	2.0%	1.6%	1.1%	1.0%	2.7%	2.5%	2.5%	2.2%	0.2%	0.3%
Manufacturer to DC	tours needed	97%	106%	108%	107%	110%	107%	109%	106%	109%	106%	107%	112%	115%
	delivery delayed	51%	48%	47%	40%	44%	42%	44%	41%	46%	40%	42%	56%	57%
	critically delayed	**13%**	**9%**	**11%**	**4%**	**7%**	**5%**	**7%**	**7%**	**11%**	**7%**	**10%**	**14%**	**17%**
	delivery fill-rate	86%	84%	84%	88%	86%	87%	87%	89%	87%	89%	88%	84%	82%
	perfect deliveries	35%	28%	27%	34%	30%	33%	34%	41%	34%	40%	39%	24%	21%
DC to retail	delivery delayed	7.6%	6.5%	7.2%	4.0%	5.0%	3.8%	4.5%	4.4%	5.2%	4.2%	5.4%	4.8%	5.5%
	critically delayed	2.6%	2.2%	2.7%	1.7%	2.1%	1.5%	1.8%	2.0%	2.5%	1.9%	2.3%	1.3%	1.8%

Table 7.2: Results for SC framework 1 – fixed reorder date and medium level of collaboration

Taking demand visibility another step further reveals once again substantial improvements throughout the majority of scenarios compared to the default as well as to the low collaboration scenarios. Most improved figures once again are service level, manufacturers' inventory and critically delayed deliveries between manufacturer and retailer distribution centres. The most fruitful partnership is to be expected if customers 3 and 4 are engaged in collaboration. This combination is a major leap ahead of both customers engaging individually. The overall performance advantage compared to any other combination of two involved customers is remarkable apart from delivery punctuality figures which are somewhat decreased due to the much reduced manufacturer inventory level. On the other hand, the least recommendable setting is collaboration with customers 1 and 2. Even though performance is somewhat improved compared to the non-collaborative scenario, it lacks real progress and falls behind most of the low-collaboration scenarios in the previous table. It will thus surely lead to disappointment.

High collaboration scenarios

Ultimately, there is the situation of almost pure VMI/CPFR replenishment. Most likely we can expect the best results from all scenarios so far. The high collaboration case reveals once more the degree of improvement that is possible with adopting advanced replenishment methods. Especially the CPFR scenarios reveal vastly improved performance outcomes. The reason why the VMI scenarios achieve rather disappointing results is due to the very low manufacturer inventory level as a result of improved replenishment efficiency. Since we decided not to fix inventory within this first framework, inventory and service level performance can only be appraised together.

Framework 1 - high collaboration: max 1 customers fixed date ROP & min 3 VMI or CPFR

		FFFF	CCCF	VVVF	CCFC	VVFV	CFCC	VFVV	FCCC	FVVV	CCCC	VVVV
Global	**overall SL gap**	**6.2%**	**2.0%**	**4.1%**	**2.9%**	**4.5%**	**1.7%**	**3.7%**	**1.4%**	**3.6%**	**0.7%**	**3.4%**
	typical SL gap	28%	22%	29%	23%	26%	14%	22%	11%	18%	7%	12%
	largest overall SL gap	100%	100%	100%	100%	100%	92%	100%	79%	100%	29%	65%
	perfect weeks	78%	89%	84%	89%	84%	91%	87%	89%	82%	91%	75%
	FC accuracy gap	8.2%	5.5%	6.2%	5.8%	6.3%	5.6%	6.3%	5.3%	6.0%	5.9%	6.7%
inventory	**Manufact. Inventory**	**100%**	**91%**	**80%**	**94%**	**84%**	**82%**	**76%**	**79%**	**72%**	**79%**	**67%**
	total DC inventory	**100%**	**107%**	**93%**	**107%**	**94%**	**103%**	**93%**	**102%**	**88%**	**102%**	**75%**
	Excessive Inventory	2.0%	2.3%	1.0%	2.8%	1.5%	0.6%	0.2%	0.9%	0.5%	1.2%	0.2%
Manufacturer to DC	tours needed	97%	112%	118%	111%	117%	117%	122%	116%	122%	120%	129%
	delivery delayed	52%	42%	54%	40%	52%	47%	55%	51%	63%	51%	79%
	critically delayed	**14%**	**5%**	**11%**	**5%**	**11%**	**6%**	**11%**	**12%**	**18%**	**9%**	**30%**
	delivery fill-rate	85%	88%	84%	89%	85%	85%	82%	86%	82%	86%	78%
	perfect deliveries	34%	39%	27%	40%	29%	30%	22%	30%	19%	32%	13%
DC to retail	delivery delayed	7.8%	3.0%	4.5%	3.1%	4.7%	2.6%	3.5%	2.9%	5.1%	1.9%	6.8%
	critically delayed	2.7%	1.1%	1.8%	1.3%	1.8%	0.8%	1.2%	0.7%	1.5%	0.3%	2.3%

Table 7.3: Results for SC framework 1 – fixed reorder date and high level of collaboration

Once again there are remarkable differences between the individual customer combinations. As we already found out before, improving replenishment of customers 3 and 4 is much more vital and results altogether in better results. Consequently, scenarios that do not include these two customers do not achieve as good results as the ones that do. The overall best three CPFR or VMI customer scenarios are FCCC/FVVV where customers 2, 3 and 4 engage in collaborative replenishment. Even though the outcome for this case is very convincing, an all customer CPFR framework pushes performance another leap ahead to make this scenario (CCCC) superior to all others by far. The only observed shortcoming of increased collaboration within this framework was the increase in necessary delivery tours. This increase by up to 20% is a result of a flexibilisation of replenishment since in case of supply shortage delivered quantities are not sufficient to last for the regular replenishment interval which makes earlier replenishments necessary. This behaviour accumulates to an overall increase in necessary tours.

7.1.3 Supply Chain Framework 1 - Flexible date ROP delivery

The second investigated case is also based on the distribution framework of manufacturer 1. Opposite to the previous section we base the investigation on the flexible date ROP delivery. Furthermore, the manufacturer inventory is set to a fixed level which should allow us to obtain a better picture about improvements among the other key performance indicators.

Low collaboration scenarios

The outcome for the low collaboration scenarios here is much more homogenous compared to the previous fixed date ROP approach. Any single customer engaged in collaborative replenishment improves the overall supply chain performance noticeably. The lack of difference is due to the flexible date delivery approach adopted for the three remaining ROP customers, the very similar share of overall demand among the customers and the fixed manufacturer inventory level. We can see once again that CPFR outperforms VMI in most performance categories except for delivery punctuality where they perform equally well.

Framework 1 - low collaboration: 3 customers flexible date ROP & 1 VMI or CPFR

		RRRR	CRRR	VRRR	RCRR	RVRR	RRCR	RRVR	RRRC	RRRV
Global	**overall SL gap**	**2.4%**	**1.7%**	**2.1%**	**1.4%**	**1.7%**	**1.7%**	**1.9%**	**2.1%**	**2.1%**
	typical SL gap	13%	13%	14%	12%	13%	13%	14%	13%	13%
	largest overall SL gap	49%	54%	62%	51%	61%	56%	62%	55%	56%
	perfect weeks	84%	89%	87%	88%	88%	88%	88%	86%	87%
	FC accuracy gap	8.2%	7.2%	7.5%	6.4%	6.7%	6.5%	6.8%	7.0%	7.3%
inventory	**Manufacturer Inventory**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	total DC inventory	**100%**	**104%**	**104%**	**105%**	**104%**	**105%**	**103%**	**101%**	**102%**
	Excessive Inventory	1.0%	1.2%	1.1%	1.0%	0.9%	0.7%	0.8%	0.6%	1.1%
Manufacturer to DC	tours needed	121%	120%	121%	120%	121%	120%	121%	122%	122%
	delivery delayed	70%	57%	55%	60%	59%	58%	58%	59%	58%
	critically delayed	**32%**	**21%**	**21%**	**20%**	**20%**	**21%**	**22%**	**25%**	**24%**
	delivery fill-rate	81%	83%	83%	83%	83%	83%	83%	82%	82%
	perfect deliveries	22%	27%	28%	26%	27%	27%	26%	24%	24%
DC to retail	delivery delayed	4.5%	3.4%	3.7%	3.2%	3.3%	3.4%	3.8%	3.9%	4.0%
	critically delayed	1.6%	1.1%	1.3%	0.9%	1.0%	1.0%	1.3%	1.3%	1.5%

Table 7.4: Results for SC framework 1 –flexible reorder date and low level of collaboration

Altogether the involvement of customer 2 in collaborative replenishment seems to be the most worthwhile especially if CPFR is put into place. We can see that by only managing a single customer that accounts for 29% of overall demand, service level gap can be cut down almost by half and the proportion of critically delayed deliveries by one third. Since even the least favourable case of customer 4 being supplied via CPFR/VMI approach seems to have no significant shortcoming in any of the performance categories we can undoubtedly support any form of collaborative engagement within this case.

Medium collaboration scenarios

Framework 1 - medium collaboration: 2 customers flexible date ROP & 2 VMI or CPFR

		RRRR	CCRR	VVRR	CRCR	VRVR	CRRC	VRRV	RCCR	RVVR	RCRC	RVRV	RRCC	RRVV
Global	**overall SL gap**	**2.4%**	**1.2%**	**1.8%**	**1.6%**	**2.0%**	**1.9%**	**2.1%**	**1.2%**	**1.8%**	**1.5%**	**1.9%**	**1.8%**	**2.2%**
	typical SL gap	13%	11%	15%	13%	16%	13%	15%	11%	15%	12%	15%	14%	15%
	largest overall SL gap	49%	59%	78%	68%	74%	59%	71%	61%	75%	62%	68%	68%	74%
	perfect weeks	84%	90%	89%	90%	89%	88%	89%	90%	89%	89%	88%	89%	89%
	FC accuracy gap	8.2%	5.9%	6.4%	6.0%	6.6%	6.4%	6.8%	5.3%	5.9%	5.7%	6.2%	5.6%	6.2%
inventory	**Manufact. Inventory**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	total DC inventory	**100%**	**105%**	**104%**	**105%**	**105%**	**103%**	**104%**	**105%**	**102%**	**104%**	**102%**	**102%**	**105%**
	Excessive Inventory	1.0%	1.0%	0.9%	1.1%	1.0%	0.8%	1.1%	0.8%	0.9%	0.6%	1.1%	0.5%	1.0%
Manufacturer to DC	tours needed	121%	119%	121%	120%	121%	121%	122%	120%	122%	121%	123%	122%	122%
	delivery delayed	70%	53%	51%	52%	48%	51%	50%	54%	55%	57%	53%	54%	48%
	critically delayed	**32%**	**14%**	**14%**	**14%**	**13%**	**16%**	**15%**	**13%**	**14%**	**15%**	**15%**	**15%**	**15%**
	delivery fill-rate	81%	85%	85%	84%	85%	84%	84%	85%	84%	84%	83%	83%	84%
	perfect deliveries	22%	30%	30%	29%	30%	27%	29%	29%	29%	25%	27%	25%	29%
DC to retail	delivery delayed	4.5%	2.5%	3.2%	2.9%	3.4%	3.4%	3.5%	2.6%	3.2%	2.8%	3.3%	3.2%	3.4%
	critically delayed	1.6%	0.8%	1.0%	0.9%	1.3%	1.0%	1.2%	0.7%	1.0%	0.7%	1.2%	1.1%	1.3%

Table 7.5: Results for SC framework 1 – flexible reorder date and medium level of collaboration

After a further increase in demand transparency due to supplying another customer via CPFR or VMI, performance improves accordingly. Altogether the actual degree of improvement is not as significant compared to the first step within the previous table. In case of VMI implementation most of the global figures do not improve at all compared to the previous single customer case. The most noticeable improvements can be acknowledged if customers 1 & 2 or customers 2 & 3 are engaged in collaboration. However, the minor level of improvement compared to a customer 2 only scenario may make it unnecessary to collaborate with just a second customer.

High collaboration scenarios

The high collaboration scenarios reveal the potential degree of improvement in case the majority of demand is dispatched via collaborative replenishment.

Framework 1 - high collaboration: max 1 customers flexible date ROP & min 3 VMI or CPFR

		RRRR	CCCR	VVVR	CCRC	VVRV	CRCC	VRVV	RCCC	RVVV	CCCC	VVVV
Global	**overall SL gap**	**2.4%**	**0.9%**	**1.3%**	**1.1%**	**1.6%**	**1.7%**	**1.9%**	**1.1%**	**1.5%**	**0.7%**	**1.0%**
	typical SL gap	13%	8%	15%	11%	15%	13%	16%	9%	14%	7%	9%
	largest overall SL gap	49%	54%	98%	77%	92%	86%	91%	66%	96%	29%	50%
	perfect weeks	84%	91%	91%	91%	90%	91%	91%	90%	91%	91%	90%
	FC accuracy gap	8.2%	5.5%	6.3%	5.8%	6.4%	5.6%	6.3%	5.3%	6.0%	5.9%	6.6%
inventory	**Manufact. Inventory**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	total DC inventory	**100%**	**107%**	**104%**	**105%**	**103%**	**104%**	**104%**	**103%**	**103%**	**102%**	**98%**
	Excessive Inventory	1.0%	1.1%	1.1%	1.0%	0.9%	0.8%	1.3%	0.7%	1.2%	1.2%	1.4%
Manufacturer to DC	tours needed	121%	118%	122%	120%	123%	120%	122%	120%	122%	120%	124%
	delivery delayed	70%	47%	49%	49%	49%	47%	46%	53%	48%	51%	51%
	critically delayed	**32%**	**9%**	**9%**	**10%**	**10%**	**10%**	**9%**	**11%**	**10%**	**9%**	**11%**
	delivery fill-rate	81%	87%	86%	86%	85%	85%	86%	85%	85%	86%	85%
	perfect deliveries	22%	35%	34%	32%	32%	31%	31%	30%	32%	32%	32%
DC to retail	delivery delayed	4.5%	2.0%	2.4%	2.3%	2.5%	2.4%	2.5%	2.3%	2.5%	1.9%	2.6%
	critically delayed	1.6%	0.4%	0.7%	0.6%	0.7%	0.8%	0.8%	0.4%	0.8%	0.3%	0.6%

Table 7.6: Results for SC framework 1 – flexible reorder date and high level of collaboration

Even though all of the scenarios are based on a similar level of collaboratively distributed demand, particular service level gap figures as the dominant performance indicator are somewhat different as the worst performing scenario (CRCC) has an almost double as large gap as the best case (CCCR). Another noticeable fact is the increase in *largest overall service level gap* that is caused by a single remaining ROP customer that is neglected for the sake of optimal demand fulfilment of the CPFR/VMI customers. We will investigate the particular impact of an increasing collaboration framework later in this chapter. Once again we can see that CPFR outperforms VMI to some extent. Looking at all the cases it seems that CPFR is always ahead by a margin that is equivalent to one more customer being added to the collaborative framework. When we are having a look at results for the full four collaborative customer scenarios we can see that the improvement from a 3 out of 4 to a full implementation scenario heavily depends on which customer is missing so far. The gained performance can thus vary in between very significant (C2 joins at last) to almost negligible (C4 joins at last).

7.1.4 Supply Chain Framework 2 - Fixed date ROP delivery

The third investigation case is based on the default low-inventory replenishment setting of supply chain framework 2. To be able to further evaluate the impact of an increasing scope of collaboration on an existing fixed-date delivery ROP system, we set up the model in that way. The manufacturer inventory will not be fixed to stay consistent with the setup in case 1 earlier.

Low collaboration scenarios

The delivery framework of manufacturer 2 reveals again a somewhat different outcome for the low collaboration setting compared to the previously considered cases. Altogether service level and delivery reliability seem to improve to some extent whilst inventory figures rather show a mixed outcome with manufacturer inventory diminishing and retailers distribution centres' inventory rising.

Framework 2 - low collaboration: 3 customers fixed date ROP & 1 VMI or CPFR

		FFFF	CFFF	VFFF	FCFF	FVFF	FFCF	FFVF	FFFC	FFFV
Global	**overall SL gap**	**5.9%**	**4.8%**	**5.3%**	**4.5%**	**5.2%**	**5.1%**	**5.2%**	**5.0%**	**5.1%**
	typical SL gap	20%	19%	18%	23%	25%	20%	20%	19%	17%
	largest overall SL gap	87%	81%	78%	90%	97%	80%	84%	79%	83%
	perfect weeks	72%	79%	77%	76%	74%	80%	79%	81%	79%
	FC accuracy gap	7.6%	6.6%	7.1%	6.1%	6.4%	7.0%	7.3%	7.3%	7.4%
inventory	**Manufacturer Inventory**	**100%**	**91%**	**92%**	**94%**	**93%**	**94%**	**94%**	**95%**	**96%**
	total DC inventory	**100%**	**118%**	**118%**	**116%**	**116%**	**118%**	**115%**	**113%**	**108%**
	Excessive Inventory	7.4%	4.8%	5.2%	4.8%	5.2%	5.3%	5.7%	5.3%	6.2%
Manufacturer to DC	tours needed	100%	109%	110%	108%	109%	109%	110%	108%	111%
	delivery delayed	55%	50%	51%	54%	56%	47%	47%	36%	39%
	critically delayed	**36%**	**27%**	**28%**	**26%**	**29%**	**26%**	**27%**	**24%**	**26%**
	delivery fill-rate	80%	83%	83%	81%	80%	83%	82%	83%	82%
	perfect deliveries	16%	26%	26%	18%	15%	29%	26%	26%	24%
DC to retail	delivery delayed	10.3%	7.5%	7.7%	8.0%	8.4%	7.3%	7.7%	7.1%	7.5%
	critically delayed	3.3%	2.3%	2.7%	3.0%	3.6%	2.6%	2.8%	2.2%	2.2%

Table 7.7: Results for SC framework 2 – fixed reorder date and low level of collaboration

The level of improvement among the key performance indicators, particularly service level gap is rather disappointing since even the best scenario leads only to minor advances. Altogether the results indicate once again that a widening collaboration scope based on a fixed-date delivery setting reveals very distinctive outcome that can hardly be predicted beforehand. For example as a result of engaging customers 1 or 2 in collaborative replenishment service level and other metrics are much better in case CPFR is adopted instead of VMI. In case of customers 3 or 4 being replenished collaboratively, CPFR does not seem to have any advantage over VMI.

Apart from some increased DC inventory figures all considered increased collaboration scenarios seem to result in improved overall performance. The slight increase in DC inventory is most likely due to improved delivery reliability and thus less out of stock times which also leads to an increase in necessary tours to distribute the goods from the manufacturer to the DCs to compensate for times of shortages.

Medium collaboration scenarios

Framework 2 - medium collaboration: 2 customers fixed date ROP & 2 VMI or CPFR

		FFFF	CCFF	VVFF	CFCF	VFVF	CFFC	VFFV	FCCF	FVVF	FCFC	FVFV	FFCC	FFVV
Global	**overall SL gap**	**5.9%**	**2.1%**	**3.2%**	**4.4%**	**4.7%**	**4.2%**	**4.6%**	**2.6%**	**3.5%**	**3.4%**	**3.9%**	**4.3%**	**4.7%**
	typical SL gap	20%	19%	24%	18%	19%	17%	18%	20%	23%	19%	22%	17%	17%
	largest overall SL gap	87%	94%	100%	69%	81%	69%	81%	97%	100%	95%	97%	74%	74%
	perfect weeks	72%	84%	81%	86%	85%	86%	85%	84%	82%	84%	83%	86%	84%
	FC accuracy gap	7.6%	5.0%	5.7%	6.0%	6.8%	6.3%	6.9%	6.1%	6.3%	6.0%	6.3%	6.8%	7.2%
inventory	**Manufact. Inventory**	**100%**	**81%**	**83%**	**93%**	**95%**	**91%**	**94%**	**86%**	**85%**	**90%**	**90%**	**92%**	**97%**
	total DC inventory	**100%**	**135%**	**129%**	**132%**	**130%**	**129%**	**130%**	**138%**	**132%**	**131%**	**128%**	**130%**	**126%**
	Excessive Inventory	7.4%	1.9%	2.9%	4.8%	6.1%	4.7%	5.1%	2.5%	3.2%	3.4%	4.2%	4.8%	6.8%
Manufacturer to DC	tours needed	100%	117%	117%	116%	119%	117%	120%	116%	116%	115%	118%	116%	120%
	delivery delayed	55%	52%	58%	41%	42%	40%	40%	45%	51%	39%	42%	37%	36%
	critically delayed	**36%**	**19%**	**23%**	**16%**	**17%**	**18%**	**19%**	**18%**	**21%**	**18%**	**19%**	**17%**	**18%**
	delivery fill-rate	80%	84%	83%	86%	85%	85%	84%	86%	84%	85%	83%	85%	84%
	perfect deliveries	16%	30%	26%	38%	37%	35%	32%	34%	31%	30%	27%	34%	33%
DC to retail	delivery delayed	10.3%	4.7%	5.7%	4.6%	5.1%	4.5%	5.1%	4.8%	5.2%	4.7%	5.4%	5.0%	5.3%
	critically delayed	3.3%	1.6%	2.3%	1.8%	1.9%	1.5%	1.6%	1.8%	2.2%	1.8%	2.1%	1.7%	1.7%

Table 7.8: Results for SC framework 2 – fixed reorder date and medium level of collaboration

Taking collaboration another step further seems to acknowledge previous findings. However, the actual degree of improvement compared to the 1 collaborative customer framework is very significant as long as the right customers are chosen. Whilst delivery performance seems to improve for all the settings equally, service level as major target reveals vast differences. Taking each scenario individually, CPFR seems to outperform VMI but not by too large a margin. Overall we can state that among the scenarios of this framework there are severe performance differences. The top three scenarios either featuring CPFR or VMI by far outperform the lower three scenarios. Considering which customers to engage in collaboration with beforehand is thus absolutely vital to avoid disappointment.

High collaboration scenarios

Framework 2 - high collaboration: max 1 customers fixed date ROP & min 3 VMI or CPFR

		FFFF	CCCF	VVVF	CCFC	VVFV	CFCC	VFVV	FCCC	FVVV	CCCC	VVVV
Global	**overall SL gap**	**5.9%**	**1.2%**	**2.9%**	**1.6%**	**3.3%**	**4.0%**	**5.0%**	**2.1%**	**3.3%**	**1.1%**	**2.9%**
	typical SL gap	20%	18%	27%	16%	22%	20%	21%	17%	21%	7%	10%
	largest overall SL gap	87%	98%	100%	94%	100%	79%	91%	97%	100%	36%	67%
	perfect weeks	72%	89%	81%	90%	85%	89%	87%	90%	87%	89%	80%
	FC accuracy gap	7.6%	5.3%	5.6%	5.1%	5.6%	5.9%	6.8%	6.2%	6.2%	5.6%	5.6%
inventory	**Manufact. Inventory**	**100%**	**81%**	**81%**	**81%**	**81%**	**96%**	**96%**	**87%**	**83%**	**81%**	**81%**
	total DC inventory	**100%**	**136%**	**119%**	**141%**	**126%**	**136%**	**130%**	**148%**	**136%**	**131%**	**104%**
	Excessive Inventory	7.4%	1.4%	2.2%	1.3%	2.4%	5.1%	6.3%	2.3%	2.3%	1.7%	1.9%
Manufacturer to DC	tours needed	100%	125%	128%	124%	129%	121%	126%	122%	127%	133%	139%
	delivery delayed	55%	57%	70%	48%	59%	36%	37%	40%	48%	59%	76%
	critically delayed	**36%**	**19%**	**31%**	**16%**	**24%**	**13%**	**14%**	**14%**	**16%**	**23%**	**42%**
	delivery fill-rate	80%	84%	80%	85%	82%	87%	84%	86%	83%	83%	77%
	perfect deliveries	16%	34%	23%	35%	26%	41%	34%	39%	30%	29%	15%
DC to retail	delivery delayed	10.3%	2.8%	4.5%	2.9%	4.0%	3.6%	4.1%	2.5%	3.4%	2.3%	4.9%
	critically delayed	3.3%	1.2%	1.8%	0.8%	1.7%	1.4%	1.9%	0.8%	1.3%	0.5%	1.5%

Table 7.9: Results for SC framework 2 – fixed reorder date and high level of collaboration

The results of the high collaboration settings emphasize the previously found diversity between different scenarios. As we see from the table, overall service level gap as the most important performance indicator varies in between 1% and 4% in case of CPFR settings which is an extraordinary range considering all scenarios involve 3 out of 4 customers. Among the VMI scenarios variation is also significant but not as extreme. The differences become even more apparent when we take manufacturer inventory figures into consideration as well. The best service level scenarios lead to evidently significantly fewer inventories on top of the improved service level. The actual differences cannot just be explained by the overall percentage of demand that is replenished collaboratively. The CCFC and FCCC scenarios both have almost identical ratios in that sense but the first one results in a much better outcome than the latter. The overall most disappointing case is the CFCC/VFVV scenario which although 3 out of 4 customers being engaged in collaboration which is in this framework equal to almost 60% of overall demand does apparently not lead to any major performance improvement regarding various service level and inventory figures.

On the other hand we can see which extraordinary improvements are possible if the right customers are chosen or a full collaboration framework is established. Overall within this framework, VMI does not seem to perform too convincingly since it loses out against CPFR to a remarkable extent. Even though performance improves noticeably CPFR is clearly superior which makes a recommendation for VMI difficult to support.

7.1.5 Supply Chain Framework 2 - Flexible date ROP delivery

The fourth investigation case is based on the default low-inventory non-collaborative flexible date replenishment setting of supply chain framework 2. Hereafter, the manufacturer inventory is set to a fixed level which will focus all the attention to the service level gap.

Low collaboration scenarios

Framework 2 - low collaboration: 3 customers flexible date ROP & 1 VMI or CPFR

		RRRR	CRRR	VRRR	RCRR	RVRR	RRCR	RRVR	RRRC	RRRV
Global	**overall SL gap**	**3.7%**	**3.1%**	**3.7%**	**2.3%**	**3.3%**	**3.2%**	**3.7%**	**3.5%**	**4.0%**
	typical SL gap	12%	13%	14%	15%	17%	14%	14%	12%	13%
	largest overall SL gap	59%	56%	63%	73%	84%	60%	63%	67%	64%
	perfect weeks	74%	79%	78%	84%	79%	81%	80%	80%	78%
	FC accuracy gap	7.6%	6.6%	7.1%	6.0%	6.4%	7.0%	7.4%	7.3%	7.5%
inventory	**Manufacturer Inventory**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	total DC inventory	**100%**	**109%**	**110%**	**124%**	**117%**	**112%**	**110%**	**106%**	**103%**
	Excessive Inventory	3.0%	2.1%	3.4%	1.2%	1.9%	2.9%	3.5%	3.0%	3.4%
Manufacturer to DC	tours needed	129%	134%	134%	127%	129%	134%	135%	136%	137%
	delivery delayed	88%	72%	70%	78%	80%	68%	66%	65%	64%
	critically delayed	**76%**	**51%**	**51%**	**43%**	**50%**	**49%**	**50%**	**53%**	**53%**
	delivery fill-rate	74%	75%	76%	79%	77%	76%	75%	75%	74%
	perfect deliveries	12%	14%	15%	21%	18%	14%	14%	12%	11%
DC to retail	delivery delayed	7.4%	5.9%	6.5%	4.9%	6.7%	5.9%	6.0%	5.7%	6.3%
	critically delayed	2.6%	1.8%	2.5%	1.8%	2.7%	2.2%	2.4%	2.0%	2.2%

Table 7.10: Results for SC framework 2 – flexible reorder date and low level of collaboration

Within this analysis framework the degree of performance improvement after a single customer is replenished via CPFR/VMI seems to be directly dependent on the percentage of total demand that is represented by this customer. It is thus not surprising that upgrading the replenishment process of the largest customer 2 is most fruitful on a global basis. Apart from very much improved service level there are nevertheless some shortcomings as well that most likely result out of the increased dominance of the largest customer that leads to increasing problems for the remaining ROP customers. Altogether we can further state that VMI seems to be much less effective within this framework compared to the earlier analysed settings. Considering service level, all but the major customer scenarios (RCRR and RVRR) do not seem to achieve any improvement within this most important key performance metric. This being valid for global and inventory figures, it needs to be stated that there are certain improvements considering delivery punctuality targets. Another rather unexpected finding is the increased distribution centre inventory. Especially for the case of the main customer engaging in collaboration inventory is increased by as much as 20%. We mainly assume this is due to increased delivery reliability that overcomes the severe shortages of the default setting that are due to operating a low manufacturer inventory policy. We can thus rather presume that the default outcome is unusually low due to these shortages and increasing collaboration leads to a stabilisation of this figure.

Medium collaboration scenarios

The medium collaboration framework shows a mixture of encouraging improvement scenarios as well as disappointing outcome for others. Altogether the CPFR scenarios reveal significantly better performance than the VMI ones. Nevertheless even among CPFR cases only 3 out of 6 scenarios obtain a significant improvement over the best single customer cases. These include not surprisingly all the settings where the main customer 2 is involved.

Framework 2 - medium collaboration: 2 customers flexible date ROP & 2 VMI or CPFR

		RRRR	CCRR	VVRR	CRCR	VRVR	CRRC	VRRV	RCCR	RVVR	RCRC	RVRV	RRCC	RRVV
Global	**overall SL gap**	**3.7%**	**1.7%**	**2.9%**	**2.6%**	**3.5%**	**3.0%**	**3.9%**	**1.8%**	**2.9%**	**1.9%**	**3.0%**	**3.2%**	**3.8%**
	typical SL gap	12%	16%	21%	13%	17%	12%	15%	15%	21%	14%	17%	14%	15%
	largest overall SL gap	59%	80%	94%	63%	75%	55%	66%	81%	97%	74%	83%	73%	76%
	perfect weeks	74%	88%	83%	87%	87%	85%	84%	89%	86%	89%	85%	87%	85%
	FC accuracy gap	7.6%	4.9%	5.6%	6.0%	6.9%	6.3%	6.9%	6.0%	6.3%	5.9%	6.3%	6.8%	7.2%
inventory	**Manufact. Inventory**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	total DC inventory	**100%**	**128%**	**120%**	**122%**	**124%**	**114%**	**113%**	**134%**	**127%**	**131%**	**122%**	**120%**	**117%**
	Excessive Inventory	3.0%	1.2%	2.6%	1.7%	4.1%	1.8%	4.6%	1.5%	3.1%	1.4%	3.4%	2.9%	4.8%
Manufacturer to DC	tours needed	129%	127%	129%	134%	135%	138%	141%	127%	130%	130%	134%	138%	141%
	delivery delayed	88%	67%	73%	57%	54%	54%	53%	62%	64%	62%	65%	49%	49%
	critically delayed	**76%**	**28%**	**35%**	**29%**	**27%**	**33%**	**32%**	**24%**	**29%**	**28%**	**32%**	**31%**	**31%**
	delivery fill-rate	74%	82%	80%	79%	79%	77%	76%	82%	80%	80%	78%	77%	76%
	perfect deliveries	12%	27%	23%	22%	21%	15%	14%	29%	24%	23%	19%	15%	14%
DC to retail	delivery delayed	7.4%	3.1%	5.3%	3.7%	4.4%	4.4%	4.9%	2.9%	4.3%	3.1%	4.8%	4.0%	4.4%
	critically delayed	2.6%	1.3%	2.3%	1.1%	1.9%	1.5%	1.9%	1.1%	1.9%	1.1%	1.8%	1.4%	1.8%

Table 7.11: Results for SC framework 2 – flexible reorder date and medium level of collaboration

Considering global performance metrics, at least 2 CPFR scenarios show very disappointing outcomes since they constitute no significant improvement over the default ROP setting even though 2 out of 4 customers are engaged in collaborative replenishment. This disappointing outcome is even more apparent among the VMI scenarios. Only 2 out of 6 scenarios managed to obtain some level of improvement over the default ROP scenario whilst the 2 worst performers even reveal a slightly diminished service level. A further point of criticism are the extended largest overall service level gaps figures. These are most likely caused by neglecting the remaining ROP customers that therefore suffer substantial shortages of supply. Some VMI scenarios additionally reveal a significantly enlarged excessive inventory compared to the default scenario which is a rather negative point. In opposite to the often disappointing global service level outcome, delivery performance seems to improve significantly within all scenarios. Altogether the above case reveals very diverse outcomes with only a few scenarios revealing convincing performance whilst many others fail to improve overall supply chain efficiency.

High collaboration scenarios

Framework 2 - high collaboration: max 1 customers flexible date ROP & min 3 VMI or CPFR

		RRRR	CCCR	VVVR	CCRC	VVRV	CRCC	VRVV	RCCC	RVVV	CCCC	VVVV
Global	**overall SL gap**	**3.7%**	**0.9%**	**2.4%**	**1.1%**	**2.5%**	**2.1%**	**3.8%**	**1.4%**	**2.7%**	**0.8%**	**2.5%**
	typical SL gap	12%	15%	25%	12%	22%	13%	19%	13%	21%	7%	10%
	largest overall SL gap	59%	93%	100%	82%	100%	64%	89%	90%	100%	31%	58%
	perfect weeks	74%	91%	85%	92%	89%	92%	90%	92%	90%	91%	83%
	FC accuracy gap	7.6%	5.2%	5.7%	5.0%	5.6%	5.9%	6.8%	6.1%	6.3%	5.5%	5.6%
inventory	**Manufact. Inventory**	**100%**	**95%**	**96%**	**94%**	**97%**	**103%**	**108%**	**99%**	**99%**	**97%**	**97%**
	total DC inventory	**100%**	**131%**	**114%**	**136%**	**123%**	**130%**	**124%**	**143%**	**128%**	**127%**	**102%**
	Excessive Inventory	3.0%	1.8%	2.9%	1.5%	3.2%	2.4%	4.6%	2.3%	3.6%	2.0%	2.5%
Manufacturer to DC	tours needed	129%	127%	129%	129%	133%	137%	143%	127%	134%	130%	136%
	delivery delayed	88%	57%	69%	54%	60%	44%	43%	48%	55%	52%	71%
	critically delayed	**76%**	**19%**	**30%**	**18%**	**23%**	**17%**	**16%**	**15%**	**19%**	**18%**	**37%**
	delivery fill-rate	74%	84%	81%	84%	81%	80%	78%	85%	81%	84%	78%
	perfect deliveries	12%	35%	26%	32%	25%	22%	17%	33%	25%	33%	20%
DC to retail	delivery delayed	7.4%	1.9%	3.3%	1.7%	2.8%	2.7%	3.5%	1.9%	2.3%	1.7%	4.4%
	critically delayed	2.6%	0.7%	1.4%	0.6%	1.3%	0.9%	1.4%	0.7%	1.1%	0.4%	1.2%

Table 7.12: Results for SC framework 2 – flexible reorder date and high level of collaboration

Within the high collaboration case we see once again the great potential of improvement in case the right collaboration customers are chosen. The outcome for supply chain framework 2 is different insofar as the individual customers account for quite different shares of overall demand. As a result of that combining the largest customers is very fruitful if already only 1 or 2 of them are engaged in collaborative replenishment. As we see from Table 7.12, combining the 3 large customers we obtain results very close to a full implementation framework. On the other hand we can see from the CRCC scenario (excludes the largest customer) that even 3 out of 4 customers joining a CPFR system does not improve the overall system to a significant extent as would have been expected. Even if we account for a similar share of overall demand being replenished collaboratively, there are still significant differences between individual cases that cannot be estimated without an in-depth analysis. Another outcome of the above case is the disappointing performance of VMI. In contrast to supply chain frameworks 1 or 3, VMI here does not seem to result in significant advantages over flexible ROP.

7.1.6 Supply Chain Framework 3

Finally we will finish the investigation of global performance impact within an expanding scope of collaborative replenishment by investigating supply chain framework 3. Only the default flexible date delivery ROP setting will serve as basis for the investigation. Nevertheless we will set the inventory to a lower level as proposed within the improvement recommendations in section 6.1. This is done in accordance with the future plans of the manufacturer to compensate lower inventory with collaborative replenishment. The manufacturer inventory is again set to a fixed level to be able to focus on service level as the dominant key performance indicator.

Low collaboration scenarios

Framework 3 - low collaboration: 3 customers flexible date ROP & 1 VMI or CPFR

		RRRR	CRRR	VRRR	RCRR	RVRR	RRCR	RRVR	RRRC	RRRV
Global	**overall SL gap**	**5.2%**	**4.6%**	**5.3%**	**3.6%**	**3.9%**	**2.8%**	**3.4%**	**5.4%**	**6.1%**
	typical SL gap	12%	11%	12%	12%	10%	9%	10%	13%	14%
	largest overall SL gap	65%	55%	58%	84%	70%	57%	80%	62%	80%
	perfect weeks	79%	78%	77%	83%	79%	85%	83%	79%	78%
	FC accuracy gap	15.0%	12.9%	13.5%	9.9%	11.2%	10.5%	11.8%	13.5%	13.8%
inventory	**Manufacturer Inventory**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	total DC inventory	**100%**	**96%**	**94%**	**108%**	**109%**	**113%**	**114%**	**99%**	**96%**
	Excessive Inventory	1.5%	1.1%	1.7%	1.1%	1.0%	0.9%	0.8%	1.5%	2.7%
Manufacturer to DC	tours needed	116%	116%	118%	111%	113%	110%	111%	115%	115%
	delivery delayed	67%	62%	60%	55%	53%	53%	46%	59%	57%
	critically delayed	**30%**	**23%**	**24%**	**19%**	**20%**	**16%**	**14%**	**23%**	**24%**
	delivery fill-rate	81%	81%	81%	83%	83%	84%	86%	82%	82%
	perfect deliveries	29%	29%	29%	33%	36%	39%	43%	31%	32%
DC to retail	delivery delayed	5.1%	4.6%	5.5%	3.5%	4.0%	1.9%	3.0%	5.2%	5.8%
	critically delayed	1.4%	1.2%	1.5%	0.8%	1.0%	0.7%	0.8%	1.4%	1.6%

Table 7.13: Results for SC framework 3 – flexible reorder date and low level of collaboration

The outcome of the low collaboration case of supply chain framework 3 demonstrates very clearly how diverse the impact of engaging one customer in collaborative replenishment can be. The range of possible effects reaches from remarkable improvement with service level gap and critical delays being reduced by virtually half (RRCR, RRVR) up to noticeable performance decline with expanded service level gaps (VRRR, RRRC, RRRV). The reason for these diverse results can be partially found in the percentage of overall demand that is replenished via CPFR or VMI. Within this framework, customers 2 and 3 account each for approximately 35% of overall demand and thus more than double of either customer 1 or 4. However, we can see from the different results obtained by scenario RCRR vs. RRCR and RVRR vs. RRVR that importance of a customer is not the only reason for higher or lower performance. Apparently the involvement of customer 3 into collaboration is much more fruitful than doing the same with customer 2 even though both account for the same percentage of demand. The same is true comparing the worst scenarios where customer 4 being solely replenished collaboratively is much more harmful to overall performance than in the case of customer 1 even though they once more account for the same percentage of overall demand. Another clear finding of this case is the possibility that engaging a minority of customers in collaborative replenishment can even remarkably reduce overall performance as we can see if customer 4 is replenished via CPFR/VMI. The reason behind this performance decline is most likely due to disadvantaging the major customers 2 and 3 as a result of prioritizing the collaborative replenished customer. The above case demonstrates how diverse the impact of initial collaboration can be depending on which customer is chosen to begin with. As a result it cannot be assumed that collaboration will always lead to improvements. In particular within frameworks that are characterised by substantial differences of customer importance, neglecting major customers for the sake of collaborating with a smaller one can turn out to be very harmful.

Medium collaboration scenarios

Framework 3 - medium collaboration: 2 customers flexible date ROP & 2 VMI or CPFR

		RRRR	CCRR	VVRR	CRCR	VRVR	CRRC	VRRV	RCCR	RVVR	RCRC	RVRV	RRCC	RRVV
Global	**overall SL gap**	**5.2%**	**3.3%**	**3.7%**	**3.1%**	**3.8%**	**5.0%**	**5.5%**	**2.0%**	**2.1%**	**3.4%**	**3.6%**	**3.7%**	**3.9%**
	typical SL gap	12%	12%	12%	10%	11%	12%	14%	8%	9%	11%	11%	11%	12%
	largest overall SL gap	65%	91%	91%	79%	85%	57%	65%	100%	100%	82%	88%	74%	87%
	perfect weeks	79%	84%	83%	85%	83%	80%	80%	85%	82%	84%	83%	84%	84%
	FC accuracy gap	15.0%	8.0%	10.0%	8.9%	10.5%	11.6%	12.5%	5.4%	8.4%	7.8%	9.3%	9.0%	10.3%
inventory	**Manufact. Inventory**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	total DC inventory	**100%**	**104%**	**107%**	**108%**	**105%**	**96%**	**93%**	**122%**	**120%**	**106%**	**107%**	**105%**	**105%**
	Excessive Inventory	1.5%	0.7%	1.8%	0.5%	1.1%	1.3%	2.8%	2.4%	0.9%	1.0%	2.0%	1.2%	1.4%
Manufacturer to DC	tours needed	116%	109%	112%	108%	113%	114%	115%	105%	110%	109%	112%	111%	112%
	delivery delayed	67%	52%	42%	55%	47%	54%	51%	48%	40%	51%	43%	48%	47%
	critically delayed	**30%**	**14%**	**11%**	**15%**	**13%**	**17%**	**15%**	**9%**	**7%**	**14%**	**11%**	**15%**	**13%**
	delivery fill-rate	81%	84%	86%	84%	84%	83%	83%	85%	87%	85%	86%	84%	85%
	perfect deliveries	29%	34%	41%	34%	36%	32%	35%	36%	45%	37%	42%	34%	38%
DC to retail	delivery delayed	5.1%	3.2%	3.2%	2.2%	3.2%	4.8%	5.2%	1.7%	1.9%	3.3%	3.2%	2.9%	3.1%
	critically delayed	1.4%	0.9%	0.9%	0.7%	0.8%	1.4%	1.6%	0.4%	0.3%	0.9%	0.8%	0.9%	0.9%

Table 7.14: Results for SC framework 3 – flexible reorder date and medium level of collaboration

The medium collaboration scenarios acknowledge the findings from above since once more there are very diverse achievements among the various scenarios. In general VMI seems to perform rather well within this framework since CPFR scenarios are only ahead by a very slight margin. Altogether the best scenarios outperform the worst ones by a tremendous amount. Nevertheless, the degree of improvement is not as impressive as within the introduction of the first collaboration customer. Another noticeable aspect is the disappointing performance in case both small customers 1 and 4 are engaged in CPFR/VMI. Even though half the customer base is thus involved in collaboration which implies substantial cost for implementation and maintenance, there seems to be no significant performance improvement apart from less critical delays as a result of this. Particularly service level figures do not improve at all since the large customers being disadvantaged negatively overcompensates any performance improvements by the two small customers.

High collaboration scenarios

Framework 3 - high collaboration: max 1 customers flexible date ROP & min 3 VMI or CPFR

		RRRR	CCCR	VVVR	CCRC	VVRV	CRCC	VRVV	RCCC	RVVV	CCCC	VVVV
Global	**overall SL gap**	**5.2%**	**2.1%**	**2.6%**	**2.7%**	**3.2%**	**3.5%**	**3.9%**	**2.1%**	**2.4%**	**1.7%**	**2.1%**
	typical SL gap	12%	11%	12%	10%	11%	12%	12%	11%	10%	7%	7%
	largest overall SL gap	65%	100%	89%	100%	100%	90%	91%	92%	91%	45%	53%
	perfect weeks	79%	85%	83%	85%	85%	86%	85%	85%	85%	86%	85%
	FC accuracy gap	15.0%	4.4%	7.8%	6.2%	8.2%	7.5%	9.2%	3.1%	6.8%	2.6%	6.4%
inventory	**Manufact. Inventory**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	total DC inventory	**100%**	**113%**	**109%**	**105%**	**103%**	**104%**	**104%**	**113%**	**110%**	**115%**	**107%**
	Excessive Inventory	1.5%	1.6%	1.0%	1.4%	1.0%	0.8%	0.9%	1.8%	1.2%	2.0%	1.7%
Manufacturer to DC	tours needed	116%	102%	110%	108%	114%	107%	111%	105%	109%	103%	110%
	delivery delayed	67%	50%	44%	49%	40%	48%	43%	49%	43%	42%	40%
	critically delayed	**30%**	**11%**	**8%**	**10%**	**7%**	**9%**	**8%**	**10%**	**8%**	**8%**	**7%**
	delivery fill-rate	81%	85%	86%	85%	86%	85%	86%	86%	87%	88%	88%
	perfect deliveries	29%	36%	40%	37%	41%	38%	41%	38%	42%	44%	47%
DC to retail	delivery delayed	5.1%	2.2%	2.7%	2.9%	2.0%	2.5%	2.9%	2.3%	2.6%	2.2%	2.5%
	critically delayed	1.4%	0.8%	0.8%	0.6%	0.3%	0.8%	0.8%	0.6%	0.6%	0.4%	0.4%

Table 7.15: Results for SC framework 3 – flexible reorder date and high level of collaboration

Within the high collaboration scenarios all cases show a significant improvement over the default all ROP setting. Even though there are still differences among the scenarios, results are much closer than within the medium collaboration case. Delivery delay performance is reaching a very satisfactory level within all scenarios. Altogether the step from 2 to 3 customers participating in CPFR/VMI seems to be less significant among the best scenarios but very much important for an improvement of the previously inferior cases. The final step towards full collaboration reveals once again superior outcome compared to every other setting but the degree of improvement is rather insignificant compared to the previously best scenarios.

7.1.7 Conclusions

From an overall point of view the low collaboration cases of each framework proved to be the most interesting ones since they reveal a lot of information about probable outcome within a collaboration initiation phase or within VMI/CPFR pilot studies. As it could clearly be seen for all five frameworks and for VMI as well as CPFR, there are vast differences in overall outcome depending on which customer a manufacturer initially collaborates with and in what order further customers are incorporated later on. The possible range of achievements reaches from a remarkable decline in performance up to significant benefits. Whilst in some cases implementing collaborative replenishment with a single customer improves overall supply chain performance remarkably, among other frameworks this initial step does not seem to reveal any substantial improvement for any of the scenarios. Amid such frameworks it is often the step from 1 to 2 or more customers that is much more impressive. Overall there can be no doubt about that even a partial increase in collaboration can lead to significant improvements of supply chain performance at a global level which was one of the claims the analysis was set out to support. The information obtained should be most helpful to support decision making from the point of view of a manufacturer supplying several customers. The results from investigating various supply setups of the three involved manufacturers clearly support the idea of heterogeneous collaboration frameworks. Within nearly all of the investigated cases above considering an improvement vs. implementation & maintenance effort ratio we would always have to recommend some of the heterogeneous scenarios over the full implementation cases. However, the most important point made within the analysis is the extreme diversity of each individual case. Therefore it can be considered absolutely crucial for the success of a collaboration initiative which particular customers are engaged in collaboration and in what order. As a general trend there seems to be a positive correlation between performance improvement and percentage of demand being replenished collaboratively but no such correlation between performance and number of customers engaged in either CPFR or VMI. Therefore it should not primarily be the number of customers that is crucial for the success of a collaboration initiative but the percentage of total demand that is covered. However, this explains only part of the variation since even among customers that account for the same percentage of demand there are substantial differences in the degree of improvement. Overall there are a number of factors that determine the final level of achievement. Since it is often the interrelations in between these factors that determine the final decision about their impact on overall performance, analysis methods like simulation are needed that can realistically cope with these interrelations. A purely analytical analysis would clearly reveal only limited information within such complex frameworks. This partly proves why in reality many companies experience disappointing outcome as a result of their collaboration initiatives. The results of this analysis were very welcomed among the manufacturers involved in the research as to find out what degree of improvement could be expected out of which customer-combination being engaged in collaboration. Another finding in addition to the above is that VMI seems to be differently effective within particular distribution frameworks. Overall CPFR proved to be always superior which does not come as a surprise but by very different margins. The reason for that behaviour will be further investigated in section 7.3. Another issue that became apparent but has not been considered within this section is the actual effect of collaboration on individual customers. So far we have seen global implications which are most useful from the point of view of a supplier (manufacturer) but a customer might have very different interests in mind than optimisation of the entire supplier's distribution framework. Within the following section we will thus evaluate the implications of a widening scope of collaboration from the point of view of a single customer instead of a manufacturer.

7.2 The effects of collaboration on non-collaborating customers

One of the concerns that commonly arise when considering introducing collaborative replenishment partnerships is how that change would affect the delivery reliability of the remaining ROP customers. Both our previous findings and collaborative replenishment research in general suggest a higher total efficiency thus less delayed deliveries, lower inventories or better overall service level after the introduction of a CPFR replenishment system. Hence there is agreement about the global achievements but there has rarely any investigation been done as to what extent the remaining non-collaborating customers are affected by the changes. This problem is investigated by evaluating the individual customers' and combined outcome of four chosen key performance metrics for each of the 16 possible collaboration settings and each of the 6 possible cases of which 5 were already considered within the previous section. Within all following scenarios the manufacturer's inventory is set to a fixed level to allow a comprehensive investigation of resulting service levels and other performance indicators.

7.2.1 Cases with one collaborative customer

The focus here is on the changes that strike each individual customer after one particular customer's replenishment is changed to CPFR whilst the others remain with ROP solutions. We will evaluate every possible combination of ROP and CPFR and compare the results with the default all ROP reference scenarios. The results are presented in two tables. The first one includes the outcome for all three supply chain frameworks based on the flexible date ROP replenishment whilst the second table presents the results based on fix-date delivery ROP. The tables are structured horizontally in a way to show the supply chain frameworks outcome next to each other for easy comparison to allow drafting general conclusions. Each supply chain framework is investigated for each possible combination of ROP and CPFR customers which includes 4 possible combinations with one CPFR and 3 ROP customers, 6 combinations of 2 CPFR and 2 ROP customers and 4 combinations of 3 CPFR and 1 ROP customers. Additionally each table states the default all ROP scenario outcome for reasons of comparison which serves as a basis for the further adjusted settings. The actual presented numbers for each collaboration scenario state the deviation from the default all ROP setting. Thus negative numbers stand for diminished outcome compared to the default all ROP setting which can be either positive or negative depending on the particular performance metric. Vertically the tables show the results for four chosen key performance measures for each individual customer (marked by C1, C2, C3, C4) and the combined global outcome. The global figures are expected to be mostly identical with the figures from the previous sections but could slightly differ sometimes due to different inventory levels that were preset for each scenario. Each individual score is evaluated and highlighted green in case it constitutes a noticeable improvement over the default scenario or highlighted red in case of declining performance. If there is no significant increase or decrease, score-fields are left white.

Flexible delivery-date framework

flexible-date delivery - 1 CPFR customer 3 ROP

		SC-FW 1					SC-FW 2					SC-FW 3				
		RRRR	CRRR	RCRR	RRCR	RRRC	RRRR	CRRR	RCRR	RRCR	RRRC	RRRR	CRRR	RCRR	RRCR	RRRC
SL Gap	C1	**2.5%**	-2.3%	-1.0%	-0.2%	-0.1%	**3.3%**	-3.2%	0.2%	0.6%	0.4%	**0.1%**	0.0%	0.4%	0.3%	0.0%
	C2	**2.2%**	-0.1%	-1.7%	-0.4%	0.4%	**3.7%**	0.7%	-2.7%	0.4%	0.2%	**6.5%**	-0.7%	-4.9%	0.7%	0.6%
	C3	**2.3%**	-0.4%	-0.2%	-2.0%	0.5%	**3.9%**	-0.2%	-0.8%	-3.8%	-0.1%	**8.1%**	-1.1%	0.0%	-6.9%	0.0%
	C4	**2.6%**	0.2%	-0.5%	0.2%	-2.4%	**4.1%**	-0.4%	-0.4%	-0.2%	-4.0%	**0.8%**	0.0%	0.6%	0.8%	-0.3%
	Total	**2.4%**	**-0.7%**	**-0.9%**	**-0.6%**	**-0.2%**	**3.7%**	**-0.6%**	**-1.4%**	**-0.5%**	**-0.2%**	**5.2%**	**-0.6%**	**-1.6%**	**-1.9%**	**0.2%**
Weeks of perfect supply	C1	**85%**	10%	4%	2%	1%	**77%**	19%	5%	2%	0%	**98%**	0%	-1%	-1%	0%
	C2	**83%**	2%	8%	3%	0%	**71%**	-4%	14%	2%	1%	**62%**	0%	17%	5%	0%
	C3	**84%**	3%	2%	10%	-2%	**74%**	4%	9%	23%	0%	**62%**	-2%	5%	20%	0%
	C4	**83%**	4%	4%	2%	10%	**72%**	4%	10%	4%	24%	**92%**	-1%	-2%	-2%	1%
	Total	**84%**	**5%**	**4%**	**4%**	**2%**	**74%**	**6%**	**10%**	**8%**	**6%**	**79%**	**-1%**	**5%**	**5%**	**0%**
Critical delays Manuf-DC	C1	**31%**	-30%	-7%	-2%	1%	**77%**	-75%	-22%	-8%	-3%	**40%**	-39%	-9%	-10%	-1%
	C2	**32%**	-2%	-28%	-2%	2%	**78%**	2%	-54%	-1%	-2%	**22%**	1%	-21%	-2%	1%
	C3	**34%**	-5%	-5%	-33%	0%	**76%**	-5%	-24%	-75%	-2%	**25%**	2%	-1%	-23%	2%
	C4	**32%**	-6%	-5%	-4%	-31%	**74%**	-7%	-25%	-11%	-73%	**44%**	-2%	-11%	-10%	-43%
	Total	**32%**	**-11%**	**-12%**	**-11%**	**-8%**	**76%**	**-25%**	**-33%**	**-27%**	**-23%**	**30%**	**-6%**	**-11%**	**-12%**	**-6%**
Delays DC-Retail	C1	**4.7%**	-3.1%	-1.8%	-0.5%	-0.5%	**6.6%**	-5.9%	-0.5%	0.7%	0.6%	**1.0%**	-0.3%	0.7%	0.5%	0.3%
	C2	**3.7%**	0.2%	-1.9%	0.2%	1.6%	**7.1%**	1.4%	-5.2%	0.9%	0.2%	**7.7%**	-0.7%	-5.8%	-1.1%	1.0%
	C3	**4.9%**	-1.1%	-0.4%	-3.4%	0.4%	**8.2%**	-0.8%	-2.3%	-7.4%	-0.2%	**10.3%**	-0.7%	-1.7%	-8.2%	-0.3%
	C4	**4.6%**	-0.4%	-0.9%	-0.4%	-3.5%	**7.8%**	-0.8%	-2.2%	-0.1%	-7.4%	**1.3%**	-0.2%	0.5%	1.1%	-0.6%
	Total	**4.5%**	**-1.1%**	**-1.3%**	**-1.0%**	**-0.5%**	**7.4%**	**-1.5%**	**-2.6%**	**-1.5%**	**-1.7%**	**5.1%**	**-0.5%**	**-1.6%**	**-1.9%**	**0.1%**

Table 7.16: Results for individual customers – 1 CPFR customer cases, flexible delivery date

Within this first group of scenarios showing the scores of all possible settings with a single CPFR customer we can see the majority of cases revealing substantial improvements (green fields) or indifferent results (white) compared to the initial non-collaborative setting which does not come as a surprise. However, what is rather astonishing is the number of cases where individual and sometimes even global performance diminishes as a result of increased collaboration (red fields). Looking at the scores we see that engaging in collaboration surely and commonly remarkably improves the performance of those customers who actually engage in CPFR. Very often this increase in collaboration additionally leads to improved results for the remaining customers as well resulting in a win-win situation. What is overall concerning nevertheless are the obvious cases where one customer engaging in CPFR leads to more or less significant diminished outcome for one or more of the remaining ROP customers. It seems that supply chain frameworks 2 and 3 are more affected by these "collateral damages" than framework 1. This is certainly due to the dissimilar distribution setups for each of them and the different degree of importance (percentage of overall demand) that each customer has within each. Each of the three supply chain frameworks includes at least one case where the gains for the CPFR customer lead to shortcomings for at least two other customers. Supply chain framework 3 seems to be particularly problematic in this respect. For example, engaging customer 3 in CPFR would lead to significant service level improvements (SL gap diminishes from 8.1% to 1.2%) but has a side-effect of diminishing all remaining customers' service level. Altogether we can state that within all the above cases such "collateral damages" are not too much severe but are numerous and clearly noticeable. As a matter of fact, 11 out of 64 performance measure scores diminish as a result of a single customer engaging in CPFR in case of supply chain framework 1 which is equivalent to 17% of all cases. The figures for frameworks 2 and 3 are 20% and 34% respectively.

Fixed delivery-date framework

fixed-date delivery - 1 CPFR customer 3 ROP

		SC-FW 1					SC-FW 2					SC-FW 3				
		RRRR	CRRR	RCRR	RRCR	RRRC	RRRR	CRRR	RCRR	RRCR	RRRC	RRRR	CRRR	RCRR	RRCR	RRRC
SL Gap	C1	1.1%	-1.0%	-0.6%	2.1%	1.6%	7.2%	-7.0%	0.3%	-2.0%	-1.6%	5.0%	-4.9%	0.7%	-2.0%	1.2%
	C2	1.1%	0.5%	-0.9%	0.2%	0.4%	5.6%	2.0%	-4.9%	1.4%	0.2%	10.7%	-0.1%	-9.0%	-1.3%	1.4%
	C3	15.7%	-4.4%	1.2%	-15.5%	0.0%	7.5%	-3.0%	0.0%	-7.4%	-2.7%	5.2%	-0.4%	2.4%	-4.0%	1.5%
	C4	11.8%	-2.8%	2.4%	4.5%	-11.6%	7.9%	-2.9%	0.8%	-2.3%	-7.8%	11.8%	-1.4%	-4.1%	-1.5%	-11.2%
	Total	6.9%	-1.8%	0.4%	-2.4%	-1.8%	6.6%	-1.7%	-2.1%	-1.6%	-1.6%	8.2%	-1.1%	-3.0%	-2.4%	-0.5%
Weeks of perfect supply	C1	93%	5%	2%	-9%	-5%	69%	28%	3%	8%	7%	81%	17%	-1%	8%	-1%
	C2	92%	-3%	3%	-2%	-1%	71%	-5%	20%	-2%	1%	62%	0%	16%	3%	-5%
	C3	59%	6%	-3%	38%	4%	73%	5%	0%	25%	5%	74%	2%	-2%	7%	-2%
	C4	66%	4%	-2%	-4%	28%	71%	4%	-3%	4%	24%	59%	8%	13%	10%	33%
	Total	78%	3%	0%	6%	6%	71%	8%	5%	9%	9%	69%	7%	6%	7%	6%
Critical delays Manuf-DC	C1	14%	-12%	-7%	9%	7%	28%	-26%	-13%	4%	-2%	26%	-25%	-9%	-16%	6%
	C2	3%	1%	0%	1%	1%	49%	12%	-30%	3%	-7%	23%	0%	-21%	-6%	1%
	C3	9%	-4%	2%	-8%	9%	41%	-16%	-9%	-40%	-9%	9%	2%	2%	-8%	1%
	C4	31%	-14%	4%	-17%	-30%	40%	-10%	-1%	-12%	-39%	46%	-8%	-16%	-8%	-45%
	Total	14%	-7%	-1%	-4%	-4%	40%	-12%	-14%	-14%	-16%	23%	-6%	-11%	-9%	-6%
Delays DC-Retail	C1	2.1%	-1.3%	-0.8%	3.4%	2.5%	11.3%	-10.3%	-0.7%	-2.9%	-2.9%	6.8%	-6.2%	1.1%	-2.3%	1.3%
	C2	2.0%	1.8%	-1.0%	0.7%	1.1%	11.1%	2.5%	-9.2%	1.2%	0.0%	12.0%	0.0%	-10.3%	-1.9%	1.4%
	C3	13.9%	-1.6%	0.9%	-13.0%	0.3%	10.5%	-2.3%	-0.8%	-10.1%	-1.8%	7.2%	-0.8%	0.9%	-5.2%	1.0%
	C4	13.4%	-2.3%	-1.0%	0.2%	-12.3%	8.9%	-1.7%	1.0%	-0.7%	-8.6%	15.0%	-2.4%	-5.4%	-4.6%	-14.4%
	Total	7.6%	-0.7%	-0.6%	-2.2%	-2.1%	10.5%	-3.0%	-2.5%	-3.2%	-3.4%	10.2%	-2.4%	-3.4%	-3.6%	-2.6%

Table 7.17: Results for individual customers – 1 CPFR customer cases, fixed delivery date

The results obtained based on the fixed-date delivery setting have to be considered somewhat carefully since the actual improvement or declining performance figures very much depend on the underlying fixed-date order schedule which is set up reasonably to account for the investigated companies but is from a more general perspective somewhat arbitrary. Outcomes from all three investigated supply chain frameworks should allow for some reasonably reliable conclusions but altogether findings cannot be generalised to such a wide extent as the results from the previous flexible date delivery scenarios. This is due to the fact that investigated settings represent only individual arbitrary choices out of a pool of hundreds of possible settings that are determined by specific setup of each manufacturer's delivery context regarding number of customers, delivery intervals or days of order placements.

Having the above limitations in mind we can still draw some clear conclusions from the results obtained and visualised in Table 7.17. In fact, the findings are very similar to the flexible-date replenishment cases above. However, the degree of individually possible improvements as well as actual "collateral damages" seem to be far more substantial within this framework. It seems that engaging one customer in CPFR can on one hand dramatically improve performance for that very customer but on the other hand not just somewhat diminish performance of remaining customers but can severely harm other's replenishment system. We can see within supply chain framework 1 for example customer 3 engaging in CPFR would lead to an almost perfect result for this customer (SL gap down from 15.7% to 0.2%) but at the same time increase service level gap of C1 from 1.1% to 3.3%, C2 from 1.1% to 1.3% and C3 from 11.8% to 16.3%. Similar effects can be found among the other frameworks and performance measures. Overall supply chain framework 1 reveals 41% of scores being diminished due to introduction of as single collaborative customer whilst frameworks 2 and 3 account for 22% and 25% respectively. As a result of that, such side-effects of collaboration would have to be seriously taken into consideration before any decision about engaging a particular customer in CPFR is made.

7.2.2 Cases with two collaborative customers

For the case that half of the customer base is engaged into CPFR the focus of attention lies on how far the increasing adoption of collaborative replenishment can help to close the gap between CPFR and remaining ROP customers. We have thus to consider the question as to what extent they can possibly benefit as well from increased global demand transparency.

Flexible delivery-date framework

flexible-date delivery - 2 CPFR customers and 2 ROP

		SC-FW 1							SC-FW 2							SC-FW 3						
		RRRR	CCRR	CRCR	CRRC	RCCR	RCRC	RRCC	RRRR	CCRR	CRCR	CRRC	RCCR	RCRC	RRCC	RRRR	CCRR	CRCR	CRRC	RCCR	RCRC	RRCC
SL Gap	C1	2.5%	-2.2%	-2.2%	-2.2%	-0.8%	-0.4%	0.0%	3.3%	-3.0%	-3.2%	-3.1%	-0.3%	-0.8%	0.6%	0.1%	0.0%	0.0%	0.0%	1.8%	0.6%	0.5%
	C2	2.2%	-1.4%	0.6%	1.0%	-1.3%	-1.4%	1.1%	3.7%	-3.0%	1.5%	1.5%	-2.6%	-2.9%	1.0%	6.5%	-4.9%	-0.5%	0.5%	-4.1%	-4.7%	1.1%
	C3	2.3%	-0.4%	-1.8%	0.7%	-2.0%	0.0%	-1.8%	3.9%	-2.2%	-3.7%	-0.9%	-3.8%	-1.7%	-3.7%	8.1%	-0.9%	-6.9%	-1.0%	-6.7%	-0.6%	-6.8%
	C4	2.6%	-0.4%	0.4%	-2.1%	-0.5%	-2.0%	-2.3%	4.1%	-2.5%	-1.9%	-4.0%	-2.9%	-3.9%	-3.9%	0.8%	1.2%	0.3%	-0.3%	1.1%	-0.2%	-0.3%
	Total	**2.4%**	**-1.1%**	**-0.7%**	**-0.5%**	**-1.2%**	**-0.9%**	**-0.6%**	**3.7%**	**-2.8%**	**-1.1%**	**-0.7%**	**-2.3%**	**-2.2%**	**-0.5%**	**5.2%**	**-1.9%**	**-2.5%**	**-0.2%**	**-3.3%**	**-1.8%**	**-1.9%**
perfect weeks	C1	85%	10%	9%	10%	5%	3%	2%	77%	18%	19%	18%	11%	12%	5%	98%	0%	0%	0%	-2%	-2%	-2%
	C2	83%	5%	1%	-1%	4%	5%	1%	71%	17%	-1%	-4%	14%	16%	1%	62%	15%	11%	3%	18%	14%	8%
	C3	84%	4%	9%	-1%	10%	2%	9%	74%	17%	22%	7%	21%	15%	22%	62%	10%	19%	2%	19%	10%	20%
	C4	83%	6%	3%	10%	6%	8%	11%	72%	19%	14%	24%	20%	21%	24%	92%	-1%	-1%	1%	-4%	0%	0%
	Total	**84%**	**6%**	**6%**	**5%**	**7%**	**5%**	**5%**	**74%**	**18%**	**13%**	**11%**	**17%**	**16%**	**13%**	**79%**	**6%**	**7%**	**1%**	**8%**	**5%**	**6%**
delays Manuf	C1	31%	-27%	-27%	-28%	-7%	-7%	-2%	77%	-68%	-73%	-74%	-41%	-35%	-11%	40%	-36%	-36%	-39%	-19%	-9%	-13%
	C2	32%	-25%	-4%	1%	-24%	-25%	-2%	78%	-53%	-2%	1%	-52%	-59%	-5%	22%	-20%	-3%	3%	-18%	-20%	-1%
	C3	34%	-11%	-30%	-3%	-31%	-7%	-31%	76%	-45%	-74%	-11%	-71%	-37%	-75%	25%	-3%	-23%	2%	-20%	-3%	-23%
	C4	32%	-9%	-8%	-30%	-11%	-29%	-30%	74%	-49%	-25%	-73%	-48%	-70%	-73%	44%	-11%	-18%	-42%	-17%	-38%	-39%
	Total	**32%**	**-19%**	**-18%**	**-16%**	**-19%**	**-18%**	**-17%**	**76%**	**-54%**	**-47%**	**-43%**	**-54%**	**-52%**	**-45%**	**30%**	**-16%**	**-18%**	**-12%**	**-19%**	**-16%**	**-17%**
delays retail	C1	4.7%	-3.4%	-3.1%	-3.3%	-1.2%	-0.8%	-0.5%	6.6%	-6.0%	-5.8%	-5.8%	-3.0%	-2.1%	-0.5%	1.0%	0.0%	-0.3%	-0.3%	0.4%	1.1%	0.9%
	C2	3.7%	-1.6%	1.2%	1.8%	-1.4%	-1.8%	1.6%	7.1%	-5.3%	2.4%	2.9%	-4.9%	-4.9%	1.6%	7.7%	-5.5%	-1.9%	0.6%	-5.0%	-5.5%	-0.5%
	C3	4.9%	-1.6%	-3.3%	0.3%	-3.3%	-1.2%	-3.1%	8.2%	-5.3%	-7.6%	-1.8%	-7.2%	-3.4%	-7.2%	10.3%	-3.0%	-8.1%	-0.8%	-7.9%	-2.2%	-8.2%
	C4	4.6%	-1.2%	-0.8%	-2.9%	-1.5%	-2.8%	-3.2%	7.8%	-5.3%	-3.9%	-7.3%	-6.2%	-7.0%	-7.3%	1.3%	1.0%	0.0%	-0.5%	1.3%	-0.4%	-0.7%
	Total	**4.5%**	**-2.0%**	**-1.5%**	**-1.0%**	**-1.8%**	**-1.6%**	**-1.3%**	**7.4%**	**-5.5%**	**-3.8%**	**-3.0%**	**-5.3%**	**-4.4%**	**-3.4%**	**5.1%**	**-1.9%**	**-2.6%**	**-0.2%**	**-2.8%**	**-1.8%**	**-2.1%**

Table 7.18: Results for individual customers – 2 CPFR customers cases, flexible delivery date

In Table 7.18 all figures showing significant improved performance have once again been highlighted green whilst all declines have been highlighted red. Insignificant

improvements have been left white. As we can see from a brief eyeball test, the percentage of cases showing significant improvements have surely increased compared to the single CPFR customer case. Especially within supply chain framework 2 this progress is clearly visible. Apart from a few exceptions it seems that not just the 2 customers engaged in collaborative replenishment improve their performance but also the remaining customers are better off as a result of increased collaboration. Among supply chain frameworks 1 and 3 it is nevertheless almost solely the customers engaged in CPFR that benefit from the increased level of demand transparency whilst remaining ROP customers are merely worse off or gain insignificantly compared to the reference scenarios. Nevertheless the gap is narrowing down and can in most cases almost be neglected. At this stage of overall collaboration global performance is improved to a remarkable extent no matter which customers engaged in CPFR. There is not one single scenario among any of the frameworks that reveals a globally diminished outcome. As a further sign that outcome is improving although struggling with various drawbacks we see that the majority of scores remarkably improve due to increased collaboration. The particular figures are 44% within SC-FW1, 78% within SC-FW2 and 46% within SC-FW3.
Even though the situation for the remaining ROP customers seems to improve, there are still numerous cases that result in shortcomings for them. Overall supply chain framework 1 still has 13% of scores being diminished after introduction of two collaborative customers whilst frameworks 2 and 3 account for 10% and 23%, respectively.

Fixed delivery-date framework

fixed-date delivery - 2 CPFR customers and 2 ROP

		SC-FW 1							SC-FW 2							SC-FW 3						
		RRRR	CCRR	CRCR	CRRC	RCCR	RCRC	RRCC	RRRR	CCRR	CRCR	CRRC	RCCR	RCRC	RRCC	RRRR	CCRR	CRCR	CRRC	RCCR	RCRC	RRCC
SL Gap	C1	1.1%	-0.9%	-0.9%	-0.9%	0.4%	-0.1%	2.0%	7.2%	-7.0%	-7.0%	-6.9%	-1.0%	-0.7%	-3.7%	5.0%	-4.7%	-4.8%	-4.9%	-2.4%	0.8%	-1.0%
	C2	1.1%	-0.8%	0.8%	1.2%	-0.7%	-0.7%	1.2%	5.6%	-5.0%	3.6%	2.8%	-4.7%	-4.6%	1.8%	10.7%	-9.0%	-0.7%	1.4%	-8.9%	-9.1%	0.5%
	C3	15.7%	-3.7%	-15.5%	-3.8%	-15.4%	0.2%	-15.5%	7.5%	-3.7%	-7.4%	-5.8%	-7.3%	-1.0%	-7.3%	5.2%	3.1%	-4.1%	1.3%	-3.8%	2.9%	-4.0%
	C4	11.8%	-2.4%	2.9%	-11.6%	4.9%	-11.6%	-11.6%	7.9%	-3.3%	-6.3%	-7.8%	-1.4%	-7.7%	-7.8%	11.8%	-5.6%	-2.7%	-11.3%	-6.5%	-11.2%	-11.0%
	Total	6.9%	-1.9%	-3.3%	-3.2%	-3.0%	-2.5%	-5.3%	6.6%	-5.1%	-2.2%	-2.4%	-4.0%	-3.2%	-2.3%	8.2%	-3.7%	-2.8%	-1.5%	-5.8%	-3.9%	-3.0%
perfect weeks	C1	93%	3%	4%	4%	-1%	0%	-7%	69%	28%	28%	26%	8%	6%	13%	81%	16%	16%	17%	8%	0%	7%
	C2	92%	2%	-4%	-5%	1%	1%	-5%	71%	18%	-9%	-5%	16%	17%	0%	62%	16%	5%	-5%	16%	19%	5%
	C3	59%	5%	38%	13%	36%	4%	37%	73%	8%	24%	14%	23%	4%	23%	74%	-2%	10%	-3%	5%	-3%	7%
	C4	66%	5%	2%	28%	-4%	29%	28%	71%	8%	16%	24%	5%	22%	24%	59%	18%	14%	34%	20%	33%	32%
	Total	78%	4%	10%	10%	8%	8%	13%	71%	15%	15%	15%	13%	12%	15%	69%	12%	11%	11%	12%	12%	13%
delays Manuf	C1	14%	-12%	-12%	-12%	-3%	-5%	12%	28%	-22%	-24%	-25%	-4%	-6%	0%	26%	-22%	-22%	-25%	-21%	0%	-14%
	C2	3%	2%	3%	5%	1%	1%	1%	49%	-29%	7%	5%	-27%	-29%	1%	23%	-21%	-8%	4%	-18%	-22%	-6%
	C3	9%	-3%	-8%	3%	-7%	9%	-7%	41%	-25%	-38%	-17%	-38%	-10%	-40%	9%	5%	-7%	4%	-5%	3%	-7%
	C4	31%	-4%	-24%	-30%	-17%	-30%	-30%	40%	-19%	-29%	-39%	-16%	-38%	-39%	46%	-26%	-17%	-44%	-29%	-41%	-41%
	Total	14%	-5%	-10%	-9%	-7%	-7%	-6%	40%	-24%	-23%	-22%	-22%	-22%	-22%	23%	-14%	-12%	-10%	-17%	-14%	-14%
delays retail	C1	2.1%	-1.1%	-1.2%	-1.3%	0.5%	0.3%	3.9%	11.3%	-10.6%	-10.7%	-10.6%	-2.3%	-2.8%	-4.2%	6.8%	-5.6%	-5.6%	-6.0%	-2.4%	1.8%	-2.1%
	C2	2.0%	-0.9%	1.7%	2.0%	-0.9%	-0.7%	1.6%	11.1%	-9.2%	3.5%	1.9%	-9.5%	-9.1%	0.5%	12.0%	-9.8%	-2.2%	1.8%	-9.9%	-10.2%	-1.7%
	C3	13.9%	-0.8%	-13.1%	-4.0%	-12.7%	-0.4%	-13.3%	10.5%	-4.4%	-9.9%	-6.4%	-9.9%	-2.4%	-9.6%	7.2%	0.7%	-5.3%	1.1%	-5.1%	0.6%	-5.1%
	C4	13.4%	-2.1%	-1.9%	-12.3%	0.6%	-12.6%	-11.9%	8.9%	-2.3%	-5.8%	-8.5%	-0.7%	-8.4%	-8.4%	15.0%	-7.3%	-4.7%	-14.2%	-9.4%	-14.3%	-14.3%
	Total	7.6%	-1.2%	-3.6%	-3.8%	-3.2%	-3.4%	-4.7%	10.5%	-6.7%	-5.9%	-6.0%	-5.7%	-5.8%	-5.5%	10.2%	-5.5%	-4.5%	-4.4%	-6.6%	-5.5%	-5.8%

Table 7.18: Results for individual customers – 2 CPFR customer cases, fixed delivery date

An overall improvement can also be observed within the fixed delivery date case. Altogether there are plenty of hardship cases amongst the scores where performance of remaining ROP customers is clearly negatively impacted by half the customer base engaging in collaborative replenishment. It is altogether difficult to put a pattern behind such cases but larger customers seem to be disadvantaged more often when any other customer is engaging in collaborative replenishment. This is surely the case within supply chain framework 2 where the dominant customer 2 experiences shortcomings in any case customers other then it start being replenished via CPFR. This should be mainly due to a change in ranking system once collaboration is put into place. Altogether the percentage of scores with decreased performance outcome diminishes to 25% in case of SC-FW1, 10% in case of SC-FW2 and 20% in case of SC-FW3.

7.2.3 Cases with three collaborative customers

The final step reveals the magnitude of the individual improvements for each customer that the move from pure ROP to predominantly collaborative replenishment results in. For the case that only one customer remains with traditional ROP delivery it will be especially interesting to see how performance metrics turn out for this particular retailer.

Flexible delivery-date framework

flexible-date delivery - 3 CPFR customers and 1 ROP

		SC-FW 1						SC-FW 2						SC-FW 3					
		RRRR	CCCR	CCRC	CRCC	RCCC	CCCC	RRRR	CCCR	CCRC	CRCC	RCCC	CCCC	RRRR	CCCR	CCRC	CRCC	RCCC	CCCC
SL Gap	C1	2.5%	-2.1%	-2.0%	-2.1%	-0.8%	-2.0%	3.3%	-3.1%	-3.0%	-3.1%	0.2%	-2.8%	0.1%	0.7%	0.1%	0.2%	3.4%	0.6%
	C2	2.2%	-1.1%	-1.4%	2.2%	-1.1%	-1.3%	3.7%	-2.8%	-2.7%	0.8%	-2.8%	-2.4%	6.5%	-3.9%	-4.8%	1.8%	-3.9%	-4.0%
	C3	2.3%	-1.6%	0.3%	-1.8%	-1.6%	-1.7%	3.9%	-3.7%	-2.0%	-3.8%	-3.7%	-3.5%	8.1%	-6.4%	-2.0%	-7.0%	-6.6%	-6.6%
	C4	2.6%	-1.3%	-1.8%	-2.1%	-1.9%	-1.8%	4.1%	0.0%	-3.9%	-4.0%	-3.9%	-3.6%	0.8%	3.5%	-0.2%	0.1%	0.5%	0.4%
	Total	2.4%	-1.5%	-1.2%	-0.7%	-1.3%	-1.7%	3.7%	-2.8%	-2.8%	-1.6%	-2.3%	-2.8%	5.2%	-3.0%	-2.4%	-1.7%	-3.1%	-3.5%
perfect weeks	C1	85%	8%	9%	9%	6%	8%	77%	18%	18%	19%	13%	16%	98%	-4%	0%	0%	-5%	-3%
	C2	83%	4%	6%	1%	4%	4%	71%	15%	14%	7%	15%	13%	62%	15%	16%	12%	16%	17%
	C3	84%	7%	6%	9%	7%	8%	74%	21%	17%	22%	21%	19%	62%	19%	16%	20%	21%	19%
	C4	83%	8%	8%	8%	7%	7%	72%	17%	23%	24%	24%	21%	92%	-5%	-1%	-2%	-4%	-3%
	Total	84%	7%	7%	7%	6%	7%	74%	18%	18%	18%	18%	17%	79%	6%	8%	7%	7%	7%
delays Manuf	C1	31%	-26%	-25%	-26%	-8%	-24%	77%	-64%	-67%	-72%	-48%	-61%	40%	-23%	-34%	-35%	-15%	-26%
	C2	32%	-22%	-23%	-1%	-22%	-20%	78%	-46%	-47%	-10%	-55%	-44%	22%	-15%	-19%	0%	-15%	-15%
	C3	34%	-28%	-12%	-29%	-28%	-26%	76%	-67%	-46%	-73%	-69%	-63%	25%	-18%	-6%	-23%	-19%	-20%
	C4	32%	-16%	-27%	-28%	-26%	-25%	74%	-49%	-68%	-72%	-69%	-65%	44%	-15%	-37%	-37%	-32%	-31%
	Total	32%	-24%	-22%	-22%	-21%	-24%	76%	-57%	-57%	-59%	-61%	-58%	30%	-18%	-21%	-20%	-19%	-21%
delays retail	C1	4.7%	-3.3%	-3.0%	-3.1%	-1.6%	-3.0%	6.6%	-5.4%	-5.4%	-5.9%	-3.0%	-5.4%	1.0%	1.0%	0.0%	0.0%	1.6%	1.0%
	C2	3.7%	-1.1%	-1.7%	1.4%	-0.9%	-1.5%	7.1%	-4.6%	-5.4%	1.6%	-5.2%	-3.7%	7.7%	-5.0%	-5.6%	-1.7%	-5.3%	-5.2%
	C3	4.9%	-2.8%	-1.4%	-3.2%	-3.1%	-3.0%	8.2%	-7.3%	-5.0%	-7.5%	-7.1%	-6.8%	10.3%	-8.3%	-5.4%	-8.4%	-8.1%	-8.1%
	C4	4.6%	-2.5%	-2.6%	-3.1%	-2.9%	-2.6%	7.8%	-4.6%	-6.8%	-7.1%	-6.8%	-6.9%	1.3%	2.0%	-0.4%	0.0%	1.0%	0.7%
	Total	4.5%	-2.4%	-2.2%	-2.0%	-2.2%	-2.5%	7.4%	-5.5%	-5.7%	-4.7%	-5.6%	-5.7%	5.1%	-2.6%	-2.9%	-2.6%	-2.8%	-2.9%

Table 7.19: Results for individual customers – 3 CPFR customers cases, flexible delivery date

For the case of 3 out of 4 customers engaging in CPFR global as well as individual improvements are extremely solid among supply chain frameworks 1 and 2. Here the remaining ROP customer mainly benefits from the overall improved production and delivery planning due to better demand visibility. The number of cases with diminished performance is almost zero. When all four customers are engaged in collaboration there is not one case with non-improved outcome which is very encouraging. Nevertheless there are individual scenarios that still result in slightly degrading performance even though a high degree of collaboration is established. Such shortcomings are revealed even more obviously within supply chain framework 3. Apparently the two small customers C1 and C4 suffer substantially if both large customers C2 and C3 are replenished collaboratively. In particular the service level gap of C4 increases from 0.8% to 4.3% in case all other three customers being engaged in CPFR. Similar outcome is recorded in case C1 is the single remaining ROP customer. Furthermore both customers have even slightly diminished performance even if they engage in collaborative replenishment together with the two large customers. This kind of outcome is most likely due to the particular distribution setup of SC-FW3 with two small customers being replenished every two weeks whilst the two dominant customers that account for the vast majority of demand are replenished weekly. Due to a first come first serve policy within the all ROP cases C1 and C4 accounting for only a fraction of overall demand could achieve very superior replenishment performance which is not the case anymore if the large customers get scheduled priority due to collaborative replenishment. The overall rather disappointing outcome for C1 and C4 that is apparent even in case of a full collaboration framework is thus rather a result of the unusually good performance within the default all ROP framework than a shortcoming of CPFR.

Fixed delivery-date framework

fixed-date delivery - 3 CPFR customers and 1 ROP

		SC-FW 1						SC-FW 2						SC-FW 3					
		RRRR	CCCR	CCRC	CRCC	RCCC	CCCC	RRRR	CCCR	CCRC	CRCC	RCCC	CCCC	RRRR	CCCR	CCRC	CRCC	RCCC	CCCC
SL Gap	C1	1.1%	-0.9%	-0.9%	-0.9%	0.6%	-0.9%	7.2%	-7.0%	-7.0%	-7.0%	-0.8%	-6.9%	5.0%	-4.7%	-4.8%	-4.8%	-1.3%	-4.1%
	C2	1.1%	-0.6%	-0.7%	1.4%	-0.6%	-0.6%	5.6%	-5.0%	-5.1%	2.9%	-4.8%	-4.8%	10.7%	-8.5%	-9.2%	-0.4%	-8.8%	-8.5%
	C3	15.7%	-15.4%	-5.0%	-15.5%	-15.4%	-15.2%	7.5%	-7.3%	-4.3%	-7.4%	-7.3%	-7.3%	5.2%	-4.1%	2.0%	-4.1%	-3.9%	-3.9%
	C4	11.8%	-2.9%	-11.6%	-11.6%	-11.4%	-11.7%	7.9%	-3.1%	-7.7%	-7.7%	-7.7%	-7.7%	11.8%	-8.0%	-11.2%	-11.0%	-11.0%	-10.8%
	Total	6.9%	-4.9%	-4.0%	-6.0%	-6.2%	-6.6%	6.6%	-5.8%	-5.7%	-2.7%	-4.7%	-6.1%	8.2%	-6.3%	-5.0%	-3.9%	-6.4%	-6.7%
perfect weeks	C1	93%	3%	3%	4%	0%	3%	69%	27%	27%	27%	12%	27%	81%	17%	16%	16%	9%	15%
	C2	92%	0%	1%	-8%	1%	-2%	71%	19%	19%	-3%	17%	16%	62%	18%	17%	8%	16%	18%
	C3	59%	36%	13%	37%	35%	35%	73%	23%	14%	24%	24%	23%	74%	11%	0%	8%	9%	9%
	C4	66%	8%	28%	29%	27%	29%	71%	11%	25%	24%	24%	23%	59%	26%	33%	33%	33%	31%
	Total	78%	12%	11%	15%	15%	16%	71%	20%	21%	18%	19%	22%	69%	18%	16%	16%	17%	18%
delays Manuf	C1	14%	-10%	-11%	-11%	-3%	-10%	28%	-20%	-22%	-25%	-2%	-15%	26%	-21%	-22%	-22%	-15%	-17%
	C2	3%	2%	0%	5%	3%	3%	49%	-22%	-27%	4%	-26%	-21%	23%	-18%	-21%	-9%	-18%	-18%
	C3	9%	-6%	4%	-7%	-6%	-5%	41%	-34%	-25%	-40%	-35%	-31%	9%	-4%	3%	-7%	-5%	-4%
	C4	31%	-21%	-29%	-30%	-28%	-29%	40%	-24%	-37%	-39%	-36%	-33%	46%	-38%	-40%	-40%	-38%	-37%
	Total	14%	-9%	-9%	-11%	-8%	-10%	40%	-25%	-28%	-27%	-25%	-25%	23%	-17%	-17%	-16%	-17%	-16%
delays retail	C1	2.1%	-0.9%	-1.3%	-1.2%	0.3%	-1.1%	11.3%	-10.6%	-10.7%	-10.7%	-4.6%	-10.0%	6.8%	-5.7%	-5.9%	-5.6%	-3.6%	-5.2%
	C2	2.0%	-0.7%	-0.9%	2.9%	-0.4%	-0.9%	11.1%	-9.5%	-9.8%	2.1%	-9.1%	-8.5%	12.0%	-9.3%	-9.8%	-4.4%	-10.2%	-9.7%
	C3	13.9%	-13.0%	-3.5%	-13.3%	-12.6%	-13.0%	10.5%	-9.7%	-6.4%	-10.0%	-10.0%	-9.5%	7.2%	-5.1%	-0.2%	-5.2%	-5.4%	-5.4%
	C4	13.4%	-4.3%	-12.6%	-12.3%	-12.4%	-12.7%	8.9%	-4.0%	-8.3%	-8.3%	-8.0%	-8.1%	15.0%	-11.0%	-14.1%	-14.1%	-14.0%	-13.7%
	Total	7.6%	-4.6%	-4.5%	-5.7%	-6.1%	-6.7%	10.5%	-8.5%	-8.8%	-6.9%	-8.0%	-9.0%	10.2%	-7.7%	-7.5%	-7.3%	-8.2%	-8.4%

Table 7.20: Results for individual customers – 3 CPFR customer cases, fixed delivery date

The fixed delivery date case reveals significantly improved performance on a global as well as individual level. Interestingly we can identify one particular customer within each supply chain framework that has to be most concerned about extensive collaboration context without its participation. Within supply chain framework 1 (SC-FW1) this is customer 2 which would incur a noticeable drop in performance among all considered performance measures if all other customers apart from C2 would be involved in collaborative replenishment. A very similar situation occurs for C2 within SC-FW2 and C3 within SC-FW3.

Achievements overview

	SC-FW 1						SC-FW 2						SC-FW 3					
	flexible date			fixed date			flexible date			fixed date			flexible date			fixed date		
number of CPFR customers	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
total improved performance	30%	44%	86%	33%	43%	72%	38%	78%	94%	53%	72%	91%	31%	46%	61%	56%	64%	92%
- among ROP customers	6%	0%	63%	17%	15%	50%	17%	56%	75%	38%	44%	63%	15%	27%	50%	39%	35%	69%
- among CPFR customers	100%	88%	94%	100%	71%	79%	100%	100%	100%	100%	100%	100%	81%	65%	65%	100%	96%	100%
total diminished performance	17%	13%	6%	41%	25%	14%	20%	10%	5%	22%	10%	6%	34%	23%	23%	23%	20%	3%
- among ROP customers	23%	25%	19%	54%	50%	44%	27%	21%	19%	29%	21%	25%	46%	46%	38%	31%	40%	13%
- among CPFR customers	0%	0%	0%	0%	0%	4%	0%	0%	0%	0%	0%	0%	0%	0%	15%	0%	0%	0%

Table 7.21: Consolidated overall results

The table shows the overall achieved scores classified into significant improvement and diminished performance for each of the three supply chain frameworks grouped into flexible and fixed date delivery. The actual figures in the table state the percentage of the individual scores within each of the 18 sub-tables that were presented before. Following that outline, a *total improved performance* of 30% within the one collaborative (CPFR) customer settings within the flexible delivery date case of supply chain framework 1 stands for 30% of overall scores (19 out of 64 scores) that were highlighted green to indicate significantly improved performance. *Total diminished performance* of 17% stands for 11 out of 64 scores being highlighted red to indicate a decline in performance. Looking at the *total improved performance* we can see that there is a clear uptrend with an increasing percentage of improved outcomes for each additional customer joining collaborative replenishment. More interesting than the overall percentage is the fraction of ROP customers that actually improved their performance due to others joining CPFR. Looking at both figures we see that for each supply chain framework there is a distinct point within the widening collaboration framework from which on there is a significant stage of improvement. These points can be either after one customer joins CPFR, 2 or 3. These improvement points of each case are highlighted green. We can thus see that each of the two cases investigated for each of the three supply chain frameworks seems to have a distinct point of most significant improvement as in two cases the most significant step is achieved with just one CPFR customer, in one case it is the second step and in three cases the step from 2 to 3 customers being engaged in collaboration. This should be an interesting insight to reveal the most recommendable stage or minimum necessary scope of collaboration for each framework to reach the point of significant performance impact. The third row of numbers is the significant improvement amongst CPFR customers. As we can see this figure is always high which does not come as a surprise and shows us that whoever is engaging in CPFR commonly achieves direct benefits as a result. However, it appears that the success ratio among early adopters (first customers to engage in CPFR) is in many cases higher compared to late adopters which should promote a certain pioneer attitude. The *total diminished performance* row shows a continuous reduction of scores indicating negative outcome as the scope of collaboration widens. This goes along with the increase of overall improved performance and is another indicator of the positive effects of increased demand transparency. In contrast to the improved performance among remaining ROP customers that increased with a widening collaboration scope as was mentioned before, the percentage of diminished performance scores does not seem to reduce significantly as collaboration intensifies. Thus a non-collaborating customer is just as likely to experience a drop in performance independent of how many other customers are already involved in collaboration. Thus we can conclude that the chances of a remaining ROP customer to significantly improve performance increase as the degree of collaboration widens whilst the threat of performance decline persist even if all other customers are engaged in collaboration. The final row of the table indicates the possible threat of a CPFR customer to achieve a worse outcome as a result of engaging in collaboration. We can see from the results this fear seems rather unjustified.

7.2.4 Conclusions

The above investigation presented the outcome of a wide variety of possible replenishment settings between a supplier and various customers. We could see that a widening scope of collaboration clearly reveals benefits for the customers being involved as well as for remaining non-collaborating ones. However, considering the fact that most collaboration agreements go along with a necessary prioritization of the involved customers, there are many cases where the remaining ROP customers experience shortcomings as a result of a developing collaborative framework which they are not participating in. As we saw from the table above, between 23% to 54% of key performance indicator scores of non-collaborating customers diminish somewhat right after the first customer is engaged in collaborative replenishment. A possible solution to this might be changing prioritization towards a more balancing approach as it will be investigated within section 8.2. This nevertheless often fails to be acceptable in practice. Altogether the investigation makes it thus obvious that there are winners and losers within an increasing collaboration framework. Comparing the gains from each customer after being the first to engage in collaborative replenishment with the achievements from the all CPFR scenarios it becomes apparent that the initial improvements at least match and often even surpass the results from an all CPFR case. Hence a customer can gain significantly from being the first and maybe sole CPFR customer instead of being one amongst others. Such findings could support a strategy among customers to be the first and only collaboration partner of a manufacturer. From the perspective of a manufacturer this would nevertheless be rather unwanted since a full collaboration framework should reveal the most benefits from its perspective. However, as we saw from the outcome of section 7.1, within many cases engaging only the largest 1 or 2 customers often reveals global achievements fairly close to a full CPFR implementation case. Any additional, often minor performance improvement would thus have to be measured against substantial implementation and maintenance efforts due to further collaboration agreements which might not be worthwhile doing. From another perspective, a large retail company could urge a supplier not to engage further customers in collaboration since its own performance might slightly drop and its competitors would be advantaged. Within other cases such as supply chain framework 3 it might be the small customers that due to their special circumstances should discourage any collaborative progress since it would bring them no benefits or could make them being worse of altogether. Overall the results of the investigation give very interesting insights into a developing collaboration context and should be of high value to any decision maker of any involved supplier or customer. The outcome of an in depth investigation could surely influence the attitude towards collaboration among all involved supply chain parties and detailed knowledge can prove to reveal a significant strategic and operational advantage in the process of defining a supply chain collaboration framework in one's own favour.

7.3 The influence of distinct collaboration components on global and individual supply chain performance

Within the third part of heterogeneous framework investigation chapter we analyse which particular components of a collaboration replenishment framework promise to be most rewarding. We will therefore evaluate a variety of supply chain scenarios to obtain detailed information about which considered collaboration modules are worth implementing and to what extent other elements can possibly be neglected. This would be of particular interest for companies that might want to pick the individual elements out of a VMI/CPFR framework that are most rewarding for their specific situation whilst avoiding having to take less important components. One of the reasons for doing so can simply be wishing to avoid the costs associated with the introduction, another would be companies' obvious wish to protect their data and avoid having to share crucial information with other market participants.

7.3.1 Outline of several typical collaboration components

To be able to address the outlined investigation subject it is preliminarily necessary to identify, isolate and later individually reintegrate particular collaboration components in the supply chain model. After investigating the practical aspects of a typical CPFR system implementation on a theoretical as well as at a practical level (i.e. considering the companies' circumstances), four components could be isolated that should be somewhat representative for a typical collaborative replenishment system. These collaboration modules were defined after in-depth evaluation of typical collaboration layouts among SME manufacturers within the investigated industries. They should thus be representative for such supply chain constellations but will surely not be exhaustive or necessarily applicable for other industries and markets. The four defined modules were promotional activities, seasonal sales deviations, short/mid term sales-trend forecast and an "intelligent" allocation system. A detailed discussion about promotional activities, seasonalities and trend forecast has already been presented within Chapters 4 and 5. Thus we will state the characteristics of these modules rather briefly.

The ***promotional activities*** component basically incorporates the collaborative effort between the manufacturer and retail customers to work out, update and adhere to detailed promotional schedules and impact estimation. Thus particularly the manufacturer can adjust its production and delivery schedule to be able to cope with temporary demand boosts. To be able to incorporate this into the model past promotional schedules were obtained for the involved products with the help of the involved companies and an impact analysis has been carried out to judge about what kind of promotion will typically have what kind of sales impact.

Seasonal factors as a further component tackle sales deviations that show regular pattern within a certain timeframe. This can be irregularities within a week, a month, a season or a year. Within the assumed collaboration initiative it is anticipated that retailers and manufacturer combine their market expertise to generate time-pattern dependent deviation forecasts that are as accurate as possible and will be reviewed on a regular basis. The importance of seasonal factor analysis depends on how strong the regular sales deviations are. The product groups under investigation have moderate (Supply chain frameworks 1 and 2) to strong (Framework 3) seasonality patterns. Prior to collaboration initiatives (pure ROP state) manufacturer 1 handled seasonal sales deviations in a way that within the four strong sales months production is somewhat increased whilst during typically weaker sales months it is somewhat decreased. Manufacturer 2 had a system in place working with a simple distinction between summer (lowered production) and winter (higher production) whilst manufacturer 3 used to uplift production remarkably for the major sales period (December and January) whilst reducing it during summer. Overall, it was agreed that a more detailed consideration is required and should be highly beneficial. Consequently, the analysis found typical pattern at intra-weekly sales (individual days have distinct demand levels), intra-monthly sales (higher sales at the beginning of a month-lower in the final week), monthly sales (e.g. less demand during summer more during winter) and increased sales ahead of major holidays. Altogether, the use of 3 years of detailed sales data and further up to 5 years of historic figures, together with personal judgement of management, made it possible to obtain very comprehensive consolidated sales deviation factors on a daily or weekly basis.

The ***short-term trend forecast*** incorporates a sales forecasting system that uses exponential smoothing and regression techniques to identify short/mid-term sales deviations caused by some sort of abnormal behaviour. For example sales deviations due to unusual weather conditions are an issue for product groups that have a certain weather dependency for part of the demand. Other factors of influence are varying vacation periods, food trends (dietary-waves etc.) or competitors' promotions. Other short term influences could be due to delivery problems, strikes, product expiration, price or competition. The variety of influences makes it already obvious that it is not easy to distinguish between events that need to be included into production planning and delivery scheduling and others that should not. There has to be a certain balance between long-term smoothing and incorporation of short term deviations which the parameter settings of the particular forecasting method needs to take care of (for further details about the implemented forecasting approach see Chapters 4 and 5).

The ***intelligent allocation system*** is typically an integral part of every CPFR system since it enables to prioritize deliveries according to actual urgency. Therefore it uses available information about inventory levels at DC centres and retail outlets to decide how a scarce product should be distributed best to avoid service level gaps. The ROP case in this analysis uses a first come first served policy whilst simultaneously incoming orders are dispatched on a random (impartial) basis. Apart from this default strategy companies often tend to have an internal prioritization setting that prefers major customers from smaller ones. This case and general influence of various prioritization strategies are investigated in more detail in section 8.2. The prioritization within this investigation context is mostly identical with the CPFRprio setting from this section. Hence, incoming orders (or rather replenishment notifications triggered via a VMI/CPFR system) that cannot be sufficiently fulfilled simultaneously are carried out according to an urgency ranking. The actual urgency is defined by the level of inventory at the particular customers' distribution centre as well as inventory at retail outlets. The highest level of urgency is thus given to the customer that would most shortly run into an out of stock scenario at any retail outlet that could not be remedied by replenishment from the distribution centre. In addition there is a minimum 70% fill-rate barrier in place that prevents extensive delivery tours due to low replenishment quantities. This barrier often leads to additional delays but has been put in place in accordance with practical rules. In addition to the above, the intelligent allocation system updates required order quantities even in case an order is delayed. Given the case an order cannot be fulfilled for several days, the requested quantity is adjusted to changes within the demand forecast during this period. Finally, within the intelligent allocation system, reorder-trigger barriers are somewhat lower compared to the standard ROP system due to widely increased demand transparency which requires less safety inventory. As a result of that average inventory held at distribution centres should diminish. Altogether the altered distribution system is certainly different from the standard ROP order dispatch approach and the following investigation will reveal if its implementation will help to improve supply chain performance not only as a part of a full CPFR system but also as standalone collaboration module.

<u>Interdependencies between collaboration modules</u>

It has to be mentioned here that even though we will analyse supply chain settings that include all sorts of independent combinations of the above factors there is some degree of dependency between them. Seasonal factors as well as promotional activities are the only two modules which do not rely on any other component. The trend forecast component for example actually uses promotional activity data as well as monthly seasonal factors to decompose the sales data prior to computation. This is very much necessary since without deseasonalisation and "depromotionalising" a short term sales trend forecast would be pretty useless. Intelligent allocation on the other hand requires the trend forecast and thus the underlying promotional and seasonal analyses in order to predict forthcoming demand

which is necessary to obtain a proper urgency classification as basis of order fulfilment prioritisation. The actual implications of totally isolating even the trend forecast as well as the intelligent allocation have been tested with rather discouraging results. Altogether the impact of promotion and seasonalities prevent the trend forecasting system to reveal any meaningful outcome in case these factors have not been decomposed beforehand. Possible remedies for that problem would be adopting a self-adjusting forecasting method that takes seasonalities into account "on the fly" but even such techniques could not be much successful without any information about promotional activities. A slightly different picture arises in case of the "intelligent allocation" module since here prioritisation can be based on inventory figures only instead of individual demand forecast. Overall results are fairly similar although the complex forecast based approach performs somewhat better.
Within the result presentation we will thus keep all four modules fully functional. Promotional activity and seasonal factors should not be affected altogether anyway whilst unrealistic side effects of using any of the other two modules should be minimal since the actual production planning does in the case of e.g. trend forecast implementation not incorporate seasonal factors or promotional activity data. Therefore production planning would be based on the obtained trend but promotional activity information and detailed seasonal factors would not be incorporated. The same accounts for the intelligent delivery approach. Since a decision about how to distribute scarce products can only reasonably be made on the basis of a demand prediction, the implemented forecasting system is used to make these decisions. Once again this does not involve production planning, hence all figures for these individual settings will be sufficiently valid we just have to keep in mind that for example implementing an "intelligent allocation" system could in real life not reasonably be done without initially obtaining detailed information about promotional activities, seasonal factors, market trends etc.

Collaboration requirements for identified collaboration modules

The four collaboration modules introduced above can all be considered as reasonably important for an advanced distribution process but require nonetheless very different levels of collaboration and information exchange between the various supply chain members.
Seasonal factors are somewhat more unproblematic since they can to some extent be obtained by a simple one-time data analysis of several years of historic sales information. Thus data protection issues and IT utilisation cost should be minimal. Even within an advanced framework where seasonal factors are generated on a daily or weekly basis and adjusted according to public holidays and vacation periods the overall effort and involved cost should rather be manageable. Somewhat more effort is necessary to incorporate promotional activities since this necessitates at least semi-annual meetings to lay out promotional activity schedules and furthermore intense collaboration to obtain realistic promotional impact estimates. Partners would also have to incorporate some sort of emergency scheme that informs about possible alterations regarding time and impact. Depending on the particular product group, retail companies would have also to reveal promotional activities of supplier's competitors since this should clearly influence expected sales. The highest requirements regarding time, effort and cost would however be necessary for sales trend forecast and "intelligent allocation" system. Both would not just require preliminary seasonal factor and promotional activity analyses but also EDI connections to provide information about inventory at DCs and store level. This is necessary to generate a reasonable sales forecast which is an essential requirement for both of these collaboration modules. Additionally, a sales-trend-forecast would require further investigation about global market trends whilst an "intelligent allocation" system would need up to date information about inventory levels at distribution centre level as well as

deeper insight into the distribution process within the particular retail-companies. Altogether the individual modules require very distinct levels of implementation and maintenance effort, shared data, trust and collaboration willpower. This should be the major reason why a full-scale collaboration context is often unsuitable for many supply chain partnerships and partial integration of only one or two of the available modules could be a suitable option to reap some extra benefits within an environment rather sceptical about collaboration.

7.3.2 Investigation overview

In order to obtain a sufficient overview of the area of investigation we evaluate numerous cases operating within each of the three supply chain frameworks. A main focus of attention will lie on the step of introducing a single collaboration module since this is expected to reveal what effect each individual module has on the performance metrics outcome. Therefore we look at low as well as medium inventory scenarios for the single module implementation cases. Apart from this initial step the implementation outcome for every possible combination of the four identified collaboration modules will be considered. Altogether we thus evaluate 22 individual scenarios for each supply chain framework. The result presentation first starts with the initial one collaboration module cases, followed by the two, three and finally full modules scenarios. The choice of selected performance measures will be similar to previous analyses. We will state *overall service level gap* as main performance indicator. The *manufacturer inventory* will not be stated in the tables since it will be fixed to a certain level within each of the following investigation settings. The reason for that is to emphasize on service level as general overall performance indicator which is only truly significant as long as inventory remains at the same level. Apart from the overall figure we also include the individual service level gaps of each customer which gives a better idea about who gains the most from what kind of collaboration and who might experience shortcomings. Further we include *perfect supply weeks* that state the percentage of weeks where demand was fulfilled to 100% (on time in full). A rather interesting factor within this investigation framework should be the *forecast accuracy gap* figure since it directly indicates the improvement in production forecast accuracy due to increased demand visibility and predictability. Another measure of special interest is *total distribution centre inventory* which gives a combined level of average stock held at retailers' distribution centres throughout the simulated period. Altogether most collaboration research suggests that there should be a substantial drop in DC inventory due to more efficient replenishment and less safety stock. This nevertheless is mostly the case within supply chain frameworks that are characterised by rather excessively high safety inventory to cope with demand and supply uncertainty. Within a supply shortage environment stock level at retailer DCs will rather be lower than anticipated due to delayed order fulfilment and low fill rates. We thus expect rather increasing average DC inventory level as the replenishment process becomes more reliable. Finally there are several delivery punctuality performance measures stated to observe the progress within this context. Considering the non-collaborative low manufacturer inventory framework as the start-up scenario, delivery punctuality is commonly very poor due to insufficient production planning and delivery scheduling as a result of lacking demand visibility and thus predictability. Implementation of various collaboration modules should improve these shortcomings substantially as we see later on.

The results provided hereafter aim to support a better judgement about which are the most effective collaboration factors and factor-combinations and which components do not significantly contribute to an improved overall outcome. Hence we will be able to estimate what particular modules are worth investing in and which others can rather be neglected to save cost and make it unnecessary to reveal too much information to possibly antagonistic market participants. The following tables will, apart from the evaluated partly collaborative scenarios, also state the initial all ROP as well as the final all CPFR settings that serve as references. The individual outcomes of these settings have already been discussed within previous sections and shall not be repeated here.

7.3.3 Implementation of 1 out of 4 modules

In the first stage we have a look at the improvements various performance measures show after one individual CPFR component is introduced. The four components under investigation are illustrated as ***PA*** - detailed knowledge of promotional activities, ***SF*** - detailed seasonal factors, ***TF*** - a trend-prediction according to an underlying forecast-system and ***IA*** - intelligent delivery allocation to distribute scarce products according to particular demand-urgency. These are compared to the initial pure ***ROP*** and the full collaboration ***CPFR*** setup.

Supply Chain FW 1 - 1 collaboration module implemented

	low inventory						medium inventory					
	ROP	PA	SF	TF	IA	CPFR	ROP	PA	SF	TF	IA	CPFR
overall SL gap	**3.3%**	**2.0%**	**2.0%**	**1.1%**	**3.4%**	**0.6%**	**0.5%**	**0.2%**	**0.1%**	**0.2%**	**0.7%**	**0.1%**
SL gap C1	2.9%	1.9%	1.6%	0.9%	3.1%	0.5%	0.4%	0.2%	0.1%	0.1%	0.4%	0.1%
SL gap C2	2.9%	1.7%	1.8%	1.0%	4.3%	0.8%	0.5%	0.2%	0.1%	0.3%	1.0%	0.1%
SL gap C3	3.5%	2.3%	2.4%	1.4%	2.9%	0.6%	0.5%	0.3%	0.1%	0.2%	0.7%	0.1%
SL gap C4	4.1%	2.3%	2.1%	1.3%	3.3%	0.6%	0.7%	0.4%	0.2%	0.2%	0.7%	0.2%
perfect supply weeks	**79%**	**85%**	**85%**	**88%**	**81%**	**92%**	**94%**	**96%**	**97%**	**97%**	**93%**	**97%**
FC accuracy gap	**8.2%**	**7.7%**	**6.2%**	**8.0%**	**8.2%**	**5.9%**	**8.2%**	**7.7%**	**6.2%**	**8.1%**	**8.2%**	**6.0%**
total DC inventory	**100%**	**110%**	**109%**	**115%**	**98%**	**111%**	**100%**	**103%**	**107%**	**107%**	**89%**	**95%**
DC delivery delayed	**77%**	**71%**	**74%**	**69%**	**58%**	**51%**	**40%**	**38%**	**33%**	**32%**	**30%**	**21%**
DC critically delayed	**39%**	**31%**	**32%**	**29%**	**20%**	**9%**	**14%**	**10%**	**8%**	**4%**	**8%**	**2%**
DC perfect deliveries	**17%**	**21%**	**17%**	**23%**	**28%**	**32%**	**49%**	**51%**	**53%**	**52%**	**55%**	**63%**
Retail delivery delayed	**6.1%**	**3.9%**	**4.1%**	**2.6%**	**5.6%**	**1.9%**	**1.1%**	**0.8%**	**0.5%**	**0.4%**	**1.6%**	**0.9%**

Table 7.22: One collaboration module implemented- results for SC framework 1

The table states the results of the low and medium manufacturer inventory scenarios for reasons of comparison. Whilst the medium inventory case reveals an overall satisfactory outcome even for the non-collaboration case, the low inventory framework which is more applicable to the future strategy of the manufacturer demonstrates severe shortcomings. Overall we can see clear differences within the performance impact among the four collaboration modules. Altogether the trend forecast performs most impressively and can be considered as the most recommendable single module. Promotional activity analysis and seasonal factor analysis reveal clear improvements as well with service level gap figures way below the default scenario. The best production forecast accuracy is obtained by implementing the seasonal factors module. The most controversial collaboration component seems to be the intelligent allocation. Despite its obvious goal to close most urgent retail outlet supply gaps it does not seem to accomplish a reduced overall service level gap. One reason for that seems to be the disregard of major customers' (mainly C2 within this framework) large order quantities that are often neglected in order to fulfil a smaller request better and quicker. On the positive side we can notice much reduced distribution centre inventory level especially compared to the other three modules as well as much improved delivery punctuality. The lower inventory should be due to the enhanced order quantities generation and the lower reorder barrier which are due to extended demand visibility as outlined before. The improved delivery performance seems to result from abandoning the first come first served policy with adjustments for the major customer(s) that is in place within the non-collaborative framework. Replacing this with the advanced technique of urgency classification which is calculated according to demand forecast and actual DC and retail outlet inventories seems to fulfil more small orders on time whilst a few larger orders are delayed and eventually lead to service level gaps. The negative implications of this behaviour could be circumvented by abandoning the preset minimum 70% fill-rate barrier. After some testing we found that the service level would be substantially better if the minimum fill-rate was lowered to 50% for very urgent delivery cases but this would come at the price of severely increased tours needed to carry out all orders. After further consideration we decided thus to leave the earlier proposed and practically approved minimum 70% fill rate barrier in place since a vast increase among delivery tours is in practice not considered as a sufficient remedy to make up for some service level shortcomings.

Supply Chain FW 2 - 1 collaboration module implemented

	low inventory						medium inventory					
	ROP	PA	SF	TF	IA	CPFR	ROP	PA	SF	TF	IA	CPFR
overall SL gap	**3.7%**	**1.7%**	**3.6%**	**1.3%**	**4.5%**	**0.7%**	**1.1%**	**0.5%**	**1.1%**	**0.1%**	**1.4%**	**0.1%**
SL gap C1	3.4%	1.6%	3.6%	1.0%	2.4%	0.4%	0.9%	0.4%	0.9%	0.1%	1.1%	0.2%
SL gap C2	3.8%	1.5%	3.6%	1.3%	7.0%	1.2%	1.1%	0.5%	1.2%	0.1%	2.6%	0.2%
SL gap C3	3.6%	1.9%	3.7%	1.2%	2.6%	0.4%	1.2%	0.5%	1.2%	0.1%	0.7%	0.1%
SL gap C4	3.8%	2.3%	4.0%	1.5%	2.0%	0.4%	1.4%	0.6%	1.1%	0.1%	0.7%	0.1%
perfect supply weeks	**75%**	**84%**	**74%**	**87%**	**79%**	**92%**	**91%**	**94%**	**90%**	**98%**	**90%**	**97%**
FC accuracy gap	**7.7%**	**7.9%**	**7.8%**	**6.6%**	**7.7%**	**5.4%**	**7.6%**	**7.9%**	**7.8%**	**6.5%**	**7.6%**	**5.4%**
total DC inventory	**100%**	**123%**	**100%**	**128%**	**94%**	**124%**	**100%**	**104%**	**103%**	**134%**	**79%**	**96%**
DC delivery delayed	**88%**	**79%**	**89%**	**82%**	**72%**	**54%**	**66%**	**65%**	**63%**	**36%**	**50%**	**29%**
DC critically delayed	**75%**	**62%**	**75%**	**59%**	**44%**	**18%**	**41%**	**40%**	**39%**	**9%**	**19%**	**6%**
DC perfect deliveries	**11%**	**18%**	**12%**	**14%**	**20%**	**33%**	**30%**	**31%**	**33%**	**51%**	**40%**	**55%**
Retail delivery delayed	**7.4%**	**4.5%**	**7.5%**	**3.2%**	**6.0%**	**1.5%**	**2.5%**	**1.6%**	**2.3%**	**0.3%**	**2.6%**	**0.7%**

Table 7.23: One collaboration module implemented- results for SC framework 2

Within supply chain framework 2 we can draw similar conclusions to the previous case. It seems the trend forecast is the most successful single module achieving absolutely remarkable service level improvement and good production forecast accuracy compared to the default all ROP case. Within this supply chain framework promotional activity analysis seems to be highly successful as well with substantial improvements. Seasonal factor analysis on the other hand does not seem to give any advantage compared to the default case. There should thus be not much need for putting any effort into implementation. Once more the "intelligent allocation" performs most controversially, most likely due to the same reasons as outlined above. The impact is even more substantial here since supply chain framework 2 features a dominant customer (C2) which seems to suffer substantially once intelligent allocation is implemented which seems to be the reason behind the overall inferior service level performance.

Supply Chain FW 3 - 1 collaboration module implemented

	low inventory						medium inventory					
	ROP	PA	SF	TF	IA	CPFR	ROP	PA	SF	TF	IA	CPFR
overall SL gap	**4.9%**	**4.7%**	**2.1%**	**3.0%**	**5.9%**	**1.5%**	**1.8%**	**1.8%**	**0.9%**	**1.2%**	**2.4%**	**1.0%**
SL gap C1	0.2%	0.1%	0.0%	0.1%	7.4%	0.6%	0.0%	0.0%	0.0%	0.0%	1.5%	0.4%
SL gap C2	6.1%	6.2%	3.2%	4.0%	6.4%	2.3%	2.7%	2.5%	1.3%	2.0%	3.3%	1.1%
SL gap C3	7.7%	6.9%	2.7%	4.2%	4.1%	1.4%	2.3%	2.7%	0.9%	1.4%	2.3%	1.4%
SL gap C4	0.6%	0.6%	0.5%	0.6%	7.6%	1.1%	0.4%	0.5%	0.4%	0.4%	1.5%	0.5%
perfect supply weeks	**78%**	**78%**	**84%**	**82%**	**77%**	**87%**	**86%**	**87%**	**90%**	**88%**	**85%**	**89%**
FC accuracy gap	**15.4%**	**13.7%**	**10.1%**	**14.5%**	**15.4%**	**2.6%**	**15.4%**	**13.7%**	**10.1%**	**14.6%**	**15.4%**	**2.6%**
total DC inventory	**100%**	**104%**	**118%**	**109%**	**89%**	**113%**	**100%**	**100%**	**113%**	**105%**	**89%**	**99%**
DC delivery delayed	**70%**	**67%**	**64%**	**64%**	**59%**	**41%**	**39%**	**38%**	**22%**	**34%**	**35%**	**22%**
DC critically delayed	**31%**	**30%**	**17%**	**23%**	**21%**	**7%**	**11%**	**11%**	**3%**	**7%**	**9%**	**3%**
DC perfect deliveries	**26%**	**29%**	**32%**	**31%**	**30%**	**44%**	**56%**	**54%**	**68%**	**59%**	**56%**	**67%**
Retail delivery delayed	**5.1%**	**5.1%**	**2.4%**	**3.0%**	**6.2%**	**2.1%**	**1.6%**	**1.9%**	**0.9%**	**1.1%**	**2.3%**	**1.3%**

Table 7.24: One collaboration module implemented- results for SC framework 3

In contrast to the previous supply chain frameworks, seasonal factors seems to be the dominant collaboration module within FW3 followed by the trend forecast. Implementing these two modules seems to lead to significant improvements in low and medium inventory circumstances. Somewhat surprisingly, promotional activity analysis does not seem to reveal any significant performance advances whatsoever. Considering the identified promotional pattern in Chapter 4 this is somewhat surprising. "Intelligent allocation" finally gives a similar impression as in the previous cases. Overall service level seems to drop noticeably which is in this case due to the small customers as their service level gap widens from almost zero to a noticeable gap. This should be mainly due to the diverse delivery frequency of small and large customers within this framework. On the other hand implementation of IA leads to significantly less DC inventory as well as a remarkably reduced number of delivery tours needed.

Altogether we can conclude over all three frameworks that introducing just one single component can surely lead to very significant improvements for the entire system as long as the right one is chosen. Implementing the right factor reveals in each supply chain framework a noticeably improved global outcome that is overall half way in between pure ROP and complete CPFR system performance. In contrast to that, choosing a collaboration module arbitrarily most certainly leads to disappointing, and sometimes even diminished overall outcome.

7.3.4 Implementation of 2 out of 4 modules

At this stage we combine two out of the four collaboration modules. Thus six possible combinations of components can be derived and will be evaluated for their impact on the entire replenishment system.

The most apparent finding when looking at the two-component table results for supply chain framework 1 is the diversity of achieved improvements. Looking at the overall service level gap as the most important measure shows results that constitute in the worst cases no improvement from the pure ROP scenario (intelligent delivery allocation combined with either promotional activity analysis or seasonal factor analysis) but in the best cases further progress towards full CPFR achievements (trend forecast combined with either promotional activity analysis or seasonal factor analysis).

Supply Chain FW 1 - 2 collaboration modules implemented

		low inventory						
	ROP	PA&SF	PA&TF	PA&IA	SF&TF	SF&IA	TF&IA	CPFR
overall SL gap	3.3%	1.7%	0.8%	3.3%	0.8%	2.9%	2.1%	0.6%
SL gap C1	2.9%	1.6%	0.6%	3.5%	0.5%	2.6%	2.1%	0.5%
SL gap C2	2.9%	1.5%	0.7%	3.6%	0.7%	3.4%	2.6%	0.8%
SL gap C3	3.5%	1.8%	0.9%	3.4%	0.9%	3.4%	2.0%	0.6%
SL gap C4	4.1%	1.7%	0.9%	2.4%	1.0%	2.0%	1.7%	0.6%
perfect supply weeks	79%	86%	91%	82%	91%	81%	84%	92%
FC accuracy gap	8.2%	6.4%	8.1%	7.7%	5.9%	6.2%	8.1%	5.9%
total DC inventory	100%	106%	120%	100%	120%	97%	103%	111%
DC delivery delayed	77%	78%	66%	57%	69%	62%	57%	51%
DC critically delayed	39%	35%	24%	20%	23%	19%	18%	9%
DC perfect deliveries	17%	17%	24%	28%	22%	24%	31%	32%
Retail delivery delayed	6.1%	3.5%	2.0%	5.4%	2.1%	5.2%	4.5%	1.9%

Table 7.24: Two collaboration modules implemented- results for SC framework 1

These results apply very similarly to the production forecast accuracy and perfect supply weeks as well. On the negative side most of improved service level scenarios imply as a side-effect a substantial increase in inventory at retailers' distribution centres which is due to fewer critical shortages as a result of improved replenishment. The resulting increase in average inventory can be considered as normalisation rather than a critical development. Overall the step from 1 to 2 modules implemented rather revealed a broadening scope of improvement while the actual degree of improvement compared to the best single module alone is not too remarkable.

Supply Chain FW 2 - 2 collaboration modules implemented

		low inventory						
	ROP	PA&SF	PA&TF	PA&IA	SF&TF	SF&IA	TF&IA	CPFR
overall SL gap	3.7%	1.7%	0.4%	2.2%	1.1%	4.5%	1.5%	0.7%
SL gap C1	3.4%	2.1%	0.2%	1.4%	0.7%	2.5%	0.6%	0.4%
SL gap C2	3.8%	1.7%	0.4%	3.4%	1.2%	7.0%	2.4%	1.2%
SL gap C3	3.6%	1.6%	0.3%	0.7%	1.1%	2.5%	0.8%	0.4%
SL gap C4	3.8%	1.9%	0.3%	1.3%	1.3%	2.0%	0.6%	0.4%
perfect supply weeks	75%	84%	95%	87%	88%	78%	89%	92%
FC accuracy gap	7.7%	6.7%	6.7%	6.7%	6.7%	7.7%	6.4%	5.4%
total DC inventory	100%	120%	156%	113%	132%	97%	119%	124%
DC delivery delayed	88%	82%	72%	61%	82%	71%	58%	54%
DC critically delayed	75%	63%	39%	31%	57%	42%	24%	18%
DC perfect deliveries	11%	18%	24%	30%	15%	21%	29%	33%
Retail delivery delayed	7.4%	4.6%	1.2%	3.6%	3.0%	6.4%	2.5%	1.5%

Table 7.25: Two collaboration modules implemented- results for SC framework 2

Once again a similar outcome is observed within supply chain framework 2. Nevertheless, results are much more extreme compared to FW1. The overall best scenario (PA&TF combined) achieves another major leap forward and considering service level even slightly exceeds full scale CPFR. Overall 5 out of 6 possible module combinations lead to significant performance improvements and leave only 1 setting with disappointing outcome (SF&IA combined).

Supply Chain FW 3 - 2 collaboration modules implemented

	low inventory							
	ROP	PA&SF	PA&TF	PA&IA	SF&TF	SF&IA	TF&IA	CPFR
overall SL gap	**4.9%**	**1.7%**	**2.8%**	**5.6%**	**1.3%**	**2.9%**	**3.5%**	**1.5%**
SL gap C1	0.2%	0.1%	0.1%	5.7%	0.0%	1.5%	2.9%	0.6%
SL gap C2	6.1%	2.4%	3.8%	5.8%	2.0%	4.0%	4.4%	2.3%
SL gap C3	7.7%	2.2%	4.0%	4.8%	1.5%	2.2%	2.8%	1.4%
SL gap C4	0.6%	0.5%	0.5%	6.7%	0.5%	2.9%	3.7%	1.1%
perfect supply weeks	**78%**	**85%**	**83%**	**79%**	**87%**	**83%**	**82%**	**87%**
FC accuracy gap	**15.4%**	**7.4%**	**12.5%**	**13.7%**	**9.3%**	**10.1%**	**14.5%**	**2.6%**
total DC inventory	**100%**	**129%**	**120%**	**95%**	**135%**	**102%**	**102%**	**113%**
DC delivery delayed	**70%**	**54%**	**56%**	**57%**	**46%**	**55%**	**53%**	**41%**
DC critically delayed	**31%**	**14%**	**20%**	**20%**	**9%**	**15%**	**15%**	**7%**
DC perfect deliveries	**26%**	**40%**	**38%**	**32%**	**46%**	**34%**	**37%**	**44%**
Retail delivery delayed	**5.1%**	**1.9%**	**2.8%**	**5.5%**	**1.4%**	**3.4%**	**3.8%**	**2.1%**

Table 7.26: Two collaboration modules implemented- results for SC framework 3

The level of diversity between the several module combinations is just as high within FW3 as it was before. Similarly to the one-module analysis the particular importance of the various factors differs between the frameworks. In case of FW3, Seasonal Factors and Trend-Forecast are of major importance whilst especially promotional activity analysis seems to be of limited use. Not surprisingly, the "winning" setting for the above case is the combination of seasonal factors and trend forecast that achieve a remarkably good outcome very close to full-scale CPFR. Altogether four out of six settings can be considered sufficiently improved whilst only two disappoint.

Comparing the results from the best possible cases from all three supply chain frameworks with the reference full-featured CPFR figures makes it obvious that it is possible to achieve nearly CPFR quality outcome with only two out of four components enabled. Thus a company being aware of the crucial aspects within their demand behaviour and thus supply chain delivery structure can save a considerable amount of money and implementation effort by focusing only on the components that are most useful for them. On the other hand the tables above show that taking the wrong components can result in an even inferior outcome compared to the pre-implementation phase. If for example manufacturer 1 would spend vast effort in running either a detailed seasonal factor analysis or evaluating promotional activities and additionally implementing an intelligent allocation system without further information about underlying sales trends – poor service level gaps would barely diminish. This would render the implementation effort and cost virtually worthless. The same would happen if manufacturer 2 decided for a detailed seasonal factor analysis and an intelligent allocation system to improve their delivery/replenishment process. The overall achievements in these cases would most likely be very disappointing. The same accounts for manufacturer 3 as well in case promotional activity analysis and intelligent allocation are chosen for implementation.

7.3.5 Implementation of 3 out of 4 modules

In a final step we have a look at the 3 components scenarios. There are four possible combinations that are compared with the 4-components, full-featured CPFR setting. The results for all three supply chain frameworks have been combined in one table for reasons of clarity and comprehensibility.

3 collaboration modules implemented (low inventory cases)

	Supply Chain FW 1						Supply Chain FW 2						Supply Chain FW 3					
	ROP	PA SF TF	PA SF IA	PA TF IA	SF TF IA	CPFR	ROP	PA SF TF	PA SF IA	PA TF IA	SF TF IA	CPFR	ROP	PA SF TF	PA SF IA	PA TF IA	SF TF IA	CPFR
overall SL gap	3.3%	0.5%	1.8%	2.0%	1.0%	0.6%	3.7%	0.3%	2.5%	1.0%	1.1%	0.7%	4.9%	1.2%	2.1%	3.7%	2.0%	1.5%
SL gap C1	2.9%	0.4%	1.1%	1.3%	0.9%	0.5%	3.4%	0.3%	1.4%	0.6%	0.5%	0.4%	0.2%	0.0%	1.1%	3.8%	1.0%	0.6%
SL gap C2	2.9%	0.4%	2.5%	3.0%	1.2%	0.8%	3.8%	0.3%	4.0%	1.6%	1.9%	1.2%	6.1%	1.8%	3.1%	4.5%	3.0%	2.3%
SL gap C3	3.5%	0.4%	1.5%	1.8%	1.1%	0.6%	3.6%	0.2%	1.0%	0.4%	0.3%	0.4%	7.7%	1.5%	1.7%	2.8%	1.8%	1.4%
SL gap C4	4.1%	0.6%	1.8%	2.1%	0.8%	0.6%	3.8%	0.5%	1.1%	0.4%	0.4%	0.4%	0.6%	0.4%	2.0%	3.8%	1.8%	1.1%
perfect weeks	79%	93%	86%	85%	89%	92%	75%	94%	85%	90%	91%	92%	78%	87%	85%	82%	85%	87%
accuracy gap	8.2%	6.1%	6.4%	8.2%	5.9%	5.9%	7.7%	5.4%	6.7%	6.5%	6.5%	5.4%	15.4%	2.8%	7.4%	12.6%	9.3%	2.6%
DC inventory	100%	125%	103%	105%	110%	111%	100%	147%	109%	120%	123%	124%	100%	138%	114%	105%	112%	113%
Delivery delayed	77%	66%	59%	55%	52%	51%	88%	77%	63%	57%	56%	54%	70%	44%	45%	49%	47%	41%
critical delayed	39%	17%	17%	17%	12%	9%	75%	46%	32%	23%	20%	18%	31%	8%	9%	14%	9%	7%
perfect deliveries	17%	23%	26%	31%	32%	32%	11%	21%	28%	31%	30%	33%	26%	47%	41%	42%	40%	44%
Delivery delayed	6.1%	1.2%	3.8%	4.1%	2.4%	1.9%	7.4%	1.1%	4.2%	1.8%	2.1%	1.5%	5.1%	1.4%	2.4%	3.6%	2.6%	2.1%

Table 7.27: Three collaboration modules implemented- results for SC frameworks 1, 2 and 3

At this stage basically all performance measures show significant improvements compared to the initial ROP scenario which does not come as a surprise. Although each setting features three out of four CPFR components the resulting outcome is still very heterogeneous. The main outcome of this scenario should be to basically find out what particular CPFR components are most negligible considering implementation. In case of supply chain framework 1 we can see that almost full CPFR like results are achievable with ignoring either the intelligent allocation system (PA+SF+TF) or detailed promotional activity information (SF+TF+IA). Within framework 2 we could apparently ignore any of the components as long as the trend forecast is implemented. Within framework 3 finally intelligent allocation seems to be the least beneficial component. Hence we can see that a company thinking about putting a CPFR replenishment system into working can get valuable information about what components are essential for a successful implementation and which ones can rather be neglected. On the other hand we can see which component is most important even in combination with any of the other three. In case of supply chain FW2 the trend forecast component is absolutely vital whilst this holds true for the seasonal factor analysis within FW3. Any three components combination including these factors leads to very satisfactory results whilst only the ones not including them disappoint. Within FW1 there is no single dominant component apparent. Another interesting point seems to be the DC inventory level figures. Since the level of manufacturers' inventory has been prefixed to a certain level within all the above cases, retailers' distribution centre inventories deserve some particular attention. Due to a much improved replenishment process the inventory at this stage recovers from the periods of severe shortages and altogether increases by a significant margin up of to 50%. The main advantage of the intelligent allocation system clearly lies in reducing this stock increase and to limit it to a manageable degree. Therefore this component should – apart from otherwise rather disappointing outcome, particularly in case of sole implementation – be of major importance if retailers' distribution centre inventory is a critical issue. Altogether intelligent allocation reveals its potential only if it is combined with other collaboration components whilst any one of the other three components (PA, SF, TF) can be considered highly effective for sole implementation as long as it is suitable within a particular supply chain framework. Nevertheless there are clearly synergy effects as soon as various components are combined. The above table evidently shows that all four are certainly necessary to obtain the absolute best results. Apart from minor deviations each full-featured CPFR system is superior to every 3-components scenario. Thus we may argue that certain components are more or less important than others but in the end they all contribute to some extent to an overall superior outcome.

7.3.6 Conclusions and Limitations

The previous analysis revealed interesting insights into the distinct performance contributions of four identified typical CPFR components. Whilst the particular recommendations about which component is somehow superior over another varied due to the heterogeneity of the individual demand behaviour, interesting conclusions were found about the possibility to choose certain components prior to any CPFR process implementation. The investigation clearly showed that remarkable efficiency advances can be achieved up to a very superior level with basically only two and sometimes even only one out of four available components in place as long as only the right ones are chosen. This should encourage companies to evaluate their delivery/demand systems as to what extent it is necessary to implement and maintain all stages of a considered CPFR system. Depending on the individual kind and level of performance improvement that is wanted, a given company should, according to the investigation results, choose which of the good scenarios is most easy and cost-effective to implement. Thus a detailed prior investigation is very much recommended to save cost and effort and avoid disappointing collaboration experiences. The positive impact of this kind of context analysis could be experienced within the cooperation with the companies that were directly involved in this research. The obtained information was much welcomed and proved to be very valuable within the definition and the negotiation process of their forthcoming collaboration scope and scale.

Limitations of the investigation

Besides the various interesting insights that could be obtained by individually combining several CPFR components it has to be mentioned that the analysis itself very much focuses on the circumstances of the involved manufacturers. Companies with dissimilar demand and delivery structures should not judge about the general importance of any particular component based on only this study. Depending on the intensity of promotional activities regarding frequency and impact, the level of seasonal sales/demand deviations, the order-behaviour/discipline of customers or the extent of short-term demand fluctuations, every one of the above mentioned four or possible other components could theoretically be the least or most important one in any other, somewhat different, supply chain environment. For the case of the traditional ROP ordering procedure rational ordering is assumed which excludes adaptive ordering behaviour according to actual received quantities (e.g. bullwhip effects). Thus a lower load-level/fill-rate will not result in artificially high adjusted demand (no "shortage-gaming") as it might be the case in reality. Another limitation constitutes the choice of CPFR components. A CPFR system usually includes somewhat more complexity than incorporated by the four taken factors. Aspects like communication advantages due to joint business forecast and thus additional informal connections could not be modelled as well as an extended level of variation that is typical for a supply chain that constantly has to adapt to new external influences. The investigated product-groups have furthermore a considerably stable demand behaviour which makes modelling more reasonable but limits the transferability of results to different kinds of products or even industries. Looking at the above findings and considering the limitations of the investigation it would be interesting for further research to carry out our analysis while varying the above assumptions and conduct more case studies to approve or adjust the previous conclusions as to give practitioners further ideas on how to benefit from evaluating individual CPFR components for their particular use in certain supply chain environments.

7.4 Summarisation and improvement recommendations for the involved companies

Within the following part we will summarise various insights that have been obtained throughout the previous investigation sections and present some overall conclusions. Furthermore we will use the obtained information to recommend possible improvement scenarios for the three supply chain frameworks under investigation.

7.4.1 General findings

Among the numerous possible adjustments within any given supply chain framework we can altogether identify some more and some less important opportunities of improvement. First of all we could clearly see that a switch towards collaboration is without doubt beneficial. This holds true in case of CPFR as well as VMI. Whilst CPFR is in most cases superior and in no case inferior to VMI, there is a variety of possible scenarios in which VMI should be the more sensible solution due to insignificant differences in performance outcome. Considering the default cases of the companies involved it is particularly the low inventory environments that gain the most from collaborative engagement. Altogether it was found that even though inventory held by the manufacturers could be reduced by up to a third, similar or even better performance could be achieved. The heterogeneous investigation framework further revealed how significantly beneficial a partial integration of collaboration can be. The clear outcome of this part of the analysis is that supplier and retail customers can all substantially benefit from even a partial increase in demand visibility. This can be achieved by either involving only part of the customer base in collaborative replenishment or to limit the scale of collaboration to individual components. Such heterogeneous collaboration settings can be nearly as beneficial as a full scale implementation (all customers, all components) and at the same time reduce implementation and maintenance effort and cost substantially. Especially within most SME business frameworks that are characterised by a lack of trust between partners, inferior market power, missing technological capabilities and financial shortcomings, partial collaboration seems to be the only feasible way to enhance supply chain performance and facilitate improved replenishment logistics.

As a result of the various previous analyses the following are our main findings:

1. Full scale implementation of collaborative replenishment leads to improved overall supply chain performance
but
- the degree of improvement heavily depends on the distribution circumstances of each supplier, the targeted inventory levels and the kind of collaboration (VMI/CPFR)
- whilst global metrics improve, the actual level of progress for each individual customer varies greatly and there is a genuine threat that particular customers experience a drop of performance due to collaboration

2. Partial implementation of collaboration can be greatly beneficial for the supplier, the involved customer and remaining customers
but
- the level of improvement depends even more on each individual case
- there is a substantial chance collaboration will not be beneficial or even lead to a drop amongst various performance metrics (e.g. amongst most fixed date delivery scenarios)

- individual customers not participating in collaboration initiatives can be substantially disadvantaged as a result of other customers engaging in collaborative replenishment.

3. Considering an improvement vs. implementation and maintenance effort ratio, heterogeneous settings would have to be recommended over full implementation cases in virtually all possible cases and supply chain frameworks.

4. Early adopters' superior degree of improvement together with a strong correlation between performance improvement and percentage of demand supplied via collaborative replenishment could initiate intense pressure from either supplier or individual customers not to extend collaboration beyond individual key customers. There is a high chance that a full scale collaboration framework would not be preferred by either the manufacturer due to disproportional cost of integrating small customers or by key customers due to early adopters' superior performance and competition with other retail customers.

5. Supply chain performance can in many cases be improved by very simple, inexpensive means such as a seasonal factor analysis, reconsideration of delivery prioritization policies or revised delivery schedules.

6. There should be a distinct optimal collaboration setting for each element within a supply chain framework. Only in a minority of cases there is an equilibrium outcome where all participants achieve their best outcome at the same time. An in depth analysis of each individual supply chain framework setting is thus vital to identify the most efficient solution for every member of the system. The outcome of such an investigation would surely influence the attitude towards collaboration among all involved supply chain parties and detailed knowledge can prove to reveal significant strategic and operational advantage in the process of shaping a supply chain collaboration framework in one's own favour.

Altogether we can thus conclude that there is no overall "golden way" to be recommended. Each collaboration initiative can clearly lead to success or disappointment depending on what is done, with whom, in what order and to what extent. The most successful way to adjust a supply framework to one's own advantage should thus be a detailed investigation of the distribution environment and a performance assessment of feasible options. Within the final part of this chapter we will thus point out such optimal solution cases from the point of view of each of the three manufacturers.

7.4.2 Suggested improvement scenarios for supply chain framework 1

This section will present the proposed improvement scenarios for the supply chain framework of manufacturer 1. To begin with, we state the identified areas of shortcomings that were obtained via analysis of data that was provided by the participating companies or obtained through interviews with management of the involved companies. Just to recall the problems experienced within this framework we state again the outline from section 6.1.1:

- rather low service level as about 5-6% of sales are lost due to non-availability at retail outlets
- out of stock incidents distributed unevenly as customers 1 and 2 have very high service levels whilst customers 3 and 4 suffer substantially
- very severe gaps in supply at retail-outlets once they occur, in some cases stock-outs last for more than one week

- extensive non-critical and critical delivery delays between manufacturer and retailer-DCs as only about 2 out of 3 order requests can be carried out from available manufacturers-stock straight away and 1 out of 10 orders is substantially delayed and thus exceeds typical order lead time substantially
- about 10% of deliveries between DCs and retail outlets are delayed due to insufficient inventory
- inventory facilities are insufficient to keep the traditional stock policies and accommodate further expansion of the product assortment

Following the investigations within the previous sections there should be a large variety of possible improvement scenarios to tackle the shortcomings above. The main factors under consideration will be inventory level at manufacturer's DC, prioritization strategies in between customers, adjustment of reorder policies (fixed or flexible date ROP) or collaboration (VMI, CPFR). These will be considered for general as well as individual implementation. The exceptional issue within supply chain framework 1 surely is the default fixed-date delivery. The severe shortcomings of this approach will allow for a vast variety of possible improvement strategies. The following outline presents a choice from the pool of feasible improvement scenarios classified into three groups which represent only minor modifications, medium adjustments or finally substantial changes.

1. Possible improvement scenarios implying only minor modifications

		Recommendations Manufacturer 1 - minor						
		Default fixed ROP	Fixed ROP+SF	Fixed ROP	RFRF mixed	FFCF mixed	Flexible ROP	FFVV mixed
	distribution dates	F/Tu/m/m	F/Tu/m/m	F/F/f/f	fix&variable	fix&variable	variable	fix&variable
Global	overall SL gap	5.3%	3.4%	2.1%	2.0%	1.9%	0.4%	0.6%
	typical SL gap-size	26%	22%	15%	27%	24%	7%	9%
	largest overall SL gap	100%	100%	59%	98%	99%	22%	50%
	perfect weeks	80%	84%	88%	92%	91%	95%	94%
	FC accuracy gap	8%	6%	8%	8%	6%	8%	6%
Inventory	manufacturer inventory	100%	100%	100%	100%	100%	100%	100%
	total DC inventory	100%	108%	105%	122%	122%	122%	119%
	excessive inventory	4%	3%	11%	6%	6%	9%	7%
Manufacturer to DC	Tours needed	97%	98%	100%	102%	101%	111%	108%
	delivery delayed	41%	36%	14%	30%	25%	38%	22%
	critically delayed	10%	3%	6%	3%	3%	11%	4%
	delivery fill-rate	87%	88%	88%	91%	93%	89%	93%
	perfect deliveries	40%	46%	34%	52%	60%	51%	59%
DC to Retail	retail deliveries	7%	6%	4%	2%	3%	1%	2%
	delivery delayed	2%	2%	1%	1%	1%	0%	0%
individual	SL gap Customer1	1%	0%	2%	0%	1%	0%	1%
	SL gap Customer2	1%	0%	3%	1%	0%	0%	1%
	SL gap Customer3	12%	9%	1%	0%	0%	0%	0%
	SL gap Customer4	9%	6%	2%	8%	8%	1%	0%

Table 7.28: Improvement recommendations for SC framework 1 – minor changes only

Within this first table we present a choice of recommendations to improve the main shortcomings outlined by the company apart from reducing the manufacturers' average inventory level. All of the above scenarios do only require minor adjustments amongst the distribution system. We can see that each of them substantially improves the critical flaws of the default fixed date ROP setting (first column). The order of the presented solutions follows roughly the level of adjustment that is necessary to implement the changes.

- The first recommended setting simply adds a detailed seasonality analysis to the production planning. This should altogether be easily implementable since it does not require major data acquisition, analysis or maintenance cost. Nonetheless, this basic action has already a remarkably positive effect.
- The second setting adjusts the reorder schedule to shift reorder-dates to more suitable days and time-spans whilst they still remain as fixed date delivery. Doing so reduces the overall service level gap remarkably and would distribute service level gaps much more evenly amongst customers. The ease of implementability would depend on how flexible customers' replenishment schedules are.
- The third setting would imply two customers (i.e. C1 & C3) switching towards a flexible delivery date replenishment schedule. The outcome is convincing although maybe not as good as some of the other proposed settings whilst implementability would once more depend on the flexibility of the particular customers.
- The fourth setting suggests introducing a full scale CPFR system with one of the customers (i.e. C3) whilst the rest of the systems remains untouched. The outcome is very convincing considering the fact that only one customer would have to change its order policy. On the other hand substantial technical expertise, implementation and maintenance cost may make this option less worthwhile.
- The fifth setting represents a complete change from the fixed-date delivery to a flexible date-delivery system. The benefits of such a switch would be absolutely remarkable as we see from the table. This setting would be the most recommendable within this initial minor modification framework. On the negative side all four customers would have to agree to such a switch in reordering policy.
- Finally the sixth proposed improvement setting evolves around introducing VMI for two customers whilst the others stay put. Performance improvement is unquestionably one of the best among the above scenarios but implementation might be challenging and costly.

2. Possible improvement scenarios implying reduced inventory and medium adjustments

		Recommendations Manufacturer 1 – medium						
		Default fixed ROP	Default fixed ROP	Flexible ROP	Flexible ROP+SF	FFCC mixed	RCRR mixed	VVRR mixed
	distribution dates	F/Tu/m/m	F/Tu/m/m	variable	variable	fix&variable	variable	variable
Global	overall SL gap	5.3%	7.6%	2.4%	1.5%	2.3%	1.5%	2.2%
	typical SL gap-size	26%	31%	13%	11%	15%	12%	18%
	largest overall SL gap	100%	100%	51%	42%	74%	56%	83%
	perfect weeks	80%	75%	84%	87%	87%	88%	88%
	FC accuracy gap	8%	8%	8%	6%	5%	6%	7%
Inventory	manufacturer inventory	100%	80%	70%	70%	70%	70%	70%
	total DC inventory	100%	88%	93%	99%	93%	99%	95%
	excessive inventory	4%	2%	1%	1%	0%	1%	1%
Manufacturer to DC	Tours needed	97%	95%	121%	119%	111%	119%	122%
	delivery delayed	41%	56%	70%	66%	52%	59%	53%
	critically delayed	10%	16%	33%	27%	13%	19%	15%
	delivery fill-rate	87%	85%	81%	82%	85%	84%	84%
	perfect deliveries	40%	31%	23%	25%	26%	28%	29%
DC to Retail	retail deliveries	7%	8%	5%	3%	4%	3%	4%
	delivery delayed	2%	3%	2%	1%	1%	1%	1%
individual	SL gap Customer1	1%	1%	2%	2%	4%	2%	0%
	SL gap Customer2	1%	1%	2%	1%	3%	0%	1%
	SL gap Customer3	12%	17%	3%	1%	0%	2%	4%
	SL gap Customer4	9%	13%	3%	2%	0%	2%	4%

Table 7.29: Improvement recommendations for SC framework 1 – medium changes

The second table presents recommendable settings that imply some more severe modifications of the initial replenishment outline. As a result of this all initially criticized shortcomings of the default distribution framework are tackled. In order to include the goal of manufacturer 1 to reduce average held inventory by one third all above scenarios operate at 70% of the default average stock level. For reasons of comparison two default scenarios are stated. First there is the original inventory situation presented in the previous table already (manufacturer inventory equals 100%) and additionally a reduced inventory scenario (manufacturer inventory equals 80%) that allows direct comparison with the proposed improvement scenarios (all set to manufacturer inventory equals 70%). Obviously most performance figures are much inferior once inventory is reduced. Altogether we have to bear in mind that the scores seem somewhat inferior compared to the previous table but were achieved for the benefit of reduced inventory. The order of the presented solutions once again follows roughly the level of adjustment that is necessary to implement the changes.

- The first proposed scenario implies a complete change from fixed-date delivery to a flexible date-delivery system. This was already proposed within the minor adjustments framework and is this time adjusted to the lower inventory. As we already saw before, this adjustment proves to be highly rewarding regarding service level figures. Considering delivery punctuality measures it nevertheless falls behind within the reduced inventory case. Implementation should be possible with moderate efforts subject to feasibility and goodwill of retail customers.
- The second setting is mostly identical to the first one except for adding a detailed seasonality analysis to the production planning. This should altogether be easily implementable since it does not require major data acquisition, analysis or maintenance cost. This additional effort is highly rewarded as we can see from the much improved scores. This setting might be the most recommendable within this group of scenarios considering the level of improvement vs. the degree of adjustment. Delivery punctuality remains somewhat problematic nevertheless.
- The third setting incorporates a switch of two customers (C3 & C4) towards full scale CPFR whilst other customers remain unchanged. The positive implications are remarkable with all proposed improvement goals being just about fulfilled. This scenario provides a feasible pattern in case only a limited number of customers are capable or willing to engage in collaborative replenishment. Nevertheless, substantial technical expertise, implementation and maintenance cost may make this option less attractive.
- The fourth scenario includes all customers switching towards a flexible date delivery approach whilst one (C3) additionally engages in collaborative replenishment (CPFR). Performance-wise this setting is very beneficial with remarkable good service level outcome and no other apparent flaws.
- Finally the fifth scenario should imply the most substantial adjustments since two customers need to switch towards flexible date delivery whilst the other two engage in a basic form of collaboration (VMI). The pay-off is satisfactory but compared to the previous scenarios not too impressive considering the level of improvement vs. the degree of necessary adjustments.

3. Possible improvement scenarios implying reduced inventory and substantial changes

		Recommendations Manufacturer 1 - extensive						
		Default fixed ROP	Default fixed ROP	RCCR mixed	FCCC mixed	VVVV collaboration	CCCC-intAllo collaboration	CCCC collaboration
	distribution dates	F/Tu/m/m	F/Tu/m/m	variable	variable	variable	variable	variable
Global	overall SL gap	5.3%	7.6%	1.4%	1.4%	1.1%	0.3%	0.7%
	typical SL gap-size	26%	31%	11%	12%	9%	5%	7%
	largest overall SL gap	100%	100%	63%	80%	42%	16%	30%
	perfect weeks	80%	75%	89%	89%	89%	95%	90%
	FC accuracy gap	8%	8%	5%	5%	7%	6%	6%
Inventory	manufacturer inventory	100%	80%	70%	70%	70%	70%	70%
	total DC inventory	100%	88%	96%	96%	91%	114%	95%
	excessive inventory	4%	2%	1%	1%	1%	1%	1%
Manufacturer to DC	Tours needed	97%	95%	120%	116%	125%	116%	120%
	delivery delayed	41%	56%	57%	49%	52%	55%	49%
	critically delayed	10%	16%	15%	11%	13%	12%	9%
	delivery fill-rate	87%	85%	84%	86%	85%	86%	86%
	perfect deliveries	40%	31%	28%	30%	32%	31%	32%
DC to Retail	retail deliveries	7%	8%	3%	3%	3%	1%	2%
	delivery delayed	2%	3%	1%	1%	1%	0%	0%
individual	SL gap Customer1	1%	1%	2%	4%	1%	0%	1%
	SL gap Customer2	1%	1%	1%	1%	2%	0%	1%
	SL gap Customer3	12%	17%	0%	1%	1%	0%	1%
	SL gap Customer4	9%	13%	2%	1%	1%	0%	1%

Table 7.30: Improvement recommendations for SC framework 1 – extensive changes

The third table within the proposed improvement context of manufacturer 1 includes the scenarios with extensive changes applied to the original distribution system. The average inventory held by the manufacturer is again set to 70% of the default case to accommodate for further expansion of the product assortment as outlined before. The settings stated in the table constitute the most substantial adjustments and thus represent the most sophisticated and advanced scenarios.

- The first among the extensively adjusted scenarios is an extension of a previously considered setting featuring two customers being engaged in CPFR whilst two switch towards flexible date distribution. The actual outcome is satisfactory but does not go much beyond the previously considered RCRR case.
- The second setting is also an extension of a previously chosen scenario (FFCC). It represents the case if all but one customer are willing and capable to engage in collaborative replenishment. Although the outcome is significantly better than in the earlier scenario, the degree of improvement may not justify the additional collaboration effort.
- Case number three represents an all VMI scenario. Thus all customers engage in collaboration albeit only the rather moderate form. Due to VMI requiring significantly less implementation and maintenance effort compared to CPFR this setting could be worthwhile implementing considering its satisfactory outcome.
- Scenario four among the extensively adjusted scenarios may be the overall most recommendable setting in case superior service level is the most important target and somewhat increased inventory levels at retailers' distribution centres would not be considered a problem. Implementation would require much less effort compared to a standard full CPFR system due to non consideration of intelligent allocation as the most demanding collaboration module.

- Finally scenario five implies the case of a standard full scale CPFR implementation. As a result of this the setting reveals most homogenously improved performance and can without question be considered as reference scenario. Nevertheless apart from the DC inventory issue, the differences to scenario four are not significant enough to easily recommend this setting as overall first choice. The somewhat better overall scores do not outweigh the additional implementation and maintenance due to the inclusion of the intelligent allocation system.

From an overall perspective and considering mainly a level of improvement vs. the degree of necessary adjustments ratio the most recommendable scenarios are setting 2 (all flexible ROP+seasonality adjustment) and 4 (one CPFR and three flexible ROP customers) of the medium adjustments framework. Both scenarios sufficiently achieve the goals set out by the company and require comparably moderate adjustments. Depending on the available resources and collaboration-willingness of partners, another scenario amongst the minor modification or major revision frameworks may be more suitable.

7.4.3 Suggested improvement scenarios for supply chain framework 2

Following the outline of section 6.1.2, the main areas of concern within the default distribution framework of the investigated product group within supply chain framework 2 are:

- rather low service level as about 4% of sales are lost due to non-availability at retail outlets
- extensive non-critical and critical delivery delays between manufacturer and retailer-DCs as only about 1 out of 3 order requests can be carried out from available manufacturers-stock straight away and 5 out of 10 orders are substantially delayed and thus exceed typical order lead time substantially
- about 7% of deliveries between DCs and retail outlets are somewhat delayed whilst 3-4% are postponed beyond a critical level and lead thus directly to end-consumer service level gaps
- number of delivery tours needed to supply the distribution centres are 25% higher than expected due insufficient stock and resulting low fill-rates

It was commonly agreed that most of the performance shortcomings are due to the exceptionally low inventory level held by the manufacturer. This is due to insufficient storage facilities which cannot easily be expanded. The main improvement framework should thus evolve around enhanced production planning and collaborative replenishment. The previous analyses have demonstrated how successful particularly CPFR implementation is within this supply chain framework. The most significant modules were identified to be promotional activity analysis and trend forecast. VMI on the other hand shows a rather weak performance and will thus not play a major role amongst the proposed improvement scenarios. Due to the specific circumstances of this supply chain framework, a single customer (C2) accounts for over 40% of overall demand. Previous analyses suggested this customer as main target for possible collaboration and many proposed improvement settings will thus focus on it. Due to the particular circumstances within this framework there are only a limited number of proposed solutions. Thus we accumulate the individual settings of each of the three groups (minor, medium and substantial adjustments) within a single table.

			Proposed changes Manufacturer 2								
			Minor		Moderate			Substantial			
		Default flex ROP	RRRR +promo	RCRR	CCRR -intAlloc	CCRR	RCRR +promo	CCVV	CCCC -intAlloc	CCCC	CCCC low inv
	distribution dates	variable	variable	variable	variable	Variable	variable	variable	variable	variable	variable
Global	overall SL gap	3.7%	1.7%	1.7%	1.1%	1.0%	0.9%	0.7%	0.3%	0.5%	1.8%
Global	typical SL gap-size	12%	10%	14%	7%	12%	9%	6%	5%	5%	9%
Global	largest overall SL gap	55%	35%	69%	28%	62%	44%	25%	21%	25%	55%
Global	perfect weeks	74%	85%	87%	86%	91%	91%	91%	95%	94%	86%
Global	FC accuracy gap	8%	8%	6%	5%	5%	6%	5%	5%	5%	6%
Inventory	manufacturer inventory	100%	100%	100%	100%	100%	100%	100%	100%	100%	85%
Inventory	total DC inventory	100%	126%	132%	118%	133%	139%	120%	147%	132%	105%
Inventory	excessive inventory	3%	5%	2%	1%	2%	3%	2%	2%	3%	1%
Manufacturer to DC	Tours needed	131%	126%	125%	130%	126%	125%	131%	124%	129%	131%
Manufacturer to DC	delivery delayed	88%	79%	71%	86%	63%	69%	56%	76%	47%	71%
Manufacturer to DC	critically delayed	75%	62%	36%	65%	25%	32%	20%	45%	13%	32%
Manufacturer to DC	delivery fill-rate	74%	78%	81%	76%	83%	82%	83%	79%	86%	79%
Manufacturer to DC	perfect deliveries	11%	19%	26%	14%	32%	28%	30%	21%	38%	19%
DC to Retail	retail deliveries	7%	4%	3%	3%	2%	2%	2%	1%	1%	3%
DC to Retail	delivery delayed	2%	1%	1%	1%	1%	1%	0%	0%	0%	1%
individual	SL gap Customer1	3%	2%	2%	1%	0%	1%	0%	0%	0%	1%
individual	SL gap Customer2	4%	1%	1%	1%	1%	1%	1%	0%	1%	3%
individual	SL gap Customer3	4%	1%	2%	1%	2%	1%	0%	0%	0%	1%
individual	SL gap Customer4	4%	2%	3%	1%	2%	1%	0%	0%	0%	1%

Table 7.31: Improvement recommendations for SC-FW 2 – minor, moderate and substantial changes

All of the above scenarios more or less tackle the shortcomings of the default scenario. The order of the presented solutions follow roughly the level of adjustment that is necessary to implement the changes.

- The first setting simply introduces promotional activity analysis to the default flexible delivery date ROP framework. As we can see the improvements are remarkable with most of the shortcomings (especially service level figures) being substantially improved apart from critically delayed deliveries. Given some goodwill of the customers, implementation effort should be rather manageable considering that no permanent data exchange system needs to be set up and run.
- The second minor adjustment improvement scenario implies engaging the largest customer in full scale collaborative replenishment (CPFR). Considering collaboration negotiation and maintenance effort is required for only one customer, the results are clearly convincing. Apart from the very good service level, delivery metrics are substantially improved as well.
- The third and the fourth recommended settings are fairly similar since they imply two customers being engaged in collaboration (CPFR) whilst two others remain unchanged. The first of both has a somewhat reduced collaboration scope since the intelligent allocation module is not implemented. Overall both scenarios perform remarkably well. The reduced collaboration setting (setting 4) achieves very good service level outcome but falls behind regarding delivery punctuality metrics due to the missing intelligent allocation component. Since this collaboration component should require substantial implementation and maintenance cost on top of the remaining collaboration framework, excluding it for the sake of somewhat lower delivery performance could be a worthwhile option.
- The last scenario within the moderate implementation effort group combines the advantages of both minor adjustment settings. The combination of engaging the largest customer in CPFR and carrying out a promotional activity analysis with the

remaining customers apparently is a highly successful combination. Considering the level of improvement vs. the degree of necessary adjustments it is probably the overall most recommendable adjustment scenario.

- The overall sixth proposed improvement setting implies a full collaboration framework with two customers engaging in VMI and the two others in CPFR. The scenario performs sufficiently well but considering the degree of additional collaboration effort compared to setting five it might not be worth the minor performance advantage.
- The seventh and eight scenario are very similar. Both imply an all customer CPFR implementation. The first does not include the intelligent allocation module within the collaboration framework. As a result implementation and maintenance should be less elaborate but for the price of much reduced delivery punctuality performance. The second of both scenarios represents the standard full scale, full scope CPFR implementation. As a result of this the setting reveals most homogenously improved performance and can without question be considered as reference scenario. Nevertheless apart from the delivery punctuality issue, the differences to scenario six are not significant enough to easily recommend this setting as predominant choice.
- Finally the last setting represents a special case of the preceding full scale CPFR scenario since it demonstrates that a full collaboration framework is capable to result in sound performance even though the already very low inventory held by the manufacturer is lowered by 15%. Therefore this setting could be a possible solution if the manufacturer wants to free storage space for other product groups or expand its assortment.

From a global point of view considering the level of achievement of each of the adjustment groups it is difficult to select one group over the other. The final choice would very much depend on which key performance indicator is valued the most. From an outside point of view the three scenarios of the moderate adjustment group seem most worthwhile for implementation since they combine remarkable performance improvement with moderate cost of modification.

7.4.4 Suggested improvement scenarios for supply chain framework 3

Finally this section will present the proposed improvement scenarios for supply chain framework of manufacturer 3. Initially we state once again (from 6.1.3) the identified areas of shortcomings that were obtained via analysis of data that was provided by the participating companies or interviews with management of the involved companies:

- service level altogether on an average level (2-3% gap) but unevenly distributed as the small customers have virtually no OOS (gap <1%) while the major customers suffer rather more severely (3-4% gap)
- demand forecast accuracy is very low (around 20% average deviation) considering the nature of the product
- times of excessive inventory (weeks with average inventory of 25 days or more) are unreasonably high (15%) and need to be reduced to fulfil requested orders more timely and accurately
- number of delivery tours needed to supply the distribution centres are 10-20% higher than expected due to insufficient loading

- extensive non-critical and critical delivery delays between manufacturer and retailer-DCs as only about 2 out of 3 order requests can be carried out from available manufacturers-stock straight away and 1 out of 10 orders is substantially delayed and thus exceeds typical order lead time substantially
- inventory facilities are insufficient to keep the traditional stock policies and accommodate further expansion of the product assortment

The variety of apparent problems will be addressed by proposing numerous improvement settings. A main focus will lie on the reduced inventory held by the manufacturer as this adjustment constitutes a major change affecting most other key performance indicators. Throughout the analyses within previous chapters we found that including customers 2 and 3 in collaborative replenishment should be most worthwhile due to them being key partners. Moreover, VMI seemed to be very competitive coming very close to CPFR within most areas of measured performance. Considering implementation of individual collaboration modules, previous evaluations revealed seasonality analysis and trend-forecast as most promising. The presented improvement scenarios will take these findings into consideration. We will group the recommendations once again into three groups according to minor, medium or substantial necessary adjustments.

1. Possible improvement scenarios implying only minor modifications

The first table presents a choice of recommendations to improve the main shortcomings outlined by the company apart from reducing the manufacturers' average inventory level which will be included within the more severe adjustment cases. All of the following scenarios do only require minor adjustments among the distribution system.

Recommendations Manufacturer 3 – minor changes

		Default fixed ROP	RRVR	RVRR	RRRR +SF
	distribution dates	variabel	variable	variable	variable
Global	overall SL gap	1.9%	1.3%	1.4%	0.9%
	typical SL gap-size	6%	5%	6%	4%
	largest overall SL gap	38%	48%	64%	21%
	perfect weeks	87%	88%	88%	90%
	FC accuracy gap	15%	12%	12%	10%
Inventory	manufacturer inventory	100%	100%	100%	100%
	total DC inventory	100%	104%	102%	112%
	excessive inventory	11%	8%	10%	9%
Manufacturer to DC	Tours needed	110%	104%	104%	104%
	delivery delayed	40%	26%	27%	24%
	critically delayed	11%	5%	6%	3%
	delivery fill-rate	89%	92%	92%	93%
	perfect deliveries	54%	62%	63%	67%
DC to Retail	retail deliveries	2%	1%	1%	1%
	delivery delayed	0%	0%	0%	0%
individual	SL gap Customer1	0%	0%	0%	0%
	SL gap Customer2	3%	3%	2%	1%
	SL gap Customer3	2%	1%	2%	1%
	SL gap Customer4	0%	0%	0%	0%

Table 7.32: Improvement recommendations for SC framework 3 – minor changes

- The first and second improvement scenario engage one of the main customers (C2 or C3) in basic collaboration (VMI). Altogether VMI is much preferable over CPFR within this framework since performance differences are rather minor but implementation should necessitate much less effort. The outcome is quite promising since most of the identified shortcomings are tackled to some extent.

- The third recommended improvement setting among the minor adjustment scenarios adds seasonality analysis to the default flexible date delivery setup. Thus incorporating detailed seasonal factors in production planning seems to result in a remarkable improvement. Apart from the manufacturer's inventory level, all criticised flaws have been resolved to a wide extent. Implementation should not be too difficult since actual collaboration beyond the provision of detailed data is not required. Implementation and maintenance cost should thus be minimal.

2. Possible improvement scenarios implying reduced inventory and medium to substantial adjustments

The second table presents recommendable settings that imply more severe modifications of the default replenishment layout. Following this outline, average inventory level held by the manufacturer has been substantially lowered (-33%). All proposed settings operate at this lower level to comply with one of the major targets of an improved distribution setup. In the first two columns we state the default flexible date delivery ROP scenario operating at the initial as well as the lowered inventory level. The order of the presented solutions follows roughly the level of adjustment that is necessary to implement the changes.

Proposed changes Manufacturer 3 –moderate/substantial

				Moderate					Substantial		
		Default RRRR	Default RRRR	RRRR +SF	RVRR +SF	RCRR +SF	RVVR	RCCR -IA	VVVV	CCCC -IA	CCCC
	distribution dates	medium inv	low inv	variable	variable	variable	variable	variable	variable	variable	variable
Global	overall SL gap	1.9%	4.3%	2.2%	1.7%	1.4%	2.1%	1.5%	1.8%	1.3%	1.6%
Global	typical SL gap-size	6%	11%	7%	7%	7%	9%	5%	7%	5%	7%
Global	largest overall SL gap	38%	56%	41%	66%	56%	75%	34%	49%	30%	43%
Global	perfect weeks	87%	80%	84%	86%	88%	85%	86%	85%	88%	86%
Global	FC accuracy gap	15%	15%	10%	8%	7%	9%	5%	6%	3%	3%
Inventory	manufacturer inventory	100%	67%	67%	67%	67%	67%	67%	67%	67%	67%
Inventory	total DC inventory	100%	77%	87%	92%	93%	95%	80%	88%	85%	85%
Inventory	excessive inventory	11%	2%	1%	2%	2%	2%	2%	2%	2%	2%
Manufacturer to DC	Tours needed	110%	117%	116%	111%	109%	109%	112%	109%	110%	102%
Manufacturer to DC	delivery delayed	40%	67%	64%	43%	48%	44%	52%	39%	46%	45%
Manufacturer to DC	critically delayed	11%	27%	17%	10%	11%	9%	11%	7%	10%	9%
Manufacturer to DC	delivery fill-rate	89%	81%	83%	87%	86%	86%	86%	88%	87%	87%
Manufacturer to DC	perfect deliveries	54%	29%	33%	43%	42%	41%	42%	47%	47%	42%
DC to Retail	retail deliveries	2%	4%	2%	2%	2%	2%	2%	2%	1%	2%
DC to Retail	delivery delayed	0%	1%	1%	0%	0%	1%	0%	0%	0%	1%
individual	SL gap Customer1	0%	0%	0%	0%	0%	2%	0%	1%	0%	1%
individual	SL gap Customer2	3%	5%	3%	2%	1%	3%	1%	3%	2%	2%
individual	SL gap Customer3	2%	7%	3%	3%	3%	1%	2%	2%	1%	1%
individual	SL gap Customer4	0%	1%	0%	1%	0%	2%	0%	1%	0%	1%

Table 7.33: Improvement recommendations for SC framework 3 – moderate and substantial changes

After the reduction of the average inventory held by the manufacturer, average inventory held at retailers' distribution centres is substantially lowered and the high excessive inventory problem seems to be resolved as well. Nevertheless, service level and delivery punctuality performance suffer beyond an acceptable level, which does not come as a surprise.

- The first proposed improvement setting adds seasonality analysis to the default flexible date delivery setup. This was already done within the minor adjustments analysis before and the outcome within the reduced inventory framework is just as convincing. Although delivery punctuality is not too good and service level figures still have potential for improvement, the ease of implementation should make it worthwhile considering.

- The second and third scenario engage one of the two major customers in collaborative replenishment (VMI or CPFR) which seems to improve things even further. Altogether choosing customer 2 seems to be the most beneficial solution. Overall the CPFR case is somewhat superior to the more basic VMI implementation but considering the level of improvement vs. the degree of necessary adjustments VMI might altogether be the better option.
- Settings four and five do not include an overall seasonality analysis as they leave the two small customers unchanged while the two large ones engage in collaborative replenishment. In case of them incorporating VMI, results are overall just satisfactory but in case no seasonality data is available from certain customers this scenario might still be useful. Within the second case the two major customers implement CPFR except for the intelligent allocation module which should save substantial data exchange and maintenance effort. This case scores particularly well regarding individual and overall service level gaps and average inventory held by retailers distribution centres.
- Among the scenarios implying substantial changes within the distribution system of the manufacturer, the least cumbersome is the first setting as all customers are replenished via VMI. This should save substantial cost compared to a full CPFR implementation whilst the achieved performance outcome seems almost as good.
- Another interesting alternative to the full scale CPFR framework is the exclusion of the intelligent allocation as within setting seven. As we already saw in one of the other frameworks, service level seems even better whilst delivery performance suffers somewhat but not remarkably. The implementation and maintenance effort should nevertheless be considerably less.

Overall, we can state that all of the moderate/substantial improvement scenarios sufficiently remedy the identified performance shortcomings. Which particular one should be chosen for implementation depends on the availability of certain data, technical expertise or goodwill of individual customers. Our recommendation would go towards reducing inventory by 30% and carrying out a detailed seasonal factor analysis (setting 1). Additionally one could engage one of the major customers (preferably customer 2) in VMI replenishment which would result in better delivery punctuality and further improved service level.

Naturally the scenarios presented before constitute only a minor choice out of the pool of possible improvement scenarios. In fact, theoretically there could be over 2000 possible scenarios created for each of the three frameworks considering the combination of customers, the chosen collaboration method, individual collaboration module combinations and different inventory levels alone. If one would add prioritization, shortage gaming or various fixed-date delivery options the possible combination would be endless. The recommendations stated above were thus chosen due to common sense and feasibility with the goal of implementability in mind. We hope the outcome actively supports decision making within the companies involved in the research such as they can draft valuable information from the above considerations.

8. Complementary Analysis – Shortage gaming and customer prioritisation

Within this and the following chapter we carry out complementary analyses that are based on the same investigation framework as Chapters 6 and 7 but look at further associated issues within an evolving supply chain collaboration context. In this chapter in particular, we investigate shortage gaming and order-fulfilment prioritisation. Both are particular issues that were already touched upon within previous investigations. Due to their significant importance towards the performance outcome of the investigated supply chain frameworks, their scope of influence and impact will be analysed in more detail.
Shortage gaming in this context defines uncooperative reordering behaviour to purposefully overstate order quantities as a result of insufficient received quantity within previous deliveries. This kind of behaviour is very typical for un-collaborative supply chain relationships that are characterised by frequent supply shortages. The other interesting issue is delivery prioritisation in case of delivery request clashes. Commonly delivery requests are dealt with on a first come first serve basis but this policy is often inferior when operating in a multi-faceted, heterogeneous supply chain with frequent shortages. Other policies often found in practice are default prioritisation of either major customers or newly engaged collaboratively replenished customers. Altogether there is a wide variety of potential strategies delivery request clashes can be dealt with.

8.1 The impact of fill-rate dependent reordering behaviour

Within the following section we aim to point out the extent to which demand overstating reorder behaviour (shortage gaming) can be accommodated for in an altering supply chain. Fill-rate in the context used from now onwards, is thought of as the percentage of any ordered quantity that is in turn delivered by the manufacturer. The investigation is carried out in order to understand the influence of external factors on various aspects of supply chain performance and to give recommendations what ordering behaviour to encourage or condemn in the light of varying levels of demand transparency.

8.1.1 Investigation background

Even in a business environment that is characterised by the introduction of collaborative replenishment systems many enterprises still struggle with problems that seemed to be tackled quite some time ago by larger businesses, namely unnecessary order batching or demand amplification due to overstated order quantities that often develop their own dynamics apart from actual underlying demand (CBI, 2004). The question within changing markets prevails as to what extent demand overstating order behaviour which ultimately leads up to unstable supply and poor delivery performance can be accommodated for in a supply chain system or does actually harm performance on a global basis. This question is furthermore very much within the focus of attention when considering the business circumstances of today's small and medium sized enterprises that are characterised by a wide variety of coexisting delivery systems as outlined in Chapter 1.
The following investigation relies on the previously developed simulation model to address such issues and concerns. It is carried out in order to achieve some level of transparency as to give recommendations what reordering behaviour to encourage or condemn in the light of varying levels of demand transparency. The actual investigation outcomes expand along a wide range of mixed scenarios such as the previously defined default replenishment scenarios or a variety of suggested improvement setups including non-collaborative and

various levels of collaborative replenishment. Overall, a set of thirteen selected performance metrics is applied within fifteen individual homo- and heterogeneous distribution setups to be able to judge about seven different types of ordering behaviour. As a result, conclusions are drawn as to what impact various shortage-gaming strategies have on overall supply chain performance which will contribute to a broader understanding of the overall investigation context of the thesis.

8.1.2 Definition of distinct reordering behaviour policies

In order to find out about the influence of order generation according to previously received delivery quantities, we defined seven distinct settings that stand for numerous different strategies of customers' orders-placing.

First there is the case where customers order exactly the amount they expect to need within the forthcoming typically two weeks order interval. This would be a very logical setting if the average received fill-rate would be close to 100% and the customer thus can expect to obtain the full ordered quantity. In real life nevertheless fill rates for the investigated and many other industries lie typically around 80-90% and thus it is very unlikely that a customer will rely on receiving the ordered quantity in full. This accounts especially for supply chains with low demand transparency where the manufacturer cannot distinguish between the various levels of urgency and the truly needed quantity behind an order.

This leads to the fact that most customers overstate their actual needed quantity to ultimately receive the amount of product that matches their real demand considering a varying fill-rate in between 80% and 90%. Such behaviour, especially when combined with order batching, is a significant contributor to the bullwhip, demand amplification effect that is widely feared within many supply chains. To account for this demand overstating ordering behaviour we generated six distinct settings: The first four out of the six settings will simply overstate actual needed quantity by +10%, +20%, +30% and +40%. This range will cover the common scope of preceding fill-rate adjusted demand exaggeration. Furthermore there will be two settings that adjust dynamically to previous received fill rates. The first of these will take the average of all previously recorded fill rates and adjust the actual order quantity by that amount (*avrgFR*) whilst the second setting will take the fill rate of the single direct preceding order and assume its value for the actual order (*prevFR*).

8.1.3 Performance metrics and rating system

To evaluate the various combinations of the above stated scenarios we selected most useful performance measures out of the variety defined in section 4.5 to allow giving a good impression about the globally achieved supply-chain performance. Performance metrics will be grouped into four clusters: service level measures, inventory metrics, delivery accuracy indicators covering supply between manufacturer and retailers' distribution centres and finally delivery accuracy metrics covering replenishment between retailers' distribution centres and retail outlets. Altogether there will thus be 13 metrics divided into four groups. To be able to effectively compare the overall performances of each reordering policy we defined a rating system that ranks the results in relation to each other and accumulates these ranks to give a single overall score for each of the four performance categories which finally are again aggregated to an overall scenario score. The individual weights are defined in accordance with perceived importance which is rather subjective but should represent common standards. For a detailed explanation about each performance measure see section 4.5.

Metrics accounting for the 1st performance category (Service Level) and their weights within the category score are:

- *Overall Service level gap at store level - 50%*
- *typical service level gap size - 25%*
- *percentage of perfect weeks - 15%*
- *largest overall service level gap - 10%*

Metrics accounting for the 2nd performance category (Inventory) and their weights within the category score are:

- *excessive inventory - 40%*
- *total distribution centres inventory - 60%*

Metrics accounting for the 3rd performance category (Manufacturer to DC delivery) and their weights within the category score are:

- *delayed deliveries -30%*
- *critically delayed deliveries - 50%*
- *delivery fill-rate - 10%*
- *percentage of perfect deliveries - 10%*

Metrics accounting for the 4th performance category (DC to retail outlets delivery) and their weights within the category score are:

- *delayed deliveries - 40%*
- *critically delayed deliveries - 50%*
- *delivery fill-rate - 10%*

The four performance categories are finally aggregated into an overall figure with following weights assigned to each of them: 30%, 30%, 30%, 10%

8.1.4 Investigation outcome: The default scenarios

Within the result presentation we will first start with evaluating the default scenarios for each of the three companies which represent the delivery situation before any changes such as collaborative agreements. Later on possible advanced scenarios featuring various mixtures of fixed date, flexible date and CPFR/VMI delivery are evaluated for their particular outcome.

Supply Chain Framework 1

Table 8.1 presents the various scenarios of the first supply chain framework. The performance figures are stated in the upper half of the table grouped into four categories. The lower part of the table contains the accumulated ranks of each category and the final aggregated overall score. The column on the right hand side is a measure of variability of each performance metric which will be utilised later on. The default delivery setup of supply chain framework 1 is determined to a non-collaborative, fixed date reorder schedule that led to substantial service level gaps as outlined in section 6.1.

		Default setup SC-FW 1-ROPfix medium inv							
		default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var
Service Level	overall SL gap	4.4%	3.6%	2.1%	3.1%	2.8%	2.0%	3.8%	2.2
	typical SL gap-size	23%	28%	20%	24%	22%	21%	24%	1.4
	perfect weeks	81%	87%	89%	87%	88%	90%	84%	1.1
	largest SL gap	100%	100%	95%	96%	83%	93%	94%	1.2
inventor	excessive inventor	4%	5%	6%	6%	5%	5%	7%	1.8
	total DC inventory	100%	116%	135%	141%	148%	131%	124%	1.5
Manuf to DC	delivery delayed	41%	48%	49%	50%	62%	48%	58%	1.5
	critically delayed	9%	15%	20%	24%	34%	17%	32%	3.8
	delivery fill-rate	87%	86%	85%	84%	82%	85%	82%	1.1
	perfect deliveries	41%	37%	36%	32%	27%	34%	28%	1.5
DC to retail	delivery delayed	7%	4%	3%	4%	4%	3%	5%	2.3
	critically delayed	2%	1%	1%	2%	2%	1%	2%	2.0
	delivery fill-rate	98%	99%	99%	99%	98%	99%	98%	1.0
Rating	Service level	5.3	5.4	2.6	4.4	3.1	**2.3**	5.0	1.8
	Inventory	**1.0**	2.2	5.1	5.9	6.2	3.8	3.8	1.5
	M-DC delivery	**1.0**	2.2	3.8	5.0	7.0	3.1	6.0	2.6
	DC-R delivery	6.7	3.6	**1.6**	4.3	4.3	**1.6**	5.9	2.3
	Overall	**2.9**	**3.3**	**3.6**	**5.0**	**5.3**	**2.9**	**5.0**	**2.0**

Table 8.1: Results from the non-collaborative reference scenario – SC-FW 1

Apparently, the individual set out reorder policies lead to significant performance differences. Furthermore, performance impact is very dissimilar among the particular categories. Apparently every demand overstating policy leads to a better overall service-level outcome than the default setting, in some cases performance is significantly superior (+20%, avrgFR). Inventory and delivery performance are nevertheless a clear domain of the default policy whilst some of the demand-overstating policies lead to significant shortcomings. The overall most recommendable policy is adjusting order-quantity according to average experienced fill-rates. This policy reveals a remarkably good outcome in all categories with particularly good service-level performance. Altogether, severe demand overstating or quantity adjustment due to fill-rate of the previous order lead to inferior overall performance particularly considering inventory and delivery reliability.

Supply Chain Framework 2

		Default setup SC-FW 2-ROPflex low inv						
		default	+10%	+20%	+30%	avrgFR	prevFR	var
Service Level	overall SL gap	3.7%	4.0%	4.8%	5.2%	6.2%	6.7%	1.8
	typical SL gap-size	12%	11%	14%	18%	24%	23%	2.2
	perfect weeks	71%	68%	68%	74%	79%	75%	1.2
	largest SL gap	51%	51%	58%	73%	80%	83%	1.6
inventor	manufacturer inventory	100%	103%	108%	111%	116%	119%	1.2
	excessive inventory	3%	4%	6%	6%	8%	10%	3.3
	total DC inventory	100%	105%	110%	103%	119%	111%	1.2
Manuf to DC	delivery delayed	88%	90%	90%	92%	90%	89%	1.0
	critically delayed	78%	80%	82%	86%	78%	78%	1.1
	delivery fill-rate	74%	74%	74%	73%	74%	75%	1.0
	perfect deliveries	11%	9%	9%	7%	10%	12%	1.7
DC to retail	delivery delayed	8%	9%	11%	9%	8%	10%	1.4
	critically delayed	3%	3%	3%	2%	3%	4%	2.0
	delivery fill-rate	97%	97%	95%	95%	98%	99%	1.0
Rating	Service level	**1.6**	**1.6**	2.8	4.0	5.4	5.6	1.8
	Inventory	**1.0**	2.3	3.4	3.3	5.3	5.7	1.6
	M-DC delivery	**1.7**	4.1	4.6	6.0	2.8	1.8	1.2
	DC-R delivery	**1.9**	3.5	5.5	3.0	**1.9**	5.2	1.5
	Overall	**1.5**	**2.8**	**3.8**	**4.3**	**4.2**	**4.5**	**1.6**

Table 8.2: Results from the non-collaborative reference scenario – SC-FW 2

The delivery framework of manufacturer 2 reveals a completely different impact of adjusted ordering policies. However, the level of impact according to a particular policy chosen is as significant as in the previous scenario. Due to flexible order dates and the low level of inventory held by the manufacturer, any kind of overstating order-quantities degrades performance severely. Looking at the table shows that the more orders are overstated the more performance declines. Service level outcome is affected the most followed by inventory figures. Hence, the clearly best policy is the default non-adjusted ordering whilst the worst overall performance is recorded once more by adopting the quantity adjustment due to fill-rate of the previous order. This policy together with the floating average fill-rate adjustment can lead to disastrous supply chain performance outcome within this distribution framework.

Supply Chain Framework 2

		default setup SC-FW 3-ROPflex medium inv							
		default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var
Service Level	overall SL gap	1.9%	1.8%	1.5%	1.7%	1.7%	1.8%	1.9%	1.3
	typical SL gap-size	6%	6%	6%	7%	7%	6%	7%	1.2
	perfect weeks	84%	87%	88%	89%	88%	86%	88%	1.1
	largest SL gap	41%	38%	33%	41%	51%	41%	50%	1.5
inventor	excessive inventor	12%	12%	12%	11%	11%	11%	11%	1.1
	total DC inventory	100%	108%	113%	116%	118%	106%	106%	1.2
Manuf to DC	delivery delayed	40%	43%	47%	54%	54%	43%	45%	1.4
	critically delayed	11%	12%	16%	20%	22%	13%	18%	2.0
	delivery fill-rate	89%	88%	88%	86%	85%	88%	87%	1.0
	perfect deliveries	54%	50%	48%	43%	38%	50%	48%	1.4
DC to retail	delivery delayed	2%	1%	2%	2%	2%	2%	2%	2.0
	critically delayed	0%	0%	0%	0%	0%	0%	0%	1.0
	delivery fill-rate	99%	98%	99%	99%	99%	98%	99%	1.0
Rating	Service level	4.4	3.5	**2.0**	4.2	4.2	3.6	6.1	1.3
	Inventory	**2.0**	4.4	5.2	5.3	6.1	2.5	2.5	1.2
	M-DC delivery	**1.0**	2.3	4.4	6.2	6.9	2.8	4.6	1.7
	DC-R delivery	4.4	**1.6**	4.4	4.4	4.4	4.4	4.4	1.8
	Overall	**2.7**	**3.2**	**3.9**	**5.1**	**5.6**	**3.1**	**4.4**	1.5

Table 8.3: Results from the non-collaborative reference scenario – SC-FW 3

Looking at the outcome of manufacturer 3's delivery framework reveals again distinct conclusions. Apparently overstating demand does not have such severe consequences as within the previous two cases. However, heavy overstating by 30% or more clearly leads to significantly declining performance. Once again delivery performance suffers the most whilst service level can be somewhat improved in case of slight demand exaggeration. The altogether most satisfactory outcome is once more achieved by the default, non-overstating policy, closely followed by the +10% or average previous fill-rate slight overstating setups. The best outcome of each category is achieved by several different policies. Hence, the recommended policy depends heavily on the performance measure that is valued the most.

8.1.5 Investigation outcome: Advanced Delivery Scenarios

After having gained interesting insights about the impact of various reorder-policy choices within the default distribution frameworks of the investigated companies, we want to have some further ideas about possible changes due to various alterations within the distribution layout. We will thus evaluate if optimal reorder policies stay the same within an advanced delivery framework featuring various mixtures of fixed date, flexible date and CPFR/VMI delivery.

Supply chain framework 1

Due to manufacturer 1 operating a fixed-date delivery setting, the most obvious improvement scenarios would be flexible date delivery or a re-adjusted order-date schedule. Thus we will investigate how an all flexible-ROP as well as an improved delivery schedule F/F/f/f that was outlined in section 6.2 affect the optimal ordering policy. Apart from that, we want to draw conclusions about extreme case scenarios where for example all customers order at the same day (F/F/F/F) and evaluate the influence of increased collaboration. For reasons of clarity, only the consolidated overall-score tables of each scenario are stated instead of full performance metrics figures.

Tables 1 and 2	**Manufacturer 1 – flexible ROP (D/D/D/D)** medium inventory								**Manufacturer 1 – F/F/f/f ROPfix** medium inventory							
	default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var	default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var
Service level	2.1	1.6	3.3	4.9	5.8	3.9	6.5	2.5	4.6	3.4	3.5	3.8	3.6	3.1	6.2	1.7
Inventory	1.6	3.6	5.6	5.6	5.6	3.6	2.4	1.1	1.6	2.4	4.8	5.6	6.4	4.0	3.2	1.5
M-DC delivery	1.0	2.0	3.2	5.5	7.0	4.5	4.8	2.0	1.0	2.2	3.0	4.4	6.2	4.6	6.7	2.9
DC-Ret delivery	2.2	2.2	2.2	4.6	6.9	4.6	5.3	2.7	5.0	2.8	4.0	5.2	1.8	2.2	7.0	2.0
Overall	**1.6**	**2.4**	**3.8**	**5.2**	**6.2**	**4.1**	**4.6**	1.9	**2.7**	**2.7**	**3.8**	**4.6**	**5.0**	**3.7**	**5.5**	2.0

Tables 3 and 4	**Manufacturer 1 – F/F/F/F ROPfix** medium inventory								**Manufacturer 1 – 1 CPFR & 3 ROPfix customers** medium inventory							
	default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var	default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var
Service level	4.3	4.3	3.0	3.4	3.7	3.9	5.4	1.6	4.6	4.9	6.1	2.3	3.3	2.4	4.5	1.4
Inventory	2.2	2.3	3.1	3.9	4.7	5.5	6.3	2.2	1.6	2.0	3.4	5.6	6.9	4.0	4.5	1.6
M-DC delivery	1.9	2.7	2.7	5.5	5.5	5.5	4.5	1.5	1.4	1.8	3.7	4.7	6.4	4.3	5.9	2.0
DC-Ret delivery	6.4	5.2	5.2	2.8	2.8	2.8	2.8	1.9	6.4	3.2	3.2	3.2	3.2	3.2	5.6	1.9
Overall	**3.2**	**3.3**	**3.1**	**4.1**	**4.4**	**4.7**	**5.1**	1.8	**2.9**	**2.9**	**4.3**	**4.1**	**5.3**	**3.5**	**5.0**	1.7

Table 8.4: Consolidated scores for adjusted delivery scenarios – supply chain framework 1

Looking at the results reveals various interesting findings. As it seems, shortage gaming leads to somewhat improved service-level performance within all fixed-date delivery ROP scenarios. Altogether a moderate overstatement in between +20% and +40% reveals the best outcome. The downsides to this are significantly worse inventory and manufacturer to DC delivery figures. The more the demand is overstated the worse those figures become. This leads to an overall rather blurry conclusion since there is no clear superior policy. Depending on which performance measure category is valued the most, it is either the default policy that is recommended (low inventory and punctual delivery) or slight demand overstating (improved service level). Extensive overstating (>30%) to some extent and particularly demand exaggeration depending on direct preceding order's fill-rate have to be clearly rejected since overall achieved performance is way inferior to any other policy.

Within an extreme scenario such as F/F/F/F overstating demand certainly leads to supply chain wide improved service levels as we can see from table 3. The reason for these improved figures is mainly the manufacturer operating at maximum capacity throughout extensive periods to cope with the anticipated demand escalation thus the overall produced quantity is somewhat increased. This nevertheless leads to significantly worse inventory figures due to typical bull-whip effects. The overall best scenario was found to be the +20% overstating one due to superior service-level and good inventory and delivery performance. However, which policy to recommend within such an extreme case as within the other scenarios as well heavily depends on which performance metrics are most valued.

Supply chain frameworks 2 and 3

Since manufacturers 2 and 3 operate by default flexible-date ROP replenishment policies, we focus mainly on the effect of increasing collaboration. Thus we investigate how a broadening scope of collaboration will affect the vulnerability of the supply chain towards shortage gaming of the remaining non-collaborative customers. Within the 12 tables stated on the previous page and below, we investigate four different levels of collaboration for each manufacturer. The level of collaborative replenishment as percentage of overall demand is stated on top of each table. Moreover, we include another column called *variance* which states the ratio between the best and worst observed outcome among the evaluated policies for each performance measure. Looking at these figures gives a better idea about how diverse the observed performance within each scenario actually is since the otherwise used ranking approach does not take diminishing variability into account. It can be observed that variability decreases compared to the default scenarios stated above and further diminishes as collaborative replenishment increases.

Tables 5 and 6

Manufacturer 2 – largest customer CPFR all others flexible ROP (low-inv, 44% of total demand via CPFR)

	default	+10%	+20%	+30%	avrgFR	prevFR	var
Service level	1.6	1.5	3.7	3.9	4.8	5.6	1.4
Inventory	2.5	3.6	3.7	4.2	4.4	2.7	1.2
M-DC delivery	3.3	1.4	3.0	5.7	4.9	2.7	1.2
DC-Ret delivery	4.7	4.7	1.9	1.4	3.1	5.2	1.4
Overall	**2.7**	**2.4**	**3.3**	**4.3**	**4.5**	**3.8**	1.3

Manufacturer 2 – largest customer flexible ROP all others CPFR (low-inventory, 56% of total demand via CPFR)

	default	+10%	+20%	+30%	avrgFR	prevFR	var
Service level	1.4	2.4	3.4	4.3	4.1	5.5	1.5
Inventory	1.8	2.5	3.4	4.8	3.6	5.1	1.3
M-DC delivery	4.2	5.7	3.3	3.7	2.8	1.5	1.2
DC-Ret delivery	3.6	1.6	5.7	4.1	1.6	4.4	1.2
Overall	**2.6**	**3.3**	**3.6**	**4.2**	**3.3**	**4.1**	1.3

Tables 7 and 8

Manufacturer 2 – 2nd largest customer CPFR all others flexible ROP (low-inv, 26% of total demand via CPFR)

	default	+10%	+20%	+30%	avrgFR	prevFR	var
Service level	1.7	2.1	2.8	3.9	4.9	5.5	1.7
Inventory	1.0	2.2	3.6	3.8	4.8	5.7	1.6
M-DC delivery	4.4	4.4	3.3	4.4	3.3	1.3	1.2
DC-Ret delivery	2.9	2.9	2.9	2.9	3.5	5.9	1.6
Overall	**2.4**	**2.9**	**3.2**	**3.9**	**4.2**	**4.3**	1.5

Manufacturer 2 – largest 2 customers CPFR all others flexible ROP (low-inventory, 71% of total demand via CPFR)

	default	+10%	+20%	+30%	avrgFR	prevFR	Var
Service level	3.7	3.5	5.0	2.3	4.3	2.3	1.1
Inventory	2.9	2.9	3.4	4.0	4.0	4.0	1.0
M-DC delivery	2.9	3.9	4.2	4.2	2.6	3.3	1.1
DC-Ret delivery	3.5	3.5	3.5	3.5	3.5	3.5	1.0
Overall	**3.2**	**3.4**	**4.1**	**3.5**	**3.6**	**3.2**	1.1

Tables 9 and 10

Manufacturer 3 – 2 small customers CPFR other 2 flex ROP (med-inv, 28% of total demand via CPFR)

	default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var
Service level	3.2	3.5	1.8	4.3	4.8	4.0	6.6	1.3
Inventory	1.8	3.8	4.4	6.0	6.4	4.0	1.6	1.1
M-DC delivery	1.2	2.4	4.8	5.5	6.6	2.4	5.2	1.7
DC-Ret delivery	6.0	3.0	1.0	3.0	4.6	3.6	6.8	1.5
Overall	**2.5**	**3.2**	**3.4**	**5.0**	**5.8**	**3.5**	**4.7**	1.4

Manufacturer 3 – 2 large customers CPFR other 2 flex ROP (med-inv, 72% of total demand via CPFR)

	default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var
Service level	4.5	3.4	4.7	4.5	4.4	3.4	3.2	1.2
Inventory	1.0	3.9	4.4	5.8	6.9	2.9	3.1	1.1
M-DC delivery	3.5	3.5	3.5	4.5	5.2	3.0	5.0	1.2
DC-Ret delivery	4.0	4.0	4.0	4.0	4.0	4.0	4.0	1.0
Overall	**3.1**	**3.6**	**4.2**	**4.8**	**5.4**	**3.2**	**3.8**	1.2

Tables 11 and 12

Manufacturer 3 – 1 small/1 large customer CPFR other 2 flex ROP (med-inv, 50% of total demand via CPFR)

	default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var
Service level	3.7	4.7	3.1	2.9	4.3	2.7	6.6	1.2
Inventory	1.6	4.0	5.2	5.2	6.4	2.8	2.8	1.1
M-DC delivery	1.1	2.4	3.7	6.3	6.8	3.2	4.7	1.6
DC-Ret delivery	4.0	4.0	4.0	4.0	4.0	4.0	4.0	1.0
Overall	**2.3**	**3.7**	**4.0**	**4.7**	**5.6**	**3.0**	**4.6**	1.3

Manufacturer 3 – 1 small customer flex ROP others CPFR (med-inv, 85% of total demand via CPFR)

	default	+10%	+20%	+30%	+40%	avrgFR	prevFR	var
Service level	4.2	3.8	4.2	3.9	3.8	4.2	4.2	1.1
Inventory	4.1	4.1	4.1	4.1	4.1	3.4	4.1	1.0
M-DC delivery	2.9	3.6	3.6	3.6	5.6	3.6	5.1	1.1
DC-Ret delivery	4.0	4.0	4.0	4.0	4.0	4.0	4.0	1.0
Overall	**3.7**	**3.8**	**4.0**	**3.9**	**4.4**	**3.7**	**4.4**	1.1

Table 8.5: Consolidated scores for adjusted delivery scenarios – manufacturers 2 and 3

Looking at the investigation outcome mainly reveals that engaging in collaboration even only to a partial extent has a remarkable stabilising effect on the supply chain as a whole. Even though the non- or slight overstating scenarios seem to have an advantage overall, the

impact of extreme (+40%, prevFR etc.) shortage gaming behaviour is increasingly tamed. We can see this partly from the accumulated performance indicators above but even more so by considering the magnitude of difference between the worst and the best case scenario which is expressed by the grey variance columns. Apparently, performance outcomes of each policy are substantially converging if even only as little as a quarter of total demand is supplied via a collaborative (CPFR) approach.
We can thus conclude that every customer being engaged in VMI or CPFR diminishes the impact of shortage-gaming on the system and increased collaboration should thus make a distribution system less vulnerable. On the other hand we can see from the extensive collaboration cases (tables 8, 10 and 12) that even a system characterised by a wide extent of collaborative replenishment has to consider effects due to shortage gaming behaviour although to a lesser degree. Particularly overstating actual demand by 40% or more or according to experienced direct preceding fill-rate are policies that are highly likely to substantially diminish supply chain performance.

8.1.6 Conclusions

The presented results give a somewhat reduced but still comprehensive overview about the strengths and weaknesses of several possible types of preceding fill-rate dependent reordering behaviour within various replenishment frameworks which will support deeper understanding of interrelations between certain variables within the investigated supply chain frameworks. The actual data-accumulation into the above tables does not reveal the extensive investigation effort that was necessary to achieve this overview. Altogether we were dealing with 5 scenarios per company each containing 7 specific delivery settings which again were evaluated on the basis of 25 individual performance measures from which only 13 were chosen to be incorporated in the result-tables. Accounting for this variation, over 100 individual simulation setups had to be laid out and over 2000 individual performance figures had to be evaluated and compressed into a comprehensible form.
There are various conclusions to the outcomes of the demand overstating reordering behaviour investigation. First of all we can conclude that shortage gaming can have a remarkable negative effect on overall supply chain performance particularly if the *order adjustment according to experienced preceding fill-rate* policy is used by many customers. Adopting this strategy has to be avoided as much as possible since it is one of the causes of the bullwhip effect. We also found that it can nevertheless be beneficial for overall performance if demand is overstated to a certain degree. This seems to be particularly the case within non-collaborative, fixed date ROP delivery scenarios which typically suffer at least temporarily from severe supply shortages. Once replenishment is organised via a flexible reorder date approach, overstating demand is rather counterproductive. Within the majority of this and further advanced supply chain frameworks, the default ordering policy was proven to be most effective.
Another issue arises particularly within scenarios with low inventories held. If the inventory held by the manufacturer is preset to remain at a very low level, any kind of demand overstating dramatically decreases performance within all categories. This is not or to a much lesser extent the case in scenarios with sufficient inventory. Finally we also found that engaging in collaborative replenishment has a remarkable stabilising effect on the supply chain. Even if only part of the customer-base and thus demand is actually replenished via a CPFR system, the whole supply system profits from that since shortage gaming has a remarkably less negative impact compared to an all non-collaborative framework.

Apart from the rather global optimisation considerations within the previous investigation, it needs to be understood that particularly a small or medium size manufacturer often does not have the necessary influence to control the ordering manners of its customers. Nevertheless there should be opportunities to give recommendations and punish or reward certain kind of ordering behaviour. An implicit idea behind this investigation was that results will be revealed to the participating companies and thus some consideration process may be initiated about how to behave in future to improve the actual system. With increasing engagement into collaborative replenishment systems like VMI or CPFR, shortage gaming issues will eventually become obsolete. For the time being many smaller companies have nevertheless to struggle with the negative effects of order batching or demand amplification since at least for the foreseeable future a certain percentage of their customers will continue placing orders in a way to overstate their actual demand to secure having sufficient product at hand.

8.2 The issue of customer prioritization

In this second section, we will take a look at prioritization strategies within the delivery process between manufacturers and their retail customers. The evaluated scenarios include various strategies to handle order request clashes within a non-collaborative as well as a partly collaborative environment.

8.2.1 Prioritization context

The issue of prioritization that this section focuses on evolves around the strategic business issue of how to deal with clashing incoming orders that combined request more of a scarce product than is available. Due to commonly found lean inventory policies and non-collaborative demand planning, available stock of ready made products is often insufficient to adequately fulfil incoming order requests. This problem is particularly apparent within a non-collaborative supply chain environment since order-dates and quantities often cannot be anticipated by the manufacturer and order timing amongst various customers is far from optimal and rather tends to focus on particular points of time within a week or month or quarter which commonly intensifies the shortage problem. Manufacturers on the other hand have to cope with these uncertainties while having to operate with limited inventory space. Altogether this leads to frequent incidents when incoming orders cannot be fulfilled immediately and have to be somewhat delayed. If more than one order is requested at a period of stock shortage we face the problem of fulfilment prioritization as we must decide which order request to fulfil first and which others to delay. Within this context a variety of issues can play a role in deciding about an adequate prioritization policy. Particularly small and medium enterprises often have key customers that account for a large amount of total demand and thus often insist to be treated with priority. On the other hand a major customer could be considered as "safe" and thus a small (new) customer may be prioritized as to not drive him seeking out alternative sources of supply. Another method of priority ranking could evolve out of the idea to balance in between customers to keep the supply gaps of the most unfortunate customer as low as possible which would somewhat drop fill-rates of other customers but still keep them satisfied enough not to search for alternative sources of supply. Apart from these issues there are additional concerns arising within a partly collaborative replenishment framework. If several customers are engaged in some sort of VMI or CPFR replenishment their actual order fulfilment urgency level would be known due to information exchange systems whilst incoming non-collaborative ROP requests could not be judged for their urgency. The question arising is thus how to deal with this situation to either minimize the overall lost sales, meet punctuality targets or avoid upsetting particular customers. To investigate such issues we define various prioritization strategies and test their impact on a global as well as individual customer level. Additionally we consider such issues within a purely non-collaborative as well as partially collaborative replenishment environment and give recommendations how to balance in between collaborative and non-collaboratively replenished customers.

8.2.2 Various prioritization strategies within purely non-collaborative replenishment environments

To be able to further evaluate the impact of certain prioritization strategies within this context we first have to define a range of policies how incoming order requests are dealt with. Therefore we defined five individual policies:
(1) *default policy – first come first served* – this policy is frequently adopted, e.g. by manufacturer 1. Order requests are fulfilled according to their time of placement. No customer is further advantaged in any way.
(2) *default policy – first come first served (FCFS) + key customer advantage* – this policy is in place at manufacturers 2 and 3. It is basically a FCFS approach as in policy 1 but key customers (C2 in case of manufacturer 2 and C2&C3 in case of manufacturer 3) get delivery priority as long as already placed requests of non-key costumers are not delayed for more than 3 days
(3) *RND – random* – orders awaiting fulfilment will be carried out in random order. Thus the importance of a customer or the time of order placement do not have any impact on the fulfilment ranking.
(4) *Size prioritization – larger first* – orders awaiting fulfilment will be carried out according to importance (percentage of total demand) of the customer requesting delivery. The order ranking is thus C2>C1>C3>C4 (supply chain-FW 1), C2>C1>C3>C4 (SC-FW 2) and C3>C2>C4>C1 (SC-FW 3).
(5) *Size prioritization – smaller first* – is the opposite of policy in (4) since the smaller the customer the higher priority it gets. The actual ranking is reverse to policy (4).

For reasons of simplicity and comprehensibility we limited the number of investigated performance metrics to a necessary minimum of four. These were service level gap, non-delayed and critically delayed deliveries between manufacturer and retailers' distribution centres and finally delayed deliveries between retailers' distribution centres and retail outlets. These four metrics constitute the most important key-performance indicators and should be able to reasonably characterise each policy framework.

Outcomes for Supply Chain framework 1

The investigated scenario for manufacturer 1 does not evolve around the default fixed-delivery date ROP distribution setup that was laid out in section 6.1 since prioritization does not actually have any reasonable impact on supply chain performance due to the nature of the approach. In order to be able to evaluate certain prioritization policies within this supply chain framework we base our analysis on the all customers flexible ROP delivery improvement scenario that was proposed in section 6.2.
The results in Table 8.6 show that the five individual policies do not reveal fundamental differences. Not surprisingly, customers 1 and 2 which are the larger ones achieved superior performance when adopting policy 4 (large customers prioritized) whilst falling behind with policy 5 (small customer prioritized). The converse applies to the smaller customers 3 and 4.

Manufacturer 1		default FC prio	default FCprio+C2	RND random	size prio large first	size prio small first
Service level gap	C1	0.2%	0.2%	0.4%	0.1%	0.2%
	C2	0.2%	0.2%	0.8%	0.1%	1.7%
	C3	0.2%	0.2%	0.3%	0.4%	0.1%
	C4	0.3%	0.3%	0.3%	1.9%	0.1%
	overall	**0.2%**	**0.2%**	**0.5%**	**0.5%**	**0.6%**
Manu-DC non-delayed deliveries	C1	64%	64%	68%	67%	70%
	C2	61%	61%	66%	68%	65%
	C3	63%	63%	67%	65%	74%
	C4	64%	65%	68%	67%	79%
	overall	**63%**	**63%**	**67%**	**67%**	**72%**
Manu-DC critically delayed deliveries	C1	9.0%	8.7%	6.5%	5.1%	6.0%
	C2	9.8%	8.5%	10.9%	3.2%	16.1%
	C3	9.3%	9.0%	7.8%	10.4%	2.5%
	C4	11.3%	10.4%	6.0%	11.1%	1.2%
	overall	**9.8%**	**9.2%**	**7.8%**	**7.3%**	**6.4%**
DC-Retail delayed deliveries	C1	0.8%	0.8%	0.9%	0.6%	0.7%
	C2	0.4%	0.5%	1.6%	0.5%	2.5%
	C3	0.7%	0.8%	1.0%	1.0%	0.5%
	C4	1.0%	0.9%	0.8%	1.9%	0.4%
	overall	**0.7%**	**0.7%**	**1.1%**	**1.0%**	**1.0%**

Table 8.6: Results for various prioritisation policies – non-collaborative environment – SC-FW 1

From a global perspective we can see that the two default first come-first served policies achieve better service level as well as retail delivery outcome whilst falling behind within DC delivery metrics. The main achievement is nevertheless to balance the outcome amongst the individual customers which show much more evenly distributed results compared to the purely random or small/large customer prioritization policies and should thus lead to a rather harmonic distribution layout. The other three policies clearly failed to achieve this target since they disadvantage or advantage individual customers which directly results in remarkable distribution performance differences. From a global perspective it is thus policies 1 and 2 that are most recommendable within this context.

Outcomes for Supply Chain framework 2

The investigation of manufacturer 2's delivery framework evolves around the default low inventory scenario that is characterised by severe performance shortcomings as identified in Chapter 6. The evaluation of several prioritization policies reveals a very distinct outcome from the first supply chain framework, as a different choice of strategy has a much more severe impact on individual and overall performance than in the case above.
Overall, two default first come-first served approaches appear to be the best choice to obtain low inventory, reasonable service level figures and overall balanced performance that does not lead to vast differences among the various customers.
On the other hand delivery performance would be significantly superior if simultaneous delivery requests were handled in a random order or according to large or small customer prioritization policies. Looking at the actual figures reveals the magnitude of importance a prioritization decision can have on global performance but even more on an individual customer. According to adopted policy service level gaps can vary in between 0% and 18% which is an extraordinary range. Moreover we can see that policy changes would affect customers very differently. For example customer 1 (Service level gap range between 0% and 4%) would be much less irritated by a policy change than the other three customers which may have service level gaps increasing by 10% or more due to a policy change. This would certainly affect the eagerness of certain customers to negotiate certain delivery arrangements with the manufacturer or to look for alternative sources of supply.

Manufacturer 2		default FC prio	default FCprio+C2	RND random	size prio large first	size prio small first
Inventory	overall	100%	100%	109%	103%	108%
Service level gap	C1	3.5%	4.0%	0.5%	1.5%	0.1%
	C2	3.7%	3.6%	11.1%	0.1%	10.9%
	C3	3.5%	3.6%	0.6%	9.7%	0.1%
	C4	3.5%	4.0%	0.5%	17.8%	0.0%
	overall	3.6%	3.7%	5.3%	4.1%	5.0%
Manu-DC non-delayed deliveries	C1	12%	12%	35%	27%	47%
	C2	9%	9%	14%	19%	13%
	C3	11%	12%	41%	26%	68%
	C4	15%	14%	57%	33%	96%
	overall	12%	12%	37%	26%	58%
Manu-DC critically delayed deliveries	C1	74%	79%	21%	32%	12%
	C2	82%	79%	71%	29%	69%
	C3	74%	79%	18%	47%	2%
	C4	70%	76%	11%	43%	1%
	overall	75%	78%	29%	37%	19%
DC-Retail delayed deliveries	C1	7.6%	7.8%	1.7%	2.3%	0.3%
	C2	7.7%	7.0%	12.4%	0.5%	13.7%
	C3	7.8%	8.2%	1.2%	10.5%	0.2%
	C4	7.0%	8.2%	0.7%	7.7%	0.2%
	overall	7.5%	7.8%	3.9%	5.1%	3.4%

Table 8.7: Results for various prioritisation policies – non-collaborative environment – SC-FW 2

Another finding of this stage of investigation is the often unbalanced performance outcome of a particular chosen policy. It is very unusual that one policy can be recommended altogether. It rather depends on which performance metric is most valued and what level of performance is considered sufficient. Altogether it is again the default policies that are recommended here since the manufacturer will most likely value low inventory and lower service level gaps higher than punctual delivery. As laid out in Chapter 4, the scenario in general is characterised by one large dominant customer who demands a certain special treatment. Due to that, delivery performance of the smaller customers suffers but things could be much worse when considering the service level gaps in case the dominant customer 2 would get general priority.

Outcome for Supply Chain framework 3

The results for framework 3 that is characterised by two small and two large customers reveal similar outcome as before. Once more the default policies lead to a more balanced outcome among customers and better service level whilst falling behind considering delivery punctuality but altogether differences are much more moderate compared to the delivery framework of manufacturer 2.

Again we can see the distinct effect that policy changes have, independent of the customer being small or large. For example, a policy change from small customers getting priority to prioritizing large customers affects the small customer 1 (SLgap from 0% to 7%) and large customer 2 (SLgap from 5% to 1%) substantially whilst customers 3 (large) and 4 (small) are barely influenced.

Manufacturer 3		default FC prio	default FCprio+C2/3	RND random	size prio large first	Size prio small first
Service level gap	C1	0.0%	0.1%	0.4%	6.8%	0.0%
	C2	3.1%	2.8%	2.8%	1.0%	5.3%
	C3	2.5%	2.3%	2.1%	1.7%	1.3%
	C4	0.5%	0.5%	3.2%	1.0%	0.3%
	overall	**2.0%**	**1.9%**	**2.2%**	**2.1%**	**2.4%**
Manu-DC non-delayed deliveries	C1	63%	61%	71%	64%	84%
	C2	62%	61%	66%	71%	68%
	C3	60%	60%	66%	69%	67%
	C4	54%	54%	64%	62%	72%
	overall	**60%**	**60%**	**67%**	**68%**	**71%**
Manu-DC critically delayed deliveries	C1	10.1%	19.3%	8.8%	17.8%	1.1%
	C2	7.6%	6.7%	8.3%	0.6%	10.0%
	C3	8.6%	9.1%	9.5%	7.1%	5.1%
	C4	12.7%	15.7%	9.7%	16.1%	2.0%
	overall	**9.2%**	**11.1%**	**9.0%**	**7.9%**	**5.4%**
DC-Retail delayed deliveries	C1	0.2%	0.4%	0.3%	2.6%	0.2%
	C2	3.2%	2.7%	3.4%	1.9%	2.8%
	C3	2.9%	3.8%	3.4%	1.8%	2.6%
	C4	0.4%	0.5%	1.0%	0.8%	0.4%
	overall	**1.7%**	**1.9%**	**2.0%**	**1.8%**	**1.5%**

Table 8.8: Results for various prioritisation policies – non-collaborative environment – SC-FW 3

Summary

Altogether this preliminary analysis revealed the wide range of impact a change in prioritization policy can have on global supply chain performance and particularly individual customer's outcomes. It also shows nicely how important it can be to evaluate each particular element of a supply chain to be able to find a harmonic solution instead of solely observing global figures. The policy chosen as being the foundation of the analysis of the forthcoming second part of this section is the default policy 1 which is often used in practice as well since it can be considered most fair as no particular customer gets a special treatment. Policy 2 is widely used as well to give key-customers prioritised delivery as long as other customers will not be disadvantaged too much. Policies 4 and 5 that implied a clear priority ranking to advantage either large or small customers respectively, perform as expected as they lead to huge performance dissimilarities among customers and thus should be difficult to justify in practice particularly when a key customer would have to be deliberately disadvantaged. Apart from that they reveal substantially better delivery punctuality figures compared to the other policies. Finally policy 3 as a purely random approach has to be rejected altogether since it has not proven to be superior to the other policies in any aspect. However, this procedure can be found occasionally in practice but should be abolished by any means.

8.2.3 Prioritization within a heterogeneous replenishment environment - Introduction

When considering heterogeneous, partly collaborative replenishment environments, there is, apart from previously mentioned issues, the question of delivery prioritisation between collaborating and non-collaborating customers. Since in this case information regarding the delivery urgency is available from some customers but not from others the question arises which priority strategy is the most successful one to obtain the best possible supply chain performance. Since any particular customer would obviously always interfere to its own best the following analysis is from the point of view of the manufacturer that aims to balance between the certain retail companies to achieve the best possible overall supply chain performance. To evaluate the impact certain preferential combinations have on individual performance measures we created six settings:

1. ***ROPprio*** - ROP customers always have priority, among ROP customers there is a first come-first serve policy in place, CPFR requests are ranked according to their urgency level
2. ***ROPadv*** - ROP customers are advantaged – here ROP deliveries are set to be preferred from CPFR unless a CPFR request is classified as very urgent. To enforce this policy, all ROP requests are set as urgent within the CPFR order classification scheme. Among ROP customers there is once again a first come-first serve policy in place whilst CPFR requests are ranked according to their urgency level.
3. ***Balanced*** - balanced scenario – ROP requests are set to a mean level of urgency within the CPFR ranking system. Orders within the same urgency category are ranked according to a first come-first serve policy.
4. ***CPFRadv*** - CPFR advantaged – here ROP orders are set to below average urgency level which leads to all CPFR deliveries being preferred from ROP unless a CPFR request is classified as rather uncritical.
5. ***CPFRprio*** - CPFR customers always have priority independent of their orders' urgency level.
6. ***CPFRulti*** – within this ultimate CPFR preferential policy, orders of CPFR customers are preferred from ROP the same way as in setting five. In addition to that, no ROP request is fulfilled that could jeopardize fulfilment of any predicted forthcoming CPFR order within a 2-3 days timeframe.

The above settings represent a wide range of possible prioritization policies and can all one way or another be found in practice. The final four settings are more common than the first two since customers engaging in collaborative replenishment are often key partners that commonly expect privileged treatment which means treating their orders at least with the same priority as non-collaborative replenished customers or even better.
All of the six policies outlined above are tested in a wide range of distribution scenarios that feature a varying degree of collaboration. This includes scenarios that with 3 non-collaborating (ROP) and 1 collaborating (CPFR) customers, 2 CPFR and 2 ROP customers and finally 3 CPFR and just 1 ROP. Altogether this adds up to 14 scenarios for each of the 3 supply chain frameworks with 6 individual policy settings applied to each scenario accumulating to 252 individual simulation setups that needed to be run and analysed.
In order to shrink down the fierce amount of output data and to present the obtained outcome in a comprehensible way a marking system is introduced that awards +1 point for a particular good outcome of a specific performance measure compared to the other 5 settings and -1 for a rather inferior outcome. Moreover a mark of -2 is given to settings that resulted in a practically unacceptable outcome and thus complied with certain disqualification rules. These particularly are defined as follows.

a) Major decline of one of the key performance measures (service level, inventory and critically delayed deliveries) for a CPFR customer compared to its prior ROP status.
b) Substantial drop of several performance measures for any ROP/CPFR customer beyond a reasonable point.

The reason for red-flagging these cases is due to practical business conventions that just make it unacceptable that for example a customer engages into a CPFR relationship and as a result of changed priority ranking gets off significantly worse regarding several major performance measures. Settings containing such cases in any of their underlying performance measures are marked red in the subsequent tables and should be considered with great caution even though the actual figure will be stated for reasons of comparison.

The following tables are classified into *overall Service-Level, individual Service-Level, Inventory, overall DC-Delivery, individual DC-Delivery* and *Retail-Delivery* which each stand for particular performance measures categories. These are evaluated for the six above defined priority-settings and according to the retail-customers' replenishment methods (ROP or CPFR).

Service-Level was taken as a measure of gaps in inventory at store level and therefore represents lost sales and customer goodwill. The *Service-Level* categories include global service level outcome for all four customers combined as well as individual figures for each of them. Other metrics within this category are typical service level gap that shows how extensive an out of stock scenario was once it occurred, the percentage of weeks with no out of stock and the overall largest out of stock incidents.

Inventory category represents the impact on inventory level at manufacturers' storage facilities and retailers' distribution centres, and states the percentage of weeks where manufacturer's inventory exceeds a certain upper limit.

Delivery expresses a combination of several delivery performance measures for the distribution between the manufacturer and the customers' distribution centres as well as in between retailers' distribution centres and retail outlets. Included are key-performance indicators such as critically delayed deliveries on a global basis as well as for each individual customer. Additionally percentage of non-delayed deliveries, fill-rates or percentage of perfect deliveries are considered.

The accumulation process of the marking system

To be able to evaluate various aspects of individual and global performance of each supply chain setup, we chose 22 performance figures out of the pool of available metrics outlined in section 4.5. These figures are grouped into 6 clusters each representing a different aspect of supply chain performance. The overall result table representing the outcome of one of the 14 scenarios within the supply chain framework of company 2 is stated below as an example.

Framework 2	C/R/R/R – 25% collaboration					
	ROP prio	ROP adv	balanced	CPFR adv	CPFR prio	CPFR ulti
Total SL gap	3.7%	3.0%	3.1%	3.4%	3.3%	3.3%
Typical SL gap	35%	11%	11%	14%	13%	13%
Perfect weeks	91%	77%	77%	83%	80%	79%
Largest overall gap	100%	50%	66%	78%	55%	55%
SL Gap C1	14.0%	2.6%	2.5%	0.3%	0.3%	0.2%
SL Gap C2	0.2%	3.3%	3.5%	6.0%	4.6%	4.4%
SL Gap C3	0.1%	2.7%	2.8%	2.3%	3.5%	4.1%
SL Gap C4	0.1%	2.8%	2.9%	2.4%	4.0%	3.6%
Manufacturer Inv	100%	96%	95%	97%	96%	95%
total DCs Inv	147%	101%	101%	110%	110%	109%
Excessive Inventory	3.9%	2.3%	2.4%	2.0%	2.0%	2.3%
% uncritical delayed	61.2%	86.1%	86.6%	78.6%	70.8%	69.5%
% critical delayed	26.1%	66.7%	69.8%	48.9%	50.0%	51.7%
Fill-rate	81%	75%	75%	76%	77%	76%
Perfect deliveries	23%	13%	13%	14%	17%	14%
% critical delayed C1	42.6%	64.6%	62.7%	19.1%	1.3%	1.4%
% critical delayed C2	38.2%	74.8%	74.0%	76.9%	80.5%	78.9%
% critical delayed C3	17.7%	64.9%	72.4%	57.3%	68.3%	68.9%
% critical delayed C4	8.0%	62.3%	70.6%	46.4%	62.7%	69.1%
% uncritical delayed	2.6%	6.2%	6.7%	4.9%	6.0%	5.8%
% critical delayed	1.6%	1.8%	1.8%	1.5%	2.2%	2.2%
Fill-rate	98.9%	97.6%	97.2%	98.2%	98.0%	97.5%

Table 8.9: Example for presenting results of individual scenarios

The top of the table indicates the investigated scenario (C/R/R/R) meaning customer 1 being replenished via CPFR and C2, C3 and C4 according to non-collaborative ROP. 25% collaboration indicates that one quarter of the overall demand within this scenario is replenished via CPFR. The performance indicators are grouped into *Overall Service Level* (rows 1-4), *individual service level* of each customer (rows 5-8), *overall inventory* (row 9-11), *overall manufacturer to distribution centre delivery performance* (rows 12-15), *individual manufacturer to distribution centre delivery performance* for each customer (rows 16-19) and finally *overall distribution centre to retail outlet delivery performance* (rows 20-22). Within each of these 22 performance indicators all six prioritization policies are compared with each other and particularly good results marked green (equivalent to +1 point), bad results marked light red (equivalent to -1 point) and exceptionally bad results marked red (equivalent to -2 points). The table with the resulting scores is stated below:

Framework 2	C/R/R/R – 25% collaboration					
	ROP prio	ROP adv	balanced	CPFR adv	CPFR prio	CPFR ulti
Total SL gap	-1	1	1	0	0	0
Typical SL gap	-1	0	0	0	0	0
Perfect weeks	1	0	0	0	0	0
Largest overall gap	-1	1	0	0	1	1
SL Gap C1	-2	0	0	1	1	1
SL Gap C2	1	0	0	-1	0	0
SL Gap C3	1	0	0	0	0	-1
SL Gap C4	1	0	0	0	-1	0
Manufacturer Inv	0	0	0	0	0	0
total DCs Inv	-1	1	1	0	0	0
Excessive Inventory	-1	0	0	0	0	0
% uncritical delayed	1	-1	-1	0	1	1
% critical delayed	1	-1	-1	0	0	0
Fill-rate	0	0	0	0	0	0
Perfect deliveries	1	0	0	0	0	0
% critical delayed C1	-1	-1	-1	0	1	1
% critical delayed C2	1	0	0	0	0	0
% critical delayed C3	1	0	0	0	0	0
% critical delayed C4	1	-1	-1	0	-1	-1
% uncritical delayed	1	-1	-1	0	-1	-1
% critical delayed	0	0	0	0	0	0
Fill-rate	0	0	0	0	0	0

Table 8.10: Example for presenting results as simplified scores

The score table with results accumulated for each performance category thus look like this:

Accumulated score table C/R/R/R-FW2	ROP prio	ROP adv	Balanced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-2	2	1	0	1	1
individual SL	1	0	0	0	0	0
Inventory	-2	1	1	0	0	0
overall DC delivery	3	-2	-2	0	1	1
individual DC delivery	2	-2	-2	0	0	0
retail delivery	1	-1	-1	0	-1	-1

Table 8.11: Example for presenting results as consolidated scores

After obtaining and rating all individual scenarios, the results were accumulated into three groups in two ways for further investigation. First the scenarios were grouped according to number of collaboration partners. Thus group one contained the results of all scenarios with 1 collaboration and 3 non-collaboration customers, group two consisted of all 2 non- and 2 collaborative customers cases whilst group three held all possible combinations of 3 collaborative and 1 non-collaborative retail partner. The second method for grouping was according to percentage of total demand that was dispatched via a CPFR system. This method proved to reveal more meaningful outcome compared to method one since the results of individual performance indicators seems to depend more on the quantitative scope of collaboration than the actual number of customers. Of course the difference between both approaches very much depends on each investigated supply chain framework since framework 1, e.g. has a rather homogenous distribution of demand amongst customers (25%, 30%, 25%, 20%) whilst within framework 2 and 3 the share of each customer is much more different (25%, 45%, 20%, 10% and 14%, 36%, 34%, 16% respectively). For the sake of comprehensibility we will only comment on the outcome of the second grouping method which groups the 14 scenarios of each supply chain framework according to overall percentage of demand replenished via CPFR.

The three groups account for up to 35% (Group 1), between 35% and 65% (Group 2) and 65% or more (Group 3) of demand managed via CPFR. As an example, the final accumulated score table of Group 1 within framework 2 is stated below. It combines the results of 5 out of 14 scenarios (C/R/R/R, R/R/C/R, R/R/R/C, C/R/R/C and R/R/C/C) which all have less than 35% of total demand managed via CPFR.

Framework 2	Accumulated Scores Group 1					
	ROP prio	ROP adv	balanced	CPFR adv	CPFR prio	CPFR ulti
Total SL gap	-2	3	2	-2	-1	-1
Typical SL gap	-5	0	0	0	0	0
Perfect weeks	0	0	-1	0	0	0
Largest overall gap	-4	2	1	-1	3	3
SL Gap C1	-1	0	0	2	0	2
SL Gap C2	4	0	0	-5	0	-1
SL Gap C3	-1	1	0	3	2	0
SL Gap C4	-3	0	-1	3	1	2
Manufacturer Inv	0	0	1	0	0	0
total DCs Inv	-5	4	4	0	1	1
Excessive Inventory	-2	0	0	0	1	1
% uncritical delayed	1	-4	-4	0	4	4
% critical delayed	3	-5	-5	0	0	0
Fill-rate	1	0	0	0	0	0
Perfect deliveries	5	0	0	0	0	0
% critical delayed C1	3	-3	-3	0	1	1
% critical delayed C2	5	0	0	0	0	0
% critical delayed C3	3	-3	-3	0	1	1
% critical delayed C4	2	-4	-4	2	1	1
% uncritical delayed	2	-3	-5	0	-1	-1
% critical delayed	-1	0	0	0	0	0
Fill-rate	0	0	0	0	0	0

Table 8.12: Example for presenting results further consolidated to compare scenarios

The score table serves as the main means of result interpretation within the following output analysis since it gives a detailed overview about the accumulated performance of all the key indicators within a scenario group that is characterised by a similar level of collaboration. Scores are once more highlighted according to relative performance. Thus, scores of a particular performance measure that are substantially better for one prioritization policy compared to the rest are highlighted green, somewhat good scores that are not significantly better than the rest are marked light-green, neutral scores are left white, underperforming scores that are overall not too inferior are marked light red whilst considerably bad scores are marked red. This way we can see instantly which are the strengths and weaknesses of each of the six prioritization policies.

Table 8.13: Example for combined scores of each group

Accumulated score table low collaboration FW2	ROP prio	ROP adv	Balan ced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-11	5	2	-3	2	2
individual SL	-1	1	-1	3	3	3
Inventory	-7	4	5	0	2	2
overall DC delivery	10	-9	-9	0	4	4
individual DC delivery	13	-10	-10	2	3	3
retail delivery	1	-3	-5	0	-1	-1
TOTAL SCORE	5	-12	-18	2	13	13

For reasons of clarity and comprehensibility we can further accumulate the table to state only the combined scores of each performance metrics group. Doing so, we will give up some results detail for the sake of better understanding. As a bottom line the table contains an overall score which is obtained by simply adding the scores of each performance metric group. This final number is just an indicator and by no means should represent a final verdict of which policy is recommended for implementation. Only this final table will be stated for each of the investigated scenarios. Although the heavy data accumulation certainly goes along with a loss of detail, the sheer number of individual setups requires a comprehensible presentation format.

8.2.4 Prioritization within a heterogeneous replenishment environment - Results

Outcomes for supply chain framework 1

Framework 1 features by default a fixed date, non-collaboration replenishment setup with a medium inventory level. To be able to investigate the context of this investigation we decided to use the low inventory, flexible ROP/CPFR replenishment improvement scenario which was introduced in section 6.2. This setup will serve as a better foundation to investigate prioritization effects and was requested for analysis by the particular manufacturer. As already described in Chapter 4 the distribution framework includes four customers of similar size with none of them traditionally receiving any kind of priority. The adjusted low inventory setting that is used for the prioritization policy analysis is characterised by moderate service level gaps as well as somewhat noteworthy delivery delays.

Low collaboration (up to 35%) – 4 out of 14 scenarios

Table 8.14: FW1 - Scores of low collaboration scenarios

Accumulated score table low collaboration FW1	ROP prio	ROP adv	Balan ced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-12	2	1	0	3	0
individual SL	6	1	2	3	2	-1
Inventory	-7	0	0	1	0	0
overall DC delivery	9	-2	0	0	0	1
individual DC delivery	8	-4	0	0	-1	-2
retail delivery	7	0	0	0	0	-2
TOTAL SCORE	11	-3	3	4	4	-4

Within the low collaboration scenario of supply chain framework 1 we can see a rather imbalanced performance outcome. The overall lowest service level gaps are achieved by adopting either the balanced policy or *CPFRprio*. Considering the whole category (overall SL) *CPFRprio* seems to be dominant whilst *ROPprio* results in exceptional inferior outcome. This seems to stand in sharp contrast to individual SL performance. The reason why *ROPprio* obtains a remarkably good score here is due to the fact that most of the low collaboration cases involve only one customer in CPFR whilst other customers remain with ROP. This leads to the fact that if ROP customers are preferred, 3 out of 4 customers improve at the cost of the single CPFR customer. In real life such a scenario is hardly imaginable since the customer engaging in collaborative replenishment will most likely insist in prioritized delivery to sufficiently obey delivery forecasts and schedules. Considering the fact that within all of the scenarios of this investigated low collaboration context only 1 out of 4 customers is replenished via CPFR, it is encouraging to see how positive service level develops even though this single customer is prioritized at the cost of the remaining three ROP customers. Apart from very poor global service level outcome, a clear disadvantage of the *ROPprio* policy is extensive inventories. This includes increased inventory at manufacturer as well as at retailers' distribution centres. On the other hand, always prioritizing ROP customers seems to lead to improved delivery punctuality and higher fill-rates compared to more balancing policies. Nevertheless, these global achievements often come at the expense of the single CPFR customer. Altogether we can thus not recommend policy 1 despite the fact that it obtains the best overall score. This is due to severe shortcomings in individual key performance areas and particularly inferior performance for the single CPFR customers. Considering these facts, *CPFRadv* or *CPFRprio* seem to be much more reliable policies to achieve an acceptable outcome but do not upset individual customers.

Medium collaboration (35% to 65%) – 6 out of 14 scenarios

Table 8.15: FW1 - Scores of medium collaboration scenarios

Accumulated score table medium collaboration FW1	ROP prio	ROP adv	Balanced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-8	6	3	0	0	0
individual SL	2	6	6	6	6	5
Inventory	-6	4	1	5	0	0
overall DC delivery	10	-6	0	-1	4	4
individual DC delivery	1	-9	-4	-4	5	1
retail delivery	0	0	3	2	0	0
TOTAL SCORE	-1	1	9	8	15	10

Within the medium collaboration case that incorporates 6 out of 14 scenarios within supply chain framework 1 we notice a certain shift towards CPFR preferring policies. This is supported by strong delivery performance which is rather weak in case of the balancing scenarios. The overall best service level is achieved by the *ROPadv* and *balanced* policies. Individual service level scores seem to be quite high among all the policies which appears somewhat different when having a look at the detailed result table. Considering best service level, a different policy is advisable for each of the customers. Customers 1 and 3 achieved good results with either one of the policies in place whilst customer 2 is remarkably better off if either one of the clear priority (non-balancing) policies were put in place. Customer 4 finally obtains good results only with the *balanced* or *CPFRadv* prioritization strategy in place. The overall most recommendable scenario very much depends on the preferred performance category. In case overall service level is most important the balanced scenario is clear ahead, if inventory is the main focus of attention *CPFRadv* would be the way to go whilst *CPFRprio* results in the best delivery performance.

High collaboration (over 65%) – 4 out of 14 scenarios

Table 8.16: FW1 - Scores of high collaboration scenarios

Accumulated score table high collaboration FW1	ROP prio	ROP adv	Balanced	CPFR Adv	CPFR prio	CPFR ulti
overall SL	-3	2	4	1	-1	-7
individual SL	-4	2	1	1	5	4
Inventory	-1	0	1	1	1	-2
overall DC delivery	0	0	0	0	3	2
individual DC delivery	-4	-3	-1	1	5	7
retail delivery	-1	0	0	1	0	0
TOTAL SCORE	-13	1	5	5	13	4

Things change remarkably as we progress to the high collaboration scenarios. Overall service level is exceptionally inferior if any of the non-balancing policies are put into place. The three balancing policies have a clear advantage here with the *balanced* policy achieving the best results. The individual service level outcome should be considered rather carefully since within this high collaboration context, outcome of the three CPFR customers often overshadow the problems of the remaining ROP customer.

Delivery performance is clearly a stronghold of the two CPFR prioritizing policies whilst solely supporting the single remaining ROP customer via *ROPprio* leads to severe shortcomings. Overall we can recommend the *balanced* policy due to remarkably good service level outcome and somewhat acceptable remaining performance. If delivery performance is a key issue and service level is not absolutely vital, *CPFRprio* can be recommended for adaptation as well.

Outcomes for supply chain framework 2

The default scenario of supply chain framework 2 evolves around a low inventory setup with one dominant large, two medium and one small customer. This setup is characterised by severe service level gaps and delivery delays as outlined in section 6.1.

Low collaboration (up to 35%) – 5 out of 14 scenarios

Table 8.17: FW2 - Scores of low collaboration scenarios

Accumulated score table low collaboration FW2	ROP prio	ROP adv	Balanced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-11	5	2	-3	2	2
individual SL	-1	1	-1	3	3	3
Inventory	-7	4	5	0	2	2
overall DC delivery	10	-9	-9	0	4	4
individual DC delivery	13	-10	-10	2	3	3
retail delivery	1	-3	-5	0	-1	-1
TOTAL SCORE	5	-12	-18	2	13	13

The low collaboration case within framework 2 reveals remarkably good service level and inventory performance in case *ROPadv* or *balanced* policies are put into place. Both result in superior overall service level as well as low distribution centres' inventory level. Nevertheless delivery accuracy metrics are considerably inferior which prevents these policies from an overall recommendation. Moreover, we can see that implementing a *ROPprio* policy would lead to disastrous outcome regarding service level as well as inventory figures which can overall not be made up by remarkably good delivery performance. Regarding service level it seems that the single large customer would benefit from *ROPprio* policy but the smaller customers do suffer substantially. Within the results of this policy, several scores had to be red-flagged since they met one of the disqualification rules outlined above. In general it appears that service level and inventory performance seems to be better when instating one of the balancing policies (policy 2, 3 or 4) whilst delivery performance is much improved in case clear preference policies such as *ROPprio* or *CPFRprio* are put into place. The altogether most recommendable policies are the CPFR favouring ones. Even though they reveal only average performance in most of the categories, the overall outcome is very balanced without any major drawbacks. Particular strengths of these two categories are low largest service level gaps and punctual manufacturer to DC delivery performance.

Medium collaboration (35% to 65%) – 4 out of 14 scenarios

Table 8.18: FW2 - Scores of medium collaboration scenarios

Accumulated score table medium collaboration FW2	ROP prio	ROP adv	Balanced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-7	5	5	-1	2	1
individual SL	-1	2	0	4	5	1
Inventory	-6	2	6	1	2	1
overall DC delivery	7	-4	-8	-1	4	7
individual DC delivery	6	-6	-13	1	5	5
retail delivery	0	0	-1	2	1	0
TOTAL SCORE	-1	-1	-11	6	19	15

The medium collaboration case shows altogether a shift towards CPFR preferring policies and away from absolute prioritizing policies *ROPprio* and *CPFRulti*. Regarding service level and inventory there is a shift towards the middle. Individual service level figures for all customers show the best outcome when *CPFRadv* and *CPFRprio* policies are applied. Inventory figures are clearly the best within the *balanced* scenario with manufacturer inventory, DCs inventory and excessive inventory all being very low. Delivery performance is once again much better among the non-balancing settings whilst particularly *ROPadv* and *balanced* policies show much inferior results. The overall recommendation for this scenario has to be given to the *CPFRprio* policy since apart from inventory figures being slightly inferior to the balanced setting, it results in excellent outcome in each of the performance categories. *CPFRulti* which was still on par within the low collaboration framework is now clearly falling behind and cannot be recommended.

High collaboration (over 65%) – 5 out of 14 scenarios

Table 8.19: FW2 - Scores of high collaboration scenarios

Accumulated score table high collaboration FW2	ROP prio	ROP adv	Balanced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-2	8	8	2	-4	-10
individual SL	1	7	-1	6	4	-1
Inventory	-6	1	6	2	2	-5
overall DC delivery	5	0	-10	1	4	9
individual DC delivery	6	0	-13	0	8	8
retail delivery	0	2	-2	1	2	-1
TOTAL SCORE	4	18	-12	12	16	0

The high collaboration case emphasizes the previously identified trend to shift towards the middle away from extreme policies at least as far as service level and inventory are concerned. Among these first two categories *CPFRprio* policy loses ground and best performance shifts towards more balancing policies. Delivery performance is still a stronghold of *ROPprio*, *CPFRprio* and *CPFRulti* whilst particularly the *balanced* scenario reveals substantial shortcomings. The overall most recommendable policy among high collaboration scenarios has to be policy 2. Superior service level and good scores within the other categories should justify this. Finally it needs to be mentioned that enforcing a *CPFRulti* prioritization policy within a high collaboration framework has to be avoided by any means. Particularly service level and inventory figures are significantly worse compared to other policies.

Outcomes for supply chain framework 3

The prioritization analysis of the delivery system of framework 3 is based on the default medium inventory flexible ROP/CPFR delivery setup described in section 6.1. A particular characteristic of framework 3 is the fact that two customers are replenished on a weekly interval whilst the two others receive delivery fortnightly. The delivery system features two major customers that account together for almost 70% of demand whilst the other two customers contribute only 30% of overall demand. The setup is characterised by fair service level figures and reasonably good delivery punctuality.

Low collaboration (up to 35%) – 5 out of 14 scenarios

Table 8.20: FW3 - Scores of low collaboration scenarios

Accumulated score table low collaboration FW3	ROP prio	ROP adv	Balanced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-11	-1	7	3	0	1
individual SL	1	-1	5	4	5	5
Inventory	-3	1	3	1	1	2
overall DC delivery	7	-1	-6	0	1	0
individual DC delivery	7	-3	-3	1	1	0
retail delivery	-1	-1	0	2	1	0
TOTAL SCORE	0	-6	6	11	9	8

The low collaboration case within framework 3 reveals the best overall service level outcome in case *balanced* or *CPFRadv* policies are put in place. Absolute ROP prioritization seems to lead to much inferior results whilst the other three policies lie somewhere in between. Considering individual service level it seems that retailers 1 and 4 would be much better off if priority was generally given to CPFR customers whilst retailers 2 and 3 should clearly prefer ROP deliveries to be prioritized independent of which retailers actually engage in collaborative replenishment. Inventory figures are altogether not too different However, considering DC inventories the *balanced* scenario achieves the best outcome whilst *ROPprio* falls clearly behind. Delivery performance within this framework is clearly at its best if ROP customers would always be preferred. In contrast to that *ROPadv* and *balanced* policies have clear shortcomings within this area whilst the CPFR preferring policies lie somewhere in the middle. Altogether we can once again see a very mixed result table. The *balanced* scenario is the method of choice regarding service level and inventory performance but reveals shortcomings at delivery figures. Exactly the opposite outcome can be recorded for the *ROPprio* policy. The overall most convincing strategy seems to be *CPFRadv* since it combines good service level and acceptable delivery performance.

Medium collaboration (35% to 65%) – 4 out of 14 scenarios

Table 8.21: FW3 - Scores of medium collaboration scenarios

Accumulated score table medium collaboration FW3	ROP prio	ROP adv	Balan ced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-2	4	4	2	0	-1
individual SL	1	1	2	4	5	0
Inventory	-1	-1	0	0	0	0
overall DC delivery	3	-1	-3	2	1	3
individual DC delivery	2	-3	-4	0	2	1
retail delivery	0	-1	1	1	2	1
TOTAL SCORE	3	-1	0	9	10	4

Among the medium collaboration cases the outcome is rather similar to the low collaboration situation with a slight shift towards CPFR preferring policies. The overall lowest out of stock times are achieved in case *CPFRadv* policy is adopted whilst the lowest maximum supply gaps are recorded for the *balanced* policy. Considering individual service level it seems that if collaboration is overall at least on a medium level, there is much less diversity compared to a low collaboration context. The same is true for inventory figures. The differences between the certain polices are much less severe than within the low collaboration case. Delivery performance is remarkably good in case of the absolute ROP prioritization as well as within all CPFR advantaging strategies. If delivery performance is of major importance, *ROPadv* as well as *balanced* policy should not be adopted by any means among medium collaboration setups. The overall recommended scenarios are *CPFRadv* and *CPFRprio* since they achieve the most homogeneous overall scores.

High collaboration (over 65%) – 5 out of 14 scenarios

Table 8.22: FW3 - Scores of high collaboration scenarios

Accumulated score table high collaboration FW3	ROP prio	ROP adv	Balan ced	CPFR adv	CPFR prio	CPFR ulti
overall SL	-2	1	2	0	-1	-3
individual SL	-3	0	0	0	0	-2
Inventory	-1	0	1	1	1	0
overall DC delivery	2	0	1	2	2	2
individual DC delivery	3	2	5	5	10	3
retail delivery	-1	0	1	0	1	1
TOTAL SCORE	-2	3	10	8	13	1

The high collaboration case is characterised by altogether much less diverse results. This is more apparent from the detailed result table than from the accumulated table that is stated here. Overall results are much better if neither one of the radical prioritization polices (*ROPprio* & *CPFRulti*) is chosen. This is particularly true for global service level gap which is optimal in case the *balanced* strategy is adopted. Although we can state that once collaboration is implemented to a wide extent, delivery performance is sufficiently improved independent of which prioritization strategy is put in place, *CPFRprio* seems to result in superior outcome compared to other polices. Overall it is thus policies 3 and 5 that achieve the best score due to superior service level and delivery performance respectively.

Overall results and Summary

After investigating all of the scenarios individually we will try to obtain some general trends and recommendations by accumulating the outcomes for each collaboration level group.

Table 8.23: Consolidated scores for six prioritisation policies under low, medium and high level of collaboration

Accumulated scores table	ROP prio	ROP adv	Balanced	CPFR adv	CPFR prio	CPFR ulti
	accumulated low collaboration					
overall SL	-34	6	10	0	5	3
individual SL	6	1	6	10	10	7
Inventory	-17	5	8	2	3	4
overall DC delivery	26	-12	-15	0	5	5
individual DC delivery	28	-17	-13	3	3	1
retail delivery	7	-4	-5	2	0	-3
	accumulated medium collaboration					
overall SL	-17	15	12	1	2	0
individual SL	2	9	8	14	16	6
Inventory	-13	5	7	6	2	1
overall DC delivery	20	-11	-11	0	9	14
individual DC delivery	9	-18	-21	-3	12	7
retail delivery	0	-1	3	5	3	1
	accumulated high collaboration					
overall SL	-7	11	14	3	-6	-20
individual SL	-6	9	0	7	9	1
Inventory	-8	1	8	4	4	-7
overall DC delivery	7	0	-9	3	9	13
individual DC delivery	5	-1	-9	6	23	18
retail delivery	-2	2	-1	2	3	0

Altogether we can see that there is hardly one single policy fitting every kind of collaboration framework. Depending on the individual performance metric category there is a wide variety of good strategies. Nevertheless there are some trends obvious after considering all the results. First of all a *ROPprio* policy seems to be rather pointless due to persistent inferior service level and inventory figures. *CPFRulti* as another radical scenario can reasonably only be recommended in low collaboration frameworks. *CPFRprio* as the third non-balancing policy reveals reasonably good outcome in low and medium collaboration frameworks but inferior service level raises a serious doubt about its applicability within high collaboration scenarios. Among the balancing scenarios (*ROPadv*, *balanced* and *CPFRadv*) there is a great diversity of individual strengths and weaknesses. Overall it is the *balanced* policy that achieves the best overall service level and inventory figures by far. Considering minimizing out of stock times at retail outlets and low inventory at manufacturer as well as distribution centres as the major targets within supply chains the balancing policy should be the strategy of choice within most frameworks. On the other hand it is the delivery performance that raises some serious concerns. Treating all delivery requests equally apparently leads to more and longer delays, as well as lower fill-rates compared to any other policy. Within this performance category it is specifically the non-balancing policies that have clear prioritization rules in places that lead altogether to more punctual replenishment. This result seems to be mainly due to the impartial nature of the *balanced* approach that works on a first come first serve basis without any preferences in place. In reality nevertheless, the large order requests of key customers need some sort of prioritization to be delivered within the expected lead times. This should be independent from the particular customer being replenished either via ROP or CPFR. Another finding of the investigation is that choosing the optimal prioritization strategy seems not to be any

less crucial within low or high collaboration cases. Adopting the wrong strategy can cause severe performance drawbacks independent of only a minor, half or major part of the total demand being replenished collaboratively.
Altogether it seems to be a favourable strategy to instate CPFR advantaging policies (*CPFRprio* in particular) in case of low collaboration frameworks, and shift towards more balancing policies as the scope of collaboration widens. Thus we conclude by recommending that prioritization strategies should not be static but should be adjusted according to the particular level of collaboration a delivery framework features. The best way would be of course individual adjustment to every change within the distribution system but this might cause too high costs and effort to be able to realise. In case a company does not want to go through an individual adjustment investigation but rather searches for a best to fit all policy, *ROPprio* and *CPFRulti* are to be avoided under any circumstances whilst *balanced*, *CPFRadv* and *CPFRprio* can be recommended as the strategies that fit within most frameworks and obtain reasonable results.

8.3 Overall conclusions

The two complementary investigations above demonstrated clearly what significant impact underlying assumptions can have within a supply chain analysis model. The profound knowledge obtained about the influence of demand overstating reordering behaviour as well as various strategies of prioritizing customers were very helpful and necessary in order to set up proper and realistic improvement scenarios throughout other investigations. Due to a vast level of complexity that is characteristic for a simulation model which aims to realistically model a supply chain framework of a wide scope it is impossible to declare all identified influential factors as ex post adjustable variables. Therefore it is absolutely vital to have some competent knowledge about how to preset global framework factors prior to investigating various scenarios that include once again numerous local variables. The conclusions drawn from the above analyses are thus also of value beyond the investigation context of this thesis. A comprehensive framework investigation complementary to evaluating the core area of a research case should always contribute substantially to a valid, verified and robust modelling approach.

9. Complementary analyses II - Perishable goods

In this final main investigation chapter the aim is to evaluate various supply chain advancements and their impact within a perishable goods environment. The analysed aspects will be somewhat similar to the previous chapters but the perishable nature of the products will require a substantially different investigation focus. Altogether, perishable goods frameworks seem to have distinct conventions and priorities that are considerably different from environments with non-perishable or long term perishable products. The most significant difference within this context evolves around the omnipresent issue of goods that need to be individually dispatched or replaced within various echelons due to risk of expiration of their shelf-life. Considering that concept, a lot of possible scenarios arise regarding how to produce, store, deliver, control and replace these goods. All those issues evolve in addition to the already complex interrelations of distributing goods within a supply chain. Overall, the field of perishable products distribution frameworks constitutes some sort of "extreme case" scenario within the otherwise reasonably investigated field of supply chain management.

9.1 The perishable goods environment

The sale of perishable goods is of vastly increasing importance for grocery retailers worldwide. At present it accounts for almost 50% of turnover of the grocery retail industry of Western Europe and North America (First Research, 2005). This figure alone manifests the importance of this kind of goods but perishable products are also the main driver through which companies are able to create competitive advantages to attract additional customers apart from pricing strategies. They must therefore be seen as the driving force behind the industry's profitability. According to Heller (2002) the quality of perishable goods assortment is becoming the core reason many customers choose one supermarket over another. Perishable items benefit greatly from improved transportation: the sooner the items reach the market, the longer they can stay and the higher the chance they won't become obsolete. The global market for perishable goods such as refrigerated products and prepared meals is growing due to changing lifestyles and decreasing product handling costs. Nevertheless, considering the limited durability it is essential to dispatch these goods speedily to reach the consumers in due time which relies on the advancement of other technologies e.g. cold chain transportation (Bogataj *et al.*, 2005). Due to their common fragility and finite (often very short) lifetime, handling those goods is far more complex and includes much higher risks compared to non-perishable products. Altogether perishable goods account for the majority of avoidable losses within the grocery retail industry. These losses average around 15% of perishable goods turnover due to damage, spoilage and expiry which is much higher compared to non-perishable products (Ketzenberg and Ferguson, 2003; Deniz *et al.*, 2004). The high margin of evitable losses offers on the other hand significant opportunities for improvement and thus incentives for research and technology advancement within this business framework. The main idea of this analysis is thus to investigate various supply chain processes for the particular circumstances of perishable goods. The objective is to evaluate if and to what extent a change in inventory level, the alteration of product throughput or introduction of collaborative replenishment are worthwhile means of improving particular aspects of supply chain performance. Hence a large part of the investigation is devoted to investigate inventory throughput policies and actual benefits from information exchange. Due to distinct age and thus expiry date of products held in inventory being a major aspect within a perishable goods framework, product issuing and replenishment strategies are absolutely

crucial and need to be considered much more comprehensively. Consequently, numerous inventory throughput policies exist that can be applied in various situations. Leiberman (1958) and Pierskalla and Roach (1972) already evaluate conditions where inventory throughput is guided by either oldest items to leave first (FIFO), youngest items first (LIFO) or random issuing (SIRO). It should be fairly obvious that a FIFO approach is most advisable within a framework of products having a very limited lifetime span. Within the analysis we will thus discuss possible performance implications in case a FIFO or rather FPFO (first produced first out) strategy is sufficiently put into effect at each stage of the distribution process. To nevertheless obtain some practically useful recommendations we also focus on creating several sub-optimal settings (e.g. FDFO – first delivered first out, SIRO – service in random order, LIFO – last in first out) to evaluate what impact these decisions or disregard of best practice rules have on a global level.
Considering furthermore the framework of perishable goods supply chains, Ketzenberg and Ferguson (2003) and Ferguson and Ketzenberg (2005) are the only studies that investigate information sharing within a perishable context that we are aware of. They study the benefits of increased demand transparency and centralised control in a serial supply chain providing a perishable product. However, their investigation is based on a serial supply chain consisting of only a single retailer and a single supplier. They find that supply chains for perishable products benefit the most from information sharing or centralised control when product lifetimes are short, batch sizes are large, demand uncertainty is high and the penalty for mismatch in supply and demand is high. Ferguson and Ketzenberg (2005) expand this framework to investigate extended information sharing involving also the throughput policies. They find that information sharing is more beneficial in environments featuring a FIFO issuing policy and that switching from a LIFO or SIRO to FIFO policy even outweighs the introduction of information sharing. A complete review of literature on perishable goods is available in Goyal and Giri (2001).
Considering the overall ongoing research within the field of supply chain collaboration, it has to be stated that recommendations given in the majority of general purpose studies can have only limited transferability for a perishable goods environment. Altogether, perishable goods frameworks seem to have distinct conventions and priorities that are substantially different from environments with non-perishable or long term perishable products. The most substantial difference within this context evolves around issues such as dispatch or replacement strategies within various echelons due to risk of expiration of goods' shelf-life. Considering that concept, several possible scenarios arise how to produce, store, deliver, control and replace these goods. All those issues have to be considered in addition to already complex interrelations of distributing goods within a supply chain.

Some of the additional considerations arising against the background of perishable goods include:

- level of safety inventory held, as a higher inventory will necessarily add to the average age of the product at the moment of sale and thus lead directly to more expired products
- inventory throughput strategies such as FIFO, FPFO, FDFO, SIRO or LIFO have a strong influence on the quantity of goods being rendered obsolete
- customised product expiration schedules to define the strategy at what point of time or what place it is sensible to take a product out of the flow of goods
- frequency and place of expiration control such as manufacturer storage, DC or retailer-shelf determine the timeliness of expiry/product flow information that feed back into the distribution and production forecasts

Apart from addressing and clarifying the above issues the investigation within this chapter will also focus on the impact of various levels of demand transparency as a result of increased collaboration between the certain echelons of the supply chain.

9.2 The investigation framework

As means of investigation we use the same simulation model as within the previous analyses after adjusting numerous parameters to fit the investigation background. The two investigated products originate from two of the manufacturers introduced earlier. The products in particular were fresh pasta taken from the product assortment of the manufacturer of supply chain framework 2, and a special salad dressing originating from the manufacturer of supply chain framework 3. Altogether incorporated demand, sales, distribution and production data are considerably different from the products investigated earlier.

9.2.1 The default distribution scenarios

Product 1

The first product under investigation (fresh pasta) recorded a typical service level gap at store level of 8%. According to various internal sources about one third of that was due to inefficient store-ordering which will not be part of the considerations within the following analysis since it cannot reasonably be accounted for in the simulation model. The amount of obsolete products due to expired shelf life was recorded at about 7% of the total production. Inventories were set up on a lean basis to keep product expiry at a minimum. The typical product expiry time after production is 25 days. The inventory control system was set to check for products to be declared expired at manufacturer storage facility and retail outlets. By default there is no expiry check in place at retailers' distribution centre echelon. Altogether products older than 8 days still being at manufacturer's storage were declared expired as well as products 22 days or older were taken out of shelves/storage at retail outlets. Within the initial scenario it was recorded that due to this schedule about 96% of the total waste occurs at store level whilst 4% of products are taken out of the distribution flow before they even leave the manufacturer due to risk of premature expiry. The average distribution interval between manufacturer and retailers' DCs is set to 5 days in case of customers 1 and 2 and to 9 days in case of customers 3 and 4 as this represents the actual replenishment procedure.

Product 2

The second product under consideration (salad dressing) experienced average out of stock times responsible for approximately 10% of lost sales within the investigated period. Here too, inefficient store ordering for perishable goods is considered to account for at least one third of this figure. The amount of obsolete products equals about 8% of total production. Inventory levels for the product are considered rather low compared to non-perishable products which does not come as a surprise since expiries are sought to be kept at a minimum. The product is set to expire three weeks (21 days) after production. This is a figure set in cooperation with health authorities and assumes proper handling throughout transportation and storage since the cooling chain must not be interrupted. Overall there are expiry control checks before the items enter the manufacturer's loading facility, throughout storage time at retailers' distribution centres and finally at retail outlets. Following that scheme, products older than 7 days still being at manufacturer's storage were declared expired as well as products being 16 or 20 days or older were taken out of storage/shelves at distribution centres and retail outlets respectively. Due to this schedule about 85% of the total waste occurs at store level, 10% are declared obsolete at the distribution centres whilst 5% of the overall expired products are taken out of the distribution flow before they even leave the manufacturer.

Common Characteristics

The default inventory throughput policy at both manufacturers' storage could be best described as FIFO on a production-day basis meaning products were moved out of inventory and shipped according to their day of production stamp. At the retailers' distribution centres products are mainly dispatched according to their date of arrival at the DC storage facilities (FDFO-first delivered first out). Hence the actual date of production seems to have no crucial importance for the DC transhipment flow. At the retail outlets however there is no definite strategy applicable since the actual process of product arrival to final departure (sale) cannot be considered as standardised. Generally, perishable products are supposed to be put on the shelves according to date of production (the older the sooner) and within the shelves frequent repacking should aim to put older products to the front and fresher ones to the back. Altogether the targeted system is meant to operate a FPFO (first produced first out) policy. According to various interviews and observations this seems to be rather wishful thinking. Within the framework of investigation, reality at store level can be rather seen as a random dispatch thus the likelihood of a product being sold is almost independent of the production date once the products have reached the retail outlets. This seems to be typical for the investigated group of refrigerated mid-term perishable goods (20-30 days expiry time). Since separate product items do no have an individual bar-code no detailed information about the actual age of products at the moment of sale is recorded in the retailer's SIDB (sales information database). Thus actual product throughput assumptions had to be made according to recorded expiry quantities, personal observations and store manager expertise. Altogether leading outlets can be considered to have an overall throughput equivalent to a FDFS (first delivered first sold) policy meaning products passing through according to their date of arrival at the retail outlet.
This above transhipment system can be seen as a possible standard scenario for a sales framework of perishable goods. However it shows various possibilities for alteration and improvement and is certainly different for other kinds of perishable products. The actual research originated from a strong motivation of the participating companies to improve their supply chain performance figures. Particular goals were substantially diminishing the service level gap below 2% whilst keeping the percentage of expired products constant or preferably reduce them.

In order to approach the problem we identified three possible ways to tackle the actual shortcomings:

1. Adjustment of the existing ROP system, featuring an increase in average inventory held by the manufacturer, improved inventory control schemes, shorter delivery intervals and adjusted order prioritisation policies
2. Improvement of inventory dispatch policies and thus throughput efficiency throughout transhipment of goods on the way from production to moment of sale
3. Introduction of a collaborative planning forecasting and replenishment system, thus data exchange and cooperation amongst retailer and manufacturer.

Since particularly supply chain wide introduction of collaboration is a rather unrealistic issue as it was laid out before, we will further investigate particular efficiency advances if only a limited number of customers participate in the system.

9.2.2 Investigated scenarios

Various scenarios were investigated in order to improve the initial situation and give recommendations how best to reach the set efficiency goals. Following the above outline, these scenarios can be distinguished into three groups:

1. Performance improvement via increased average inventory held: Here the average inventory and thus safety inventory at the manufacturer's storage facilities is increased to a certain degree. The goal is to improve mainly service-level ahead of other performance metrics.

2. Performance improvement through advanced product throughput efficiency: Here various product forwarding strategies within several echelons of the supply chain are evaluated. This includes: introducing expiry checks at DC level, altered product handling strategies like FPFO (first produced first out), FDFO (first delivered first out), SIRO (dispatch is independent of time of production or delivery) or adjusted expiry schedules. Apart from that the impact of adjusted order prioritisation policies and reduced delivery intervals is investigated.

3. The third group of possible improvement scenarios evolve around introducing collaborative production planning and replenishment systems. Here the various echelons of the supply chain (manufacturer, retailer-DC and retail outlets) share information about actual and expected demand, promotion schedules, inventory stocks and replenishment schemes. This information is used to create common demand forecasts that drive production and delivery.

9.2.3 Performance measures

To evaluate the various combinations of the above identified settings and scenarios we use several performance measures that aim to give an impression of particular aspects of the achieved supply-chain performance. Performance metrics are taken from the range defined in Chapter 4. They are grouped into three clusters: *Global measures* including service level, percentage of expired products and product age at sale. *Delivery accuracy metrics* cover supply between manufacturer and retailers' distribution centres and between retailers' distribution centres and retail outlets. Finally *individual metrics* state the particular outcome for individual customers.

9.3 Investigation outcomes – Product 1

In the following two sections we initially investigate both supply chain frameworks separately and ultimately draw conclusions based on both products and supply chain environments. Each investigation starts by evaluating the influence of increasing inventory held by the manufacturer within non-collaboration and CPFR replenishment environments. This part defines and assesses potential improvement scenarios incorporating inventory adjustments and partial or full collaboration.

The second part of each framework investigation evaluates changes in distribution layout, delivery prioritization or inventory dispatch policies. This includes adjustments of replenishment setup and delivery prioritization rules, modification of supply chain wide inventory dispatch policies and readjusting expiration schedules and control schemes. Finally, we present a choice of recommended improvement scenarios that are based on the results from the previous investigation.

9.3.1 The influence of increasing inventory levels

We start the discussion of the investigation results with evaluating the impact of gradually increasing the inventory level at the manufacturers' ready made goods storage facility. In particular we state the outcome of key performance indicators at numerous inventory levels starting from 90% of the default inventory level and increasing up to 200%.
The first graph shows the outcome of service level gap (unsatisfied demand) and the percentage of expired products depending on various inventory level scenarios. Altogether there are 8 different scenarios starting from 90% of the default inventory level up to 208%. The default scenario is represented by the second out of the 8 scenarios. The diagram has two axes which account for service level gap and expired products on the left side (ranging from 0% to 18%) and for the inventory level on the right side (ranging from 0% to 250%).
The layout of the graphs is somewhat unusual but was chosen in that way to better visualise the correlation between the selected key performance indicators and inventory levels that increase in a not strictly linear manner. This is due to restrictions arising from practical issues within simulation modelling. Considering the random nature of simulation, the actual outcome of the targeted inventory level cannot be exactly predetermined but only estimated according to certain parameter settings. Due to extensive trial length (20 repetitions for reasons of sufficient confidence limits) and simulation run times (5 minutes per run) it is hardly possible to re-run a scenario a number of times to reach an exact inventory target. Practically it is most reasonable to test the parameter setting of a scenario within a few trial runs and finally set out the full trial run which often results in an inventory level within close proximity of the target. The design of the graphs is also consistent with later investigations that combine numerous performance metrics within a single diagram. Since most of the scenarios include performance measures with typically high values (60%-100%) as well as low values (1% -10%), a dual scale diagram allows comparing them in a single chart instead of two.
All the following diagrams assume a roughly linear increase of inventory from the left to the right. The exact inventory level is indicated by the yellow line.

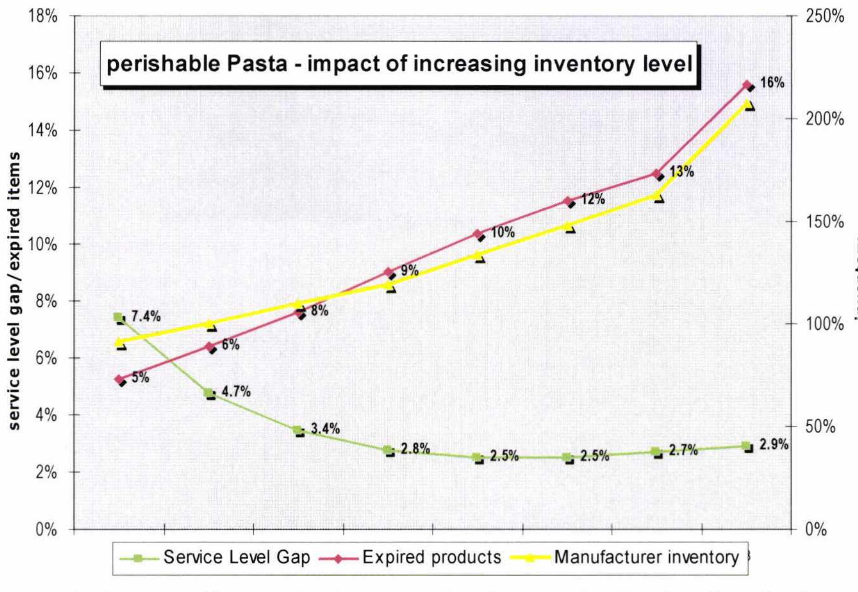


Figure 9.1: Impact of increasing inventory level on service level and expired products

As we can see from the Figure 9.1, the number of expired items grows at almost the exact degree as the inventory is increased. Within lower inventory levels expired items even outgrow the increasing inventory. Service level gaps on the other hand substantially shrink as ready made goods inventory held by the manufacturer is increased. This improvement comes to an early halt since the lowest figure is already achieved by increasing inventory by 30%. Beyond this point, service level gaps start even to increase again which is most likely due to steadily increasing expired items. When inventory level is increased the average age of products in the system is increased which leads subsequently to earlier and more frequent expiries. This is a typical problem within a perishable goods environment and is the main reason why such environments have to be considered differently compared to non-perishable products.

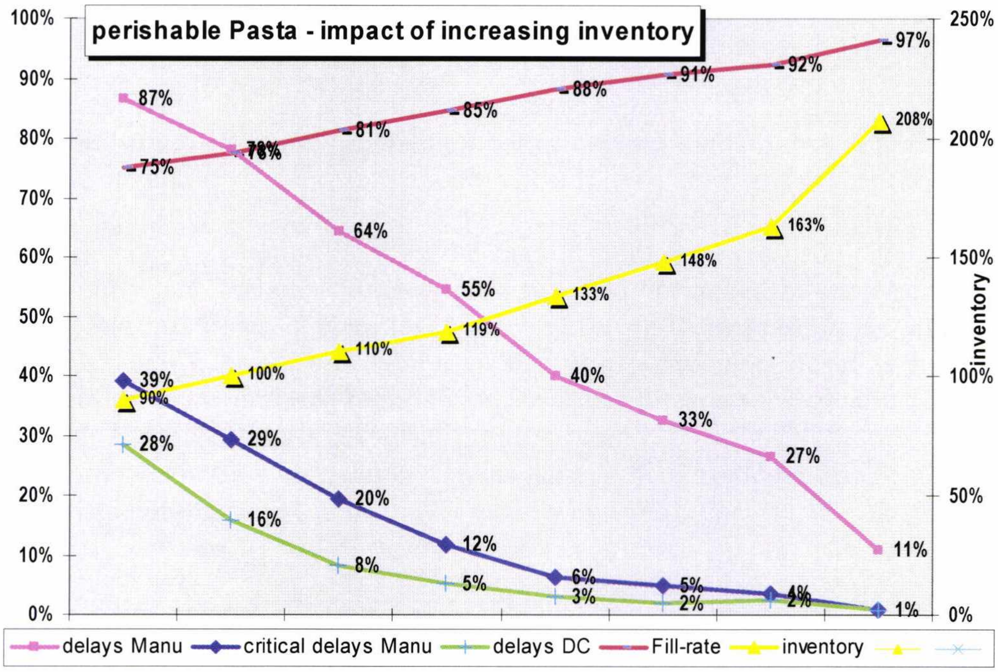


Figure 9.2: Impact of increasing inventory level on fill-rate and delivery delays

Figure 9.2 shows the impact of increased inventory towards various other key performance metrics. Contrary to the previous graph we can observe only positive developments here. Altogether there seems to be a strong positive correlation between increased inventory level and improved performance regarding delayed deliveries and fill-rates. Overall there is still the problem which level of inventory can be considered optimal since increased inventory has various negative implications as well considering increased expired items, holding cost or storage facility limits. Looking at the graph we can state that the most significant improvements are achieved for increases up to +33% over the default level. Beyond this stage there are still improvements visible but they are not as remarkable compared to earlier stages.

Within a second step we will introduce the performance outcome after the implementation of collaborative replenishment (CPFR case). The following diagrams will thus feature the same levels of inventory increases as before but present the outcome of several performance measures within an all customer CPFR system.

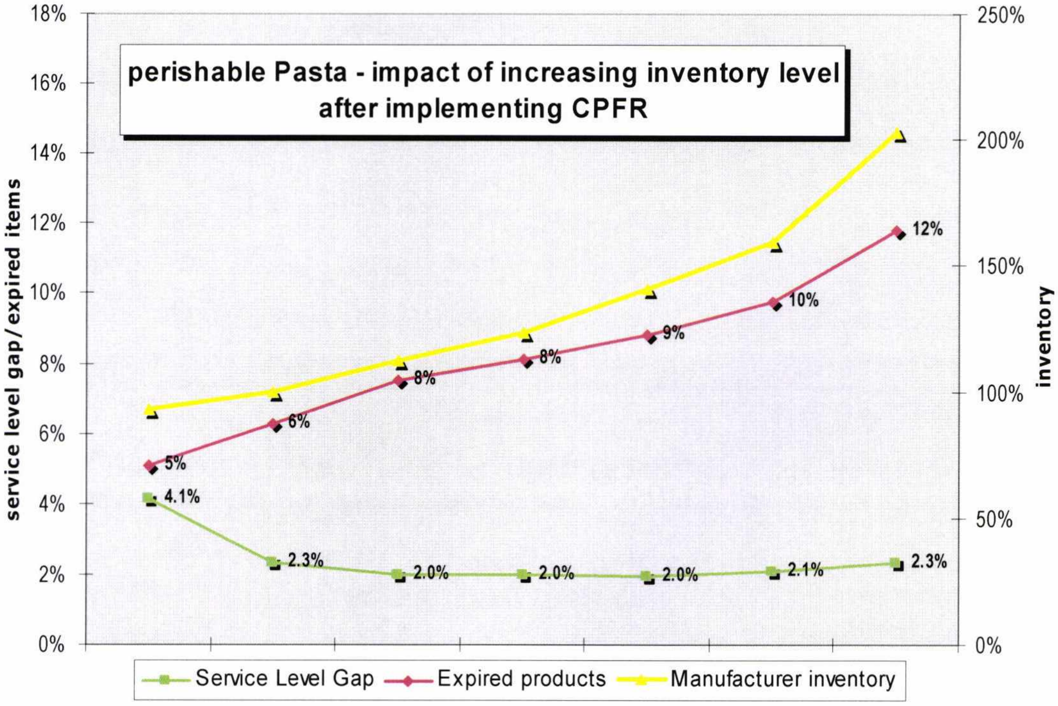


Figure 9.3: Impact of increasing inventory level on service level and expired products after introducing CPFR

We see from Figure 9.3 that expired items are somewhat reduced compared to the non-collaborative replenishment case. Nevertheless, expired products very much increase linearly with the inventory whilst service level gap shows the typical pattern of initial decrease which is followed by an optimal middle phase and finally by increasing gaps once the inventory increases beyond a certain stage.

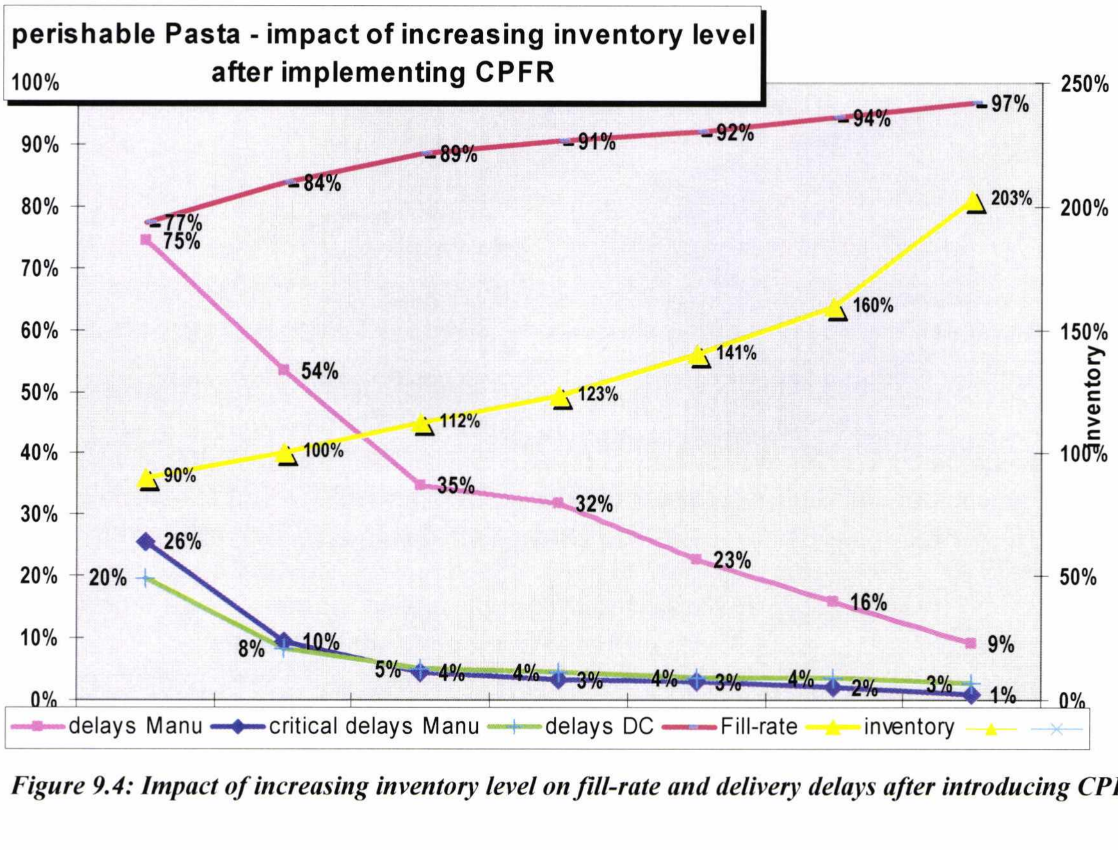


Figure 9.4: Impact of increasing inventory level on fill-rate and delivery delays after introducing CPFR

When we look at the other key performance metrics, we see a similar picture to the non-collaborative replenishment case whereas all figures improve continuously whilst inventory is expanded. However, the outcome at a particular stage is much improved compared to the previous case and major improvements are achieved with smaller inventory increases necessary. We can see from Figure 9.4 that an increase by as little as 12% additional inventory would remarkably improve performance metrics far beyond the 33% additional inventory recommendation within the non-collaborative case above.

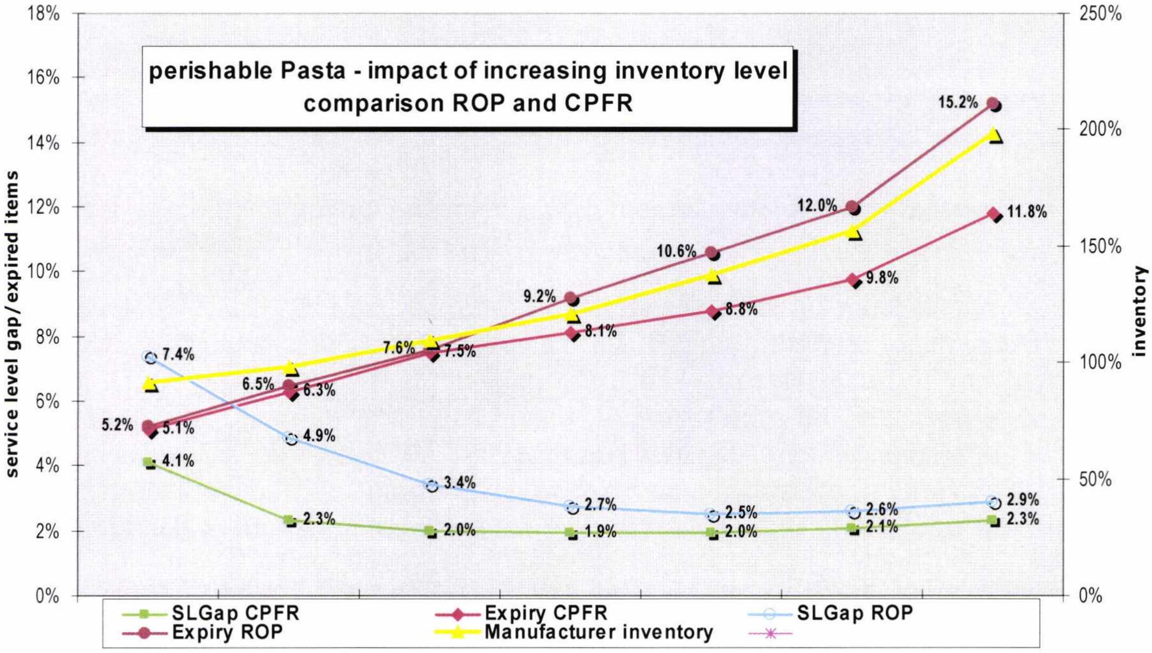


Figure 9.5: Cross comparison ROP and CPFR

Finally, we directly compare service level and expiry figures between collaborative and non-collaborative cases. We can clearly see that collaboration leads to an improved outcome independent of the considered inventory level. Considering the gap between both service level lines it seems that CPFR is more superior the lower the inventory level gets. On the other hand that also means that the advantage of collaboration decreases as inventory levels rise. Another interesting point is moreover, that the gap between both expiry lines diminishes initially and widens again as the held inventory expands. Within high inventory cases we can thus state a clear advantage for collaborative replenishment that leads to significantly less expired items compared to non-collaborative distribution.
Overall, all extended inventory cases seem to perform very well considering service level and delivery reliability metrics. Expanding the safety inventory to some extent also seems to be the only way to substantially bring down delivery delays but in turn increases the amount of expired products. This reveals the difficult nature of a perishable goods framework since a perfect solution does not seem to exist. One either has to decide for lower expiry figures or more reliable delivery, given the fact that production capacity extension or more frequent deliveries may not be feasible for the time being.

Scenario Result Overview – Collaboration and non-collaboration improvement scenarios

Table 9.1 presents a wide range of key performance indicators for selected improvement scenarios within supply chain framework 1. The parameter combinations of the presented scenarios were chosen according to promising improvements indicated during the preliminary investigations and also to give a wide range of choices to the companies.

		Default ROP	ROP +10%inv	ROP +33%inv	CPFR all	CPFR +10%inv	CPFR C2 only	CPFR C1&2	CPFR C2&3	CPFR C3&4
Misc. global	Manufacturer Inventory	**100%**	**110%**	**133%**	**100%**	**110%**	**100%**	**100%**	**100%**	**100%**
	Combined DC Inventory	100%	122%	155%	113%	131%	116%	129%	121%	107%
	Combined Retail Inventory	100%	104%	108%	107%	109%	105%	107%	107%	105%
	Combined SL gap	**4.7%**	**3.4%**	**2.5%**	**2.3%**	**2.0%**	**3.1%**	**2.4%**	**2.6%**	**3.5%**
	largest overall SL gap	43%	40%	42%	42%	44%	61%	59%	65%	46%
	Order lead-time	2.4	1.8	0.9	1.2	0.7	2.0	1.5	1.2	1.1
	% of expired products	7%	8%	10%	6%	8%	7%	8%	7%	6%
Delivery	Overall DC deliveries	100%	98%	93%	92%	93%	100%	97%	102%	114%
	Delayed by Manufacturer	**78%**	**64%**	**40%**	**50%**	**35%**	**64%**	**51%**	**51%**	**50%**
	Critical delayed by Manuf	**29%**	**20%**	**6%**	**9%**	**4%**	**19%**	**10%**	**9%**	**13%**
	Overall Fill-rate	78%	81%	88%	85%	89%	82%	84%	85%	82%
	Overall delayed by DCs	16%	8%	3%	8%	5%	11%	6%	7%	9%
Individual	SL Gap C1	5%	3%	2%	2%	1%	5%	1%	4%	4%
	SL Gap C2	6%	4%	2%	2%	2%	1%	2%	1%	4%
	SL Gap C3	3%	3%	4%	4%	3%	3%	4%	2%	2%
	SL Gap C4	3%	4%	4%	3%	3%	4%	6%	5%	2%
	critical delayed C1	26%	17%	6%	5%	2%	23%	3%	16%	21%
	critical delayed C2	28%	17%	5%	6%	3%	2%	3%	2%	23%
	critical delayed C3	35%	23%	7%	19%	9%	35%	26%	4%	1%
	critical delayed C4	33%	25%	9%	14%	5%	27%	20%	15%	1%
	Expired products C1	4%	5%	7%	5%	6%	4%	5%	5%	5%
	Expired products C2	4%	5%	6%	5%	6%	5%	5%	5%	4%
	Expired products C3	12%	14%	21%	9%	11%	13%	15%	9%	9%
	Expired products C4	14%	17%	23%	11%	13%	17%	18%	19%	11%

Table 9.1: Range of possible improvement scenarios for Product 1

The first group of presented scenarios is opened by the standard ROP setting that represents more or less the default situation of supply chain framework 1. Furthermore, several improvement cases are displayed that are either based on altered inventory levels or partial/full-scope engagement in collaboration. The referred inventory levels represent the average stock level at the manufacturer echelon. Apparently it is possible to tackle the previously outlined areas of necessary improvement by a variety of adjustments.

1. Increasing inventory held by manufacturer. This action would certainly lead to improved service level but comes with a number of side effects. In case the inventory is increased by just 10%, service level and delivery performance improve moderately whilst inventory holding cost by manufacturer and distribution centre as well as expired products increase. This outcome is even amplified within the 33% additional inventory case. Here, service level and delivery performance are very satisfactory but at the price of doubling the percentage of expired products and increasing inventory holding cost remarkably. Consequently, there is no need for investigating cases with even higher inventory levels since increasing negative side-effects will overcompensate diminishing improvements.

2. Engaging in a full-scale collaborative replenishment system with all customers. This seems to be a much more sophisticated solution to tackle the extensive service level gap problem. Here the low service level target can be reached whilst inventory and expired products remain the same. Most other crucial performance metrics such as largest service level gap or critical delivery delays are much improved as well within this approach. Apart from the additional cost of putting a collaborative replenishment system in place and maintaining it there seem to be no negative side-effects.

Even further improved key performance measures can be obtained by combining full scale collaboration with a minor increase of inventory held. This however comes at the price of more expired products and extended inventory holding cost.

3. Partial collaboration. The previous cases revealed already the overall great potential of a collaborative replenishment system. However, since the necessary supply chain wide introduction of collaboration is often a rather unrealistic assumption due to various reasons laid out earlier we investigated – apart from full scale CPFR implementation – possible efficiency advances in case only a limited number of customers joined the system. The last four columns in Table 9.1 represent various combinations of customers engaged in collaborative replenishment, including a single one (C2) and various two out of four customers sets thereafter. We see from the results that even a partial collaborative replenishment can lead to a major improvement of overall performance. Individual outcome depends on the particular customers that are involved in a collaborative replenishment. If only a single customer is engaged the impact varies from negligible to very substantial depending on the importance of that customer. The table states the outcome for the case of the largest customer C2 being engaged in collaborative replenishment. As we can see, C2's involvement would lead to major improvements among all performance measures. Due to their limited size, the other three customers were not considered for sole implementation since the outcome seemed to be less encouraging. Furthermore three cases with two collaborative customer are stated of which the first two featuring C1&C2 or C2&C3 achieve remarkable improvements. The only negative side effect is the somewhat diminished individual figures for the remaining non-collaborating customers as can be seen from the table. However, the global achievements should outweigh such shortcomings by far.

9.3.2 Changes in distribution layout, delivery prioritisation and inventory control and dispatch policies

After having evaluated the impact of increasing inventory and introducing collaboration, we will now have a look at to what extent changes in distribution layout, delivery prioritization, inventory dispatch policies and expiration schedules & control schemes affect the performance of the supply chain system.

Adjustments of replenishment setup and delivery prioritisation rules

Within this group of investigated scenarios we start with aligning the replenishment intervals of all retail customers. By default, two customers (C1 & C2) have average incoming order intervals of five days whilst the other two order and receive delivery every 9 days on average. These order characteristics lead to significant differences in service level, delivery delays and expired products amongst the four customers. Surprisingly the more frequently delivered customers suffer more from these inconsistencies compared to the other two. This is most likely due to the default order fulfilment scheme that operates via a first come first serve approach. Since the more frequently re-supplied customers have to queue twice as often they are overall more likely to run into a severe supply shortage phase. Apart from that they also rely on lower safety stock than the less frequently re-supplied customers which ultimately leads to a somewhat lower service level. On the other hand, the less frequently ordering customers have a much more severe problem with prematurely expired products. The percentage of expired items is on average 3 times as high as amongst the other two customers. Overall Table 9.2 presents several scenarios that could be feasible to improving the somewhat complicated default situation.

The first setting implies aligning delivery frequency of all four customers to the more frequent re-supply being in place for customers 1 and 2. This seems to result in major improvements for all participants and the system overall. Major improvements include service level for customers 1 and 2 as well as fewer expired products for customers 3 and 4.

		Various replenishment setup & prioritisation rules						
		Default	all weekly delivery	random prio	C2 prio	C1&C2 prio	C3&C4 prio	Units/explanation
Misc. global	Manufacturer Inventory	100%	100%	100%	100%	100%	100%	% of default inventory
	Combined DC Inventory	100%	77%	113%	111%	101%	115%	% of default scenario
	Combined SL gap	4.7%	3.9%	5.8%	5.3%	4.9%	5.8%	% of total demand
	typical SL gap	8%	7%	10%	11%	13%	9%	% of week-demand
	largest overall SL gap	43%	33%	76%	93%	100%	55%	% of week-demand
	Order lead-time	2.4	1.9	1.8	2.7	3.1	1.5	days till shipment
	% of expired products	7%	5%	8%	7%	6%	8%	% of total production
Delivery	Overall DC deliveries	100%	127%	98%	97%	99%	97%	% of anticipated no of tours
	Delayed by Manufacturer	78%	69%	61%	69%	78%	58%	% of deliveries
	Critical delayed by Manuf	29%	20%	19%	27%	24%	19%	% of deliveries delayed >2days
	Overall Fill-rate	78%	80%	80%	79%	77%	80%	% of ordered quantity
	Overall delayed by DCs	16%	12%	14%	20%	18%	16%	% of DC deliveries
Individual	SL Gap C1	5%	3%	4%	13%	2%	5%	% of total demand
	SL Gap C2	6%	4%	8%	1%	2%	8%	% of total demand
	SL Gap C3	2%	4%	5%	5%	11%	3%	% of total demand
	SL Gap C4	3%	4%	4%	5%	12%	4%	% of total demand
	critical delayed C1	26%	18%	11%	37%	13%	27%	% of deliveries by manufacturer
	critical delayed C2	28%	17%	29%	1%	12%	32%	% of deliveries by manufacturer
	critical delayed C3	35%	22%	25%	49%	51%	3%	% of deliveries by manufacturer
	critical delayed C4	33%	24%	10%	43%	47%	1%	% of deliveries by manufacturer
	Expired products C1	4%	5%	5%	3%	5%	4%	% of total shipped
	Expired products C2	4%	4%	4%	6%	5%	3%	% of total shipped
	Expired products C3	12%	5%	14%	11%	10%	16%	% of total shipped
	Expired products C4	14%	5%	18%	13%	12%	19%	% of total shipped

Table 9.2: Selected scenarios with various replenishment setups and prioritisation rules

Within the second evaluated scenario we change the prioritization of incoming orders that have to cope with limited available products towards a random approach. Thus order fulfilment is independent of waiting time, urgency, customer's importance, etc. The only positive effect of this are reduced delivery delays experienced by the smaller customers (C1, C3 and C4) at the cost of the single large customer 2. This is due to the large quantity orders placed by this retailer which do not obtain any priority anymore and since experienced waiting time is not a considered issue anymore replenishment urgency is disregarded as well. Overall this is not a recommendable strategy as can be seen be the diminished service level and expired products figures.

To tackle the obvious shortcomings of the major customer 2, which accounts for about 45% of overall turnover, scenario 3 evaluates the case where this customer receives priority treatment. As expected, all performance indicators apart from the number of expired products, vastly improve for this single customer whilst all other customers suffer. Overall this strategy might not be uncommon in practice but cannot be recommended for efficient supply chain replenishment.

The final two scenarios cover the cases where either two customers are prioritised from the remaining two. This obviously results in either improved or decreased performance for either one of them depending on the priority setting. The important finding out of the above considerations is that all proposed prioritisation adjustments are insufficient and inferior to the default setting on a global basis. It would thus certainly be worth switching the replenishment intervals of C3 and C4 to the more frequent setup but the overall first come-first served order fulfilment strategy should not be altered.

Modification of supply chain inventory dispatch policies

This part of the analysis evaluates various changes within the inventory handling policies applied at certain stages of the supply chain. The experienced default strategies were FIFO at a daily basis at manufacturer's inventory facility, FDFO (First delivered-first out) policy at most distribution centres and a rather random throughput at the majority of retail outlets. From the following tables we can clearly see the effect various inventory dispatch alterations result in.

Possible improvement approaches

		Default ROP	Manuf FPFO	DCs FPFO	Retail FDFO	Retail FPFO	CPFR+ Retail FPFO
Misc.	Combined SL gap	**4.7%**	**4.8%**	**4.8%**	**2.4%**	**2.5%**	**0.9%**
	Order lead-time in days	2.4	2.4	2.3	1.8	1.9	1.4
	% of expired products	**6.5%**	**6.4%**	**6.3%**	**3.3%**	**3.2%**	**1.3%**
	Product age at POS in days	10.9	10.9	11.1	13.0	13.0	13.1
Delivery	Delayed by Manufacturer	**78%**	**77%**	**76%**	**65%**	**66%**	**49%**
	Critical delayed by Manuf	**29%**	**30%**	**27%**	**21%**	**20%**	**9%**
	Overall Fill-rate	78%	78%	78%	81%	81%	84%
	Overall delayed by DCs	16%	17%	15%	10%	11%	8%

Table 9.3: Various alternative dispatch scenarios I

Amongst the stated improvement scenarios, the first implies changing the first produced-first out dispatch policy at the manufacturer's storage facility from a daily based to an hourly based system. Thus products are loaded not just according to their day of production stamp but also according to the hour of production. Overall this does not seem to result in any noticeable improvement.

The second suggested scenario implies changing the dispatch process at the retailers' distribution centres from a first delivered-first out to a first produced-first out system. As a result of this, products are shipped in order of their production data and not just according to the delivery they arrived with. Once again this policy does not result in any significant improvements.

Things become certainly more interesting when looking at the adjustments at retail outlet level. As already mentioned earlier the actual reality within stores was found to be modelled best by a random approach that suggested the likelihood of a product being sold to be almost independent of the production date or the date of arrival at the outlet. If it was possible via e.g. further staff training (frequent repacking, effective reallocation between in-store storage and sales-shelf stock) or technological advances (RFID) to move the actual throughput scheme more towards a FDFO (first delivered-first out) or even FPFO (first produced-first out) policy, substantial improvements would be possible regarding service level as well as amount of expired products. Sound product handling would result in vastly reduced expired products and significantly improved service level as can be seen from the above table but is nevertheless really difficult to accomplish. Even if inventory at stores was handled in that way we can see that there would still be a substantial amount of expired items. The reason for this is inadequate production and delivery planning which can be remedied by introducing collaborative replenishment as we can see from the final improvement scenario. Combining advanced inventory dispatching and CPFR would lead to virtually no service level gap or expired products whatsoever.

Further possible dispatch scenarios

		Default ROP	Manuf LIFO	Manuf SIRO	DCs LIFO	DCs SIRO	Retailer LIFO	All LIFO	All SIRO
Misc.	Combined SL gap	4.7%	7.4%	6.6%	6.1%	6.1%	6.5%	8.9%	8.0%
	Order lead-time in days	2.4	2.9	2.8	2.6	2.7	2.4	3.0	3.0
	% of expired products	6.5%	9.3%	8.4%	7.8%	7.6%	8.0%	10.9%	9.8%
	Product age at POS in days	10.9	9.9	10.2	9.5	9.7	10.4	8.8	9.0
Delivery	Delayed by Manufacturer	78%	84%	82%	80%	82%	79%	85%	84%
	Critical delayed by Manuf	29%	41%	39%	35%	35%	29%	43%	44%
	Overall Fill-rate	78%	75%	76%	77%	76%	77%	75%	75%
	Overall delayed by DCs	16%	30%	26%	24%	26%	18%	37%	35%

Table 9.4: Various alternative dispatch scenarios II

The scenarios stated in Table 9.4 should by no means be understood as proposed improvement settings but as case studies for possible shortcomings within inventory dispatching. Alterations include dispatching inventory either on a random basis (SIRO) or even worse, a last in-first out policy. Although such policies should not be in operation in any even moderately developed logistic system, it might be of interest to see their actual impact on the system. The results do not come as a surprise as any considered case leads to severe shortcomings with performance records falling far behind the outcome of the default system setup.

9.3.3 Readjusting expiration schedules & control schemes – sensitivity analysis

Within this section we investigate how sensitively the system reacts to changes within the expiry time schedule. To analyse this matter we adjust the default expiry timings at various stages of the supply chain. By default, items are taken out of the flow of goods and being declared expired if they are older than 8 days and have not left the manufacturer's storage facility and are taken out of shelves if they are older than 22 days at the retail outlets. By default there is no expiration check carried out at the retailers' distribution centres but the possible benefit from that will be evaluated later on. This default setting leads to about 6.4% of total produced items to be declared obsolete due to premature expiry. From these items 3% are taken out of the flow of goods by the manufacturer and 97% at the retail outlets.

Sensitivity analysis expiry at manufacturer's storage facility

Here we investigated the impact on the system if the original 8 days age limit that determined expiry at this supply chain echelon was altered to be in between 4 and 10 days.

The maximum age limit set by the manufacturer to declare products as prematurely expired before they are shipped does not seem to influence the overall system performance significantly. If this limit was set to 10 days there would be no products taken out at the manufacturer echelon whatsoever. This changes as we reduce this maximum age limit towards 4 days. Since taking more and more products out of the flow at this stage does not seem to have any positive impact on the overall performance of the system it is rather questionable if expiry control should be carried out by the manufacturer at all. The only reason to do so would be preventing items that are most likely to expire later on in the supply chain due to their late shipment time from being unnecessary dispatched and transported. A possible strategy could thus be to set the maximum age limit to 5 days as this would only have a minor impact on key performance metrics but would mean that 12% of overall surely to expire products could be taken out of the flow of goods straight away before even shipping them to customers.

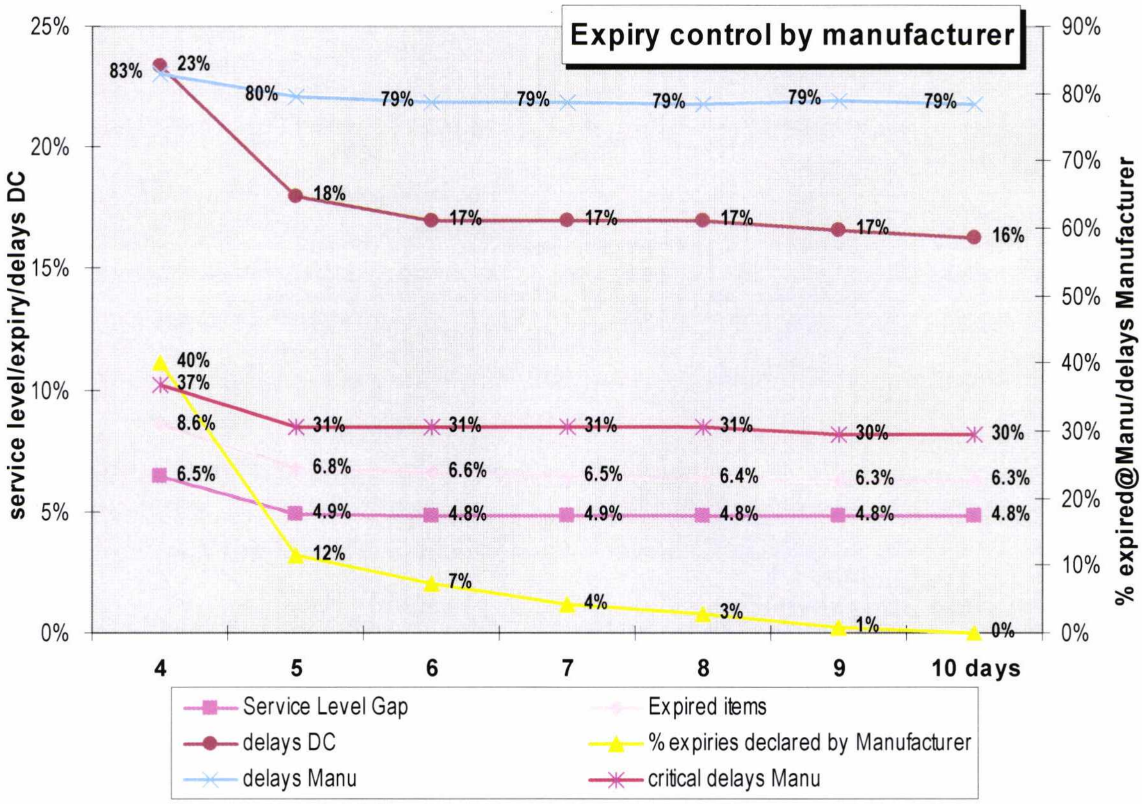


Figure 9.6: Impact of different expiry age limit at manufacturer's storage

Another outcome of this analysis is the fact that instating an expiry control at the manufacturer's storage facility with an age limit of 8 days as it is the default setting for the investigated case is pretty much pointless. At this limit only 3% of expiring products are taken out at by the manufacturer which should barely save any cost for unnecessary shipment. On the other hand there seems to be no advantage in service level or overall expiry whatsoever. It has to be mentioned that in reality expiry control by the manufacturer has also the benefit of a quality control check. Although the manufacturer operates a first produced-first shipped policy that was accounted for in the simulation model, in reality there will be most certainly some incidents where this policy is disregarded. An additional expiry control could thus be useful although the absolute terms of the simulation study outcome do not recommend it.

<u>Introducing and adjusting expiry control at retailers' distribution centres</u>

Within this step we are introducing expiry control at retailers' distribution centre in addition to expiry control at manufacturers and retail outlet echelons.
Figure 9.7 shows the major performance indicators for 12 possible scenarios of expiry control at retailers' distribution centres. These scenarios cover various limits of maximum allowed product age according to which items located at DCs are declared obsolete and being taken out of the flow of goods. The cases covered range from 11 to 22 meaning a product is only forwarded if it is younger than e.g. 11 days. The default case of no expiry control at retailers' DCs is best expressed with the case on the right hand side of the graph since an expiry limit (maximum allowed product age) of 22 days virtually has no impact

on the system as only 2% of overall expired products are declared obsolete at retailers' DCs echelons.

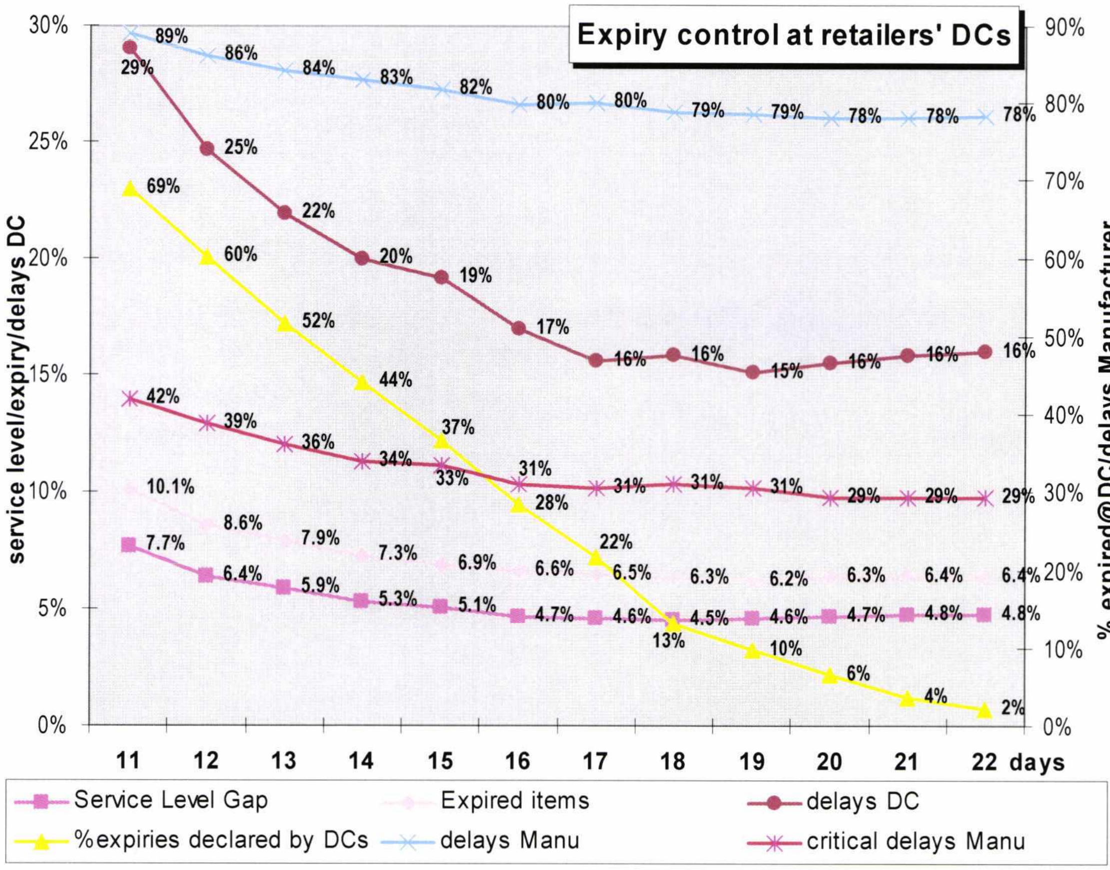


Figure 9.7: Impact of different expiry age limit at retailers' DC storage

When we decrease this age limit, we can see from the yellow line moving towards the left-hand side how the percentage of expired products being declared at this stage of the supply chain increases from virtually none to over 50%. At the same time service level gap and overall expired inventory figures seem to diminish slightly and increase with lowering expiry age limits. Interestingly the minimum service level gap is recorded for DC expiry control age limit set to 18 days whilst the minimum expired items altogether occur for a limit of 19 days. Even though the improvements are not too substantial compared to the performance figures if no expiry control was put in place at retailers' DCs altogether, performance can be improved to some extent. The decision which limit to set depends very much on the cost advantages achievable if inventory was declared obsolete earlier and products did thus not have to be transported to the following supply chain echelon unnecessarily. Since low service level gap and expired products will most likely be the overall most valued performance targets, the best choice could probably be to find a certain trade-off point from where on the additional loss of service level or additional expiries do not justify the saved cost from unnecessary shipment. In the above case this could be an expiry limit of 16 days. At this point we would lose only 0.2% of sales and have 0.4% more expired items but about 28% of expired items could already be taken out of the flow of goods at the retailers' distribution centres thus avoiding unnecessary dispatch and transport to retail outlets. If the dispatching costs are rather low a limit of 18 or 19 days would be more appropriate since this would result in the minimum number of expired items and minimum loss of sales.

Sensitivity analysis - final expiry time

Here we investigated the impact on the system if the original 22 days age limit that determined expiry was altered to be in between 20 and 26 days. The current setting has an expiry time of 25 days until the product is not recommended for sale anymore. The typical retailers' policy for this product is to take items out of sale if they have less than 3 days expiry duration. The diagram below thus presents the effect on the system in case

- retailers decide to take perishable products out of sale longer before they expire
- retailers decide to take perishable products out of sale shorter before they expire
- production and transportation improvements allow for an extended shelf life

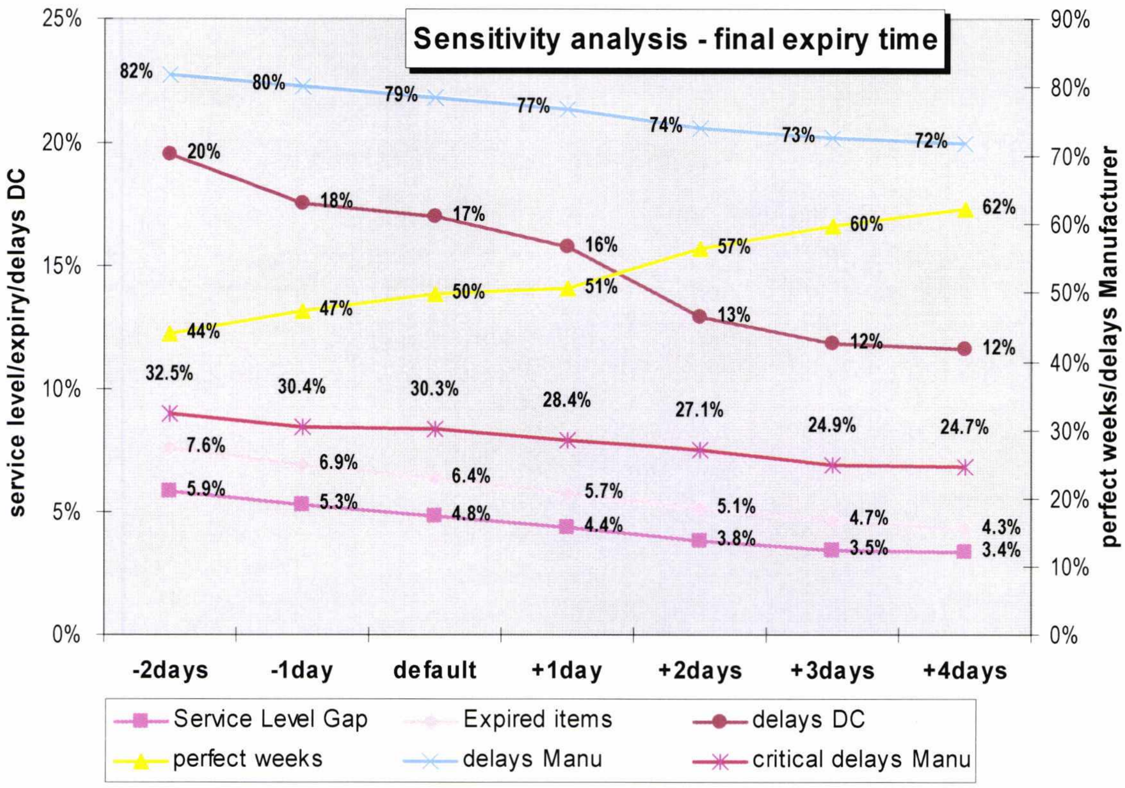


Figure 9.8: Impact of different expiry age limit at retail outlets

We can see clearly that increased shelf-life would have a positive effect on the system since fewer products would have to be taken out of the system prematurely. The outcome should also encourage improving the production or distribution system since an increase in shelf life by e.g. 2 days would lead to 1% additional sales, 4% less critically delayed deliveries or 7% more "perfect weeks" where demand could be fulfilled to 100% in all retail outlets.

9.3.4 Recommended overall improvement settings

Based on the findings of the above investigations we recommended six improvement settings to the manufacturer within supply chain framework 1. These are stated in Table 9.5. The recommended settings are combinations of previously considered factors and evolve mainly around improved throughput at store level, a moderate increase of average inventory held and partial or full introduction of collaborative replenishment. Each of the presented six scenarios has particular strengths and areas of significant improvement compared to the default scenario. Generally an increase in throughput efficiency at store level has to be considered as very important. Since a genuine FPFO process is rather implausible considering real-life practice at retail outlets, the goal needs to be to improve the actual rather random sales practice to achieve at least a FDFO situation. This way of advancement is thus included in each proposed scenario. Apart from that we discontinued the expiry control at manufacturer but introduced expiry control at retailers' distribution centres instead. The maximum age limit for products being declared as obsolete is set to 18 days.

		Default ROP	ROP +10%inv	ROP +35%inv	ROP +35%inv +all SDI	C2 CPFR	all CPFR	all CPFR +10%inv +all SDI
Misc. global	Manufacturer Inventory	**100%**	**110%**	**135%**	**135%**	**100%**	**100%**	**110%**
	Combined DC Inventory	100%	122%	158%	119%	122%	109%	111%
	Combined Retail Inventory	100%	108%	113%	113%	108%	110%	112%
	Combined SL gap	**4.7%**	**2.0%**	**1.0%**	**0.5%**	**1.7%**	**1.1%**	**0.7%**
	Perfect supply weeks	50%	78%	81%	90%	80%	85%	91%
	Order lead-time	2.4	1.8	0.7	0.8	1.8	1.7	0.8
	% of expired products	**7%**	**4.2%**	**7.4%**	**2.3%**	**3.9%**	**1.7%**	**0.9%**
	% expired at DCs	0%	51%	52%	25%	46%	34%	33%
	% expired at retail outlets	98%	49%	48%	75%	54%	66%	66%
Delivery	Overall DC deliveries	100%	96%	91%	113%	90%	86%	104%
	Delayed by Manufacturer	**78%**	**67%**	**36%**	**34%**	**62%**	**61%**	**38%**
	Critical delayed by Manuf	**29%**	**19%**	**5%**	**5%**	**18%**	**13%**	**6%**
	Overall Fill-rate	78%	81%	90%	90%	82%	82%	88%
	Overall delayed by DCs	**16%**	**9%**	**3%**	**4%**	**10%**	**10%**	**5%**
Individual	SL Gap C1	5%	2%	0%	0%	4%	1%	1%
	SL Gap C2	6%	2%	0%	0%	0%	1%	1%
	SL Gap C3	3%	1%	2%	1%	1%	2%	1%
	SL Gap C4	3%	2%	3%	1%	2%	2%	1%
	critical delayed deliveries C1	26%	17%	4%	5%	21%	8%	6%
	critical delayed deliveries C2	28%	19%	5%	5%	3%	9%	7%
	critical delayed deliveries C3	35%	24%	7%	6%	30%	26%	6%
	critical delayed deliveries C4	33%	19%	5%	7%	24%	16%	6%
	Expired products C1	4%	1%	1%	2%	0%	0%	1%
	Expired products C2	4%	0%	1%	2%	0%	0%	1%
	Expired products C3	12%	12%	23%	3%	11%	4%	1%
	Expired products C4	14%	16%	27%	2%	15%	7%	2%

Table 9.5: Recommended overall improvement setting for product 1

From the six proposed scenarios, the last three involve introducing collaborative replenishment whilst the first three remain with traditional non-collaborative operation. Apart from the adjustments applied to all improvement scenarios, the first two proposals imply an increase of inventory held by the manufacturer. This leads to significantly improved service level especially for C1 & C2 and improved delivery reliability. Uplifting the inventory to a substantial degree (+35%) nevertheless results apart from the positive issues also in extended inventory holding cost, storage capacity restrictions and expired products. If such issues are not considered to be overly harmful, extending inventory beyond +10% would be a recommendable option. Scenario 3 includes apart from increased inventory also short delivery intervals (SDI) for all four customers. This means delivery intervals of customers 3 and 4 are reduced by about half. This leads to a further improvement of service level and significantly less expired items. The last three scenarios imply the introduction of CPFR replenishment. In setting 4 only the largest customer is engaged. This should reduce implementation and maintenance effort whilst still leading to remarkable improvements of the entire system. Overall, customer 2's performance is most affected which does not come as a surprise but all other customers seem to benefit as well even though they do not contribute to the adjustment. The last two scenarios expand the CPFR framework to all customers which once more results in improved outcome. The supposedly most sophisticated improvement scenario stated in the final column would include improved throughput at retail outlets, inventory control at retailers' DCs, CPFR for all customers, slightly increased inventory and short delivery intervals for all customers. This requires a lot of changes and adjustments to the system but the possible performance improvement compared to the default situation is stunning. If these proposed changes could be put into action there would be virtually no lost sales or expired products whatsoever. Altogether, successful implementation of any one of the proposed schemes should sufficiently cover specified improvement targets set out by management and remarkably advance operational performance supply chain wide.

9.4 Investigation outcome – Product 2

The investigation outline of product 2 follows a similar procedure as within the previous case. As such we first have a look at the influence of increasing inventory levels and partial collaboration. This is followed by a sensitivity analysis of expiration control schemes and an evaluation of the impact of adjusted inventory dispatch policies. Finally we present a number of improvement scenarios that include alteration recommendations on the basis of previous findings.

9.4.1 The influence of increasing inventory level within ROP and CPFR systems

As within the investigation of product 1, we start the analysis with evaluating the influence of the ready made goods inventory held by the manufacturer towards key performance indicators and overall service level and number of expired items in particular. Once again inventory level will gradually increase starting from 85% and reaching ultimately 200% of the default level.

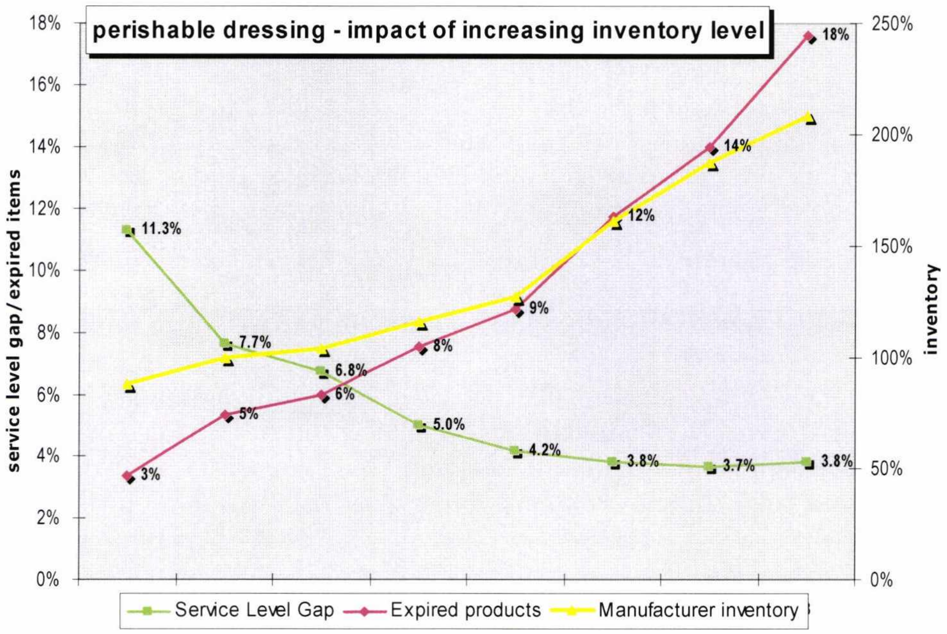


Figure 9.9: Impact of increasing inventory level on service level and expired products

Figure 9.9 shows a somewhat similar outcome to the previously investigated product. Service level diminishes and percentage of expired items increases as inventory level is raised. Somewhat different to the previous case, the degree of expired items seems to react more towards increased inventory than before. This could be due to the shorter overall expiry time. The service level reaches its best result at 187% inventory level and diminishes afterwards due to extensive expiry. Considering the sensitivity of service level towards inventory, the best improvement recommendation seems to be increasing inventory by 10% to 20% since within this range there are substantial improvements possible without having to expand inventory by too much. On the other hand any inventory reduction below the default level should be avoided by any means.

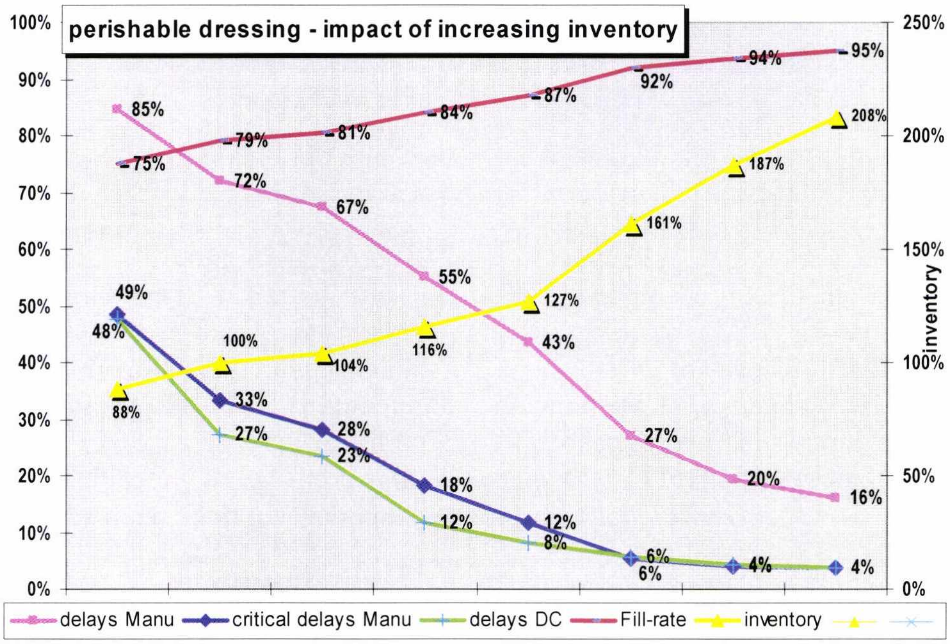


Figure 9.10: Impact of increasing inventory level on fill-rate and delivery delays

From Figure 9.10 we see the positive impact of increasing inventory on various other key performance indicators. Overall there seems to be a steady correlation between inventory and the metrics under investigation. What is more interesting is the ratio of improvement depending on the initial level of inventory held. The step from 88% to 100% level clearly results in vast improvements as well as the step from 100% to 116%. Compared to these, improvements beyond the 150% inventory level do not seem to have the same degree of impact even though the degree of inventory expansion should be fairly similar to the initial steps. Assuming an even more substantial increase in average inventory held at manufacturer's ready made goods storage facility is not possible, it would be most advisable to increase inventory moderately by up to 30%. Any inventory reduction would on the other hand decrease performance substantially so any attempts of further reducing the default inventory level would not be advisable whatsoever.

As outlined earlier, within a second step, we introduce the performance outcome after implementation of collaborative replenishment. The following diagrams will thus feature the same levels of inventory increases as before but state the outcome of several performance measures within a full scope CPFR system.

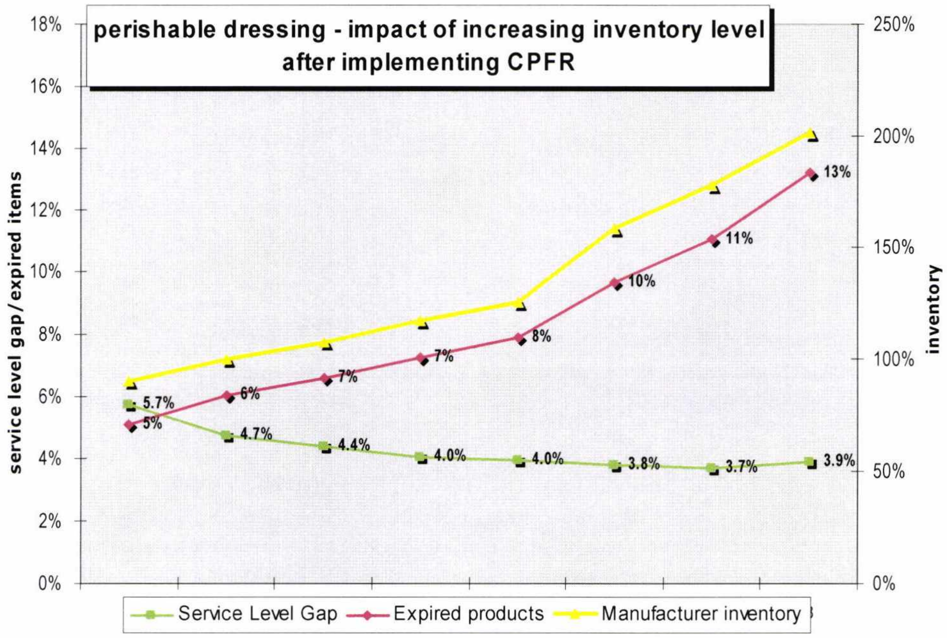


Figure 9.11: Impact of increasing inventory level on service level and expired products after introducing CPFR

When looking at the Figure 9.11 we can see a similar outcome as within the ROP scenario. The percentage of expired items is nevertheless lower and more linearly connected to the inventory level as within the ROP case.

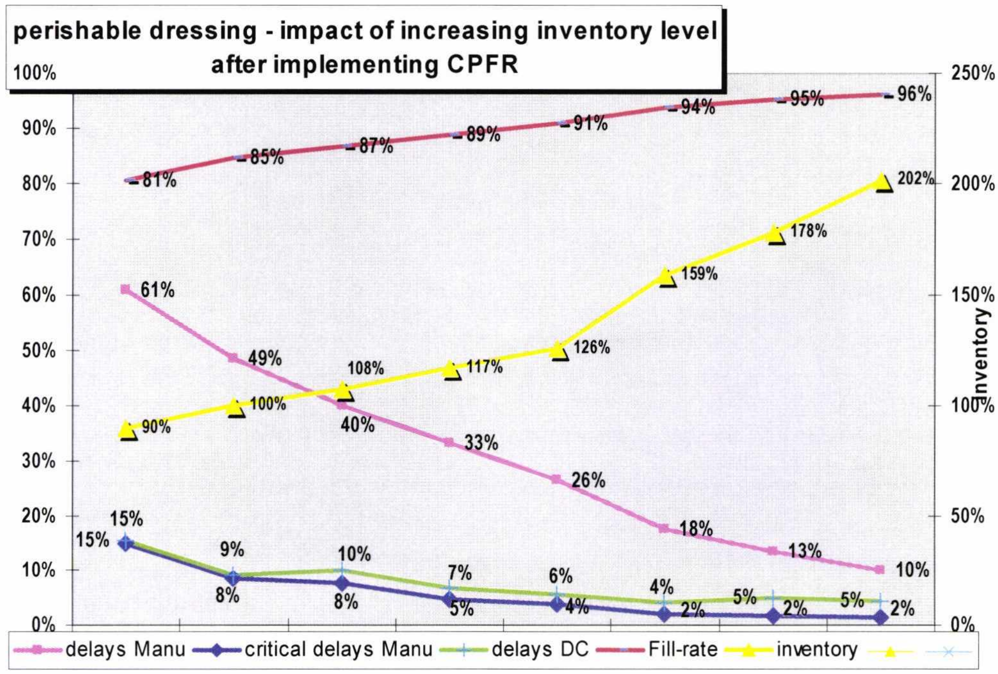


Figure 9.12: Impact of increasing inventory level on fill-rate and delivery delays after introducing CPFR

The other key performance indicators show substantial improvement with increased inventory as it could be expected. A significant difference to the ROP scenarios is the level of inventory that is necessary to reach a substantial improvement. Overall this level is much lower as additional 10-20% of inventory lead to the same level of improvements as to +50% inventory within the non-collaboration framework.

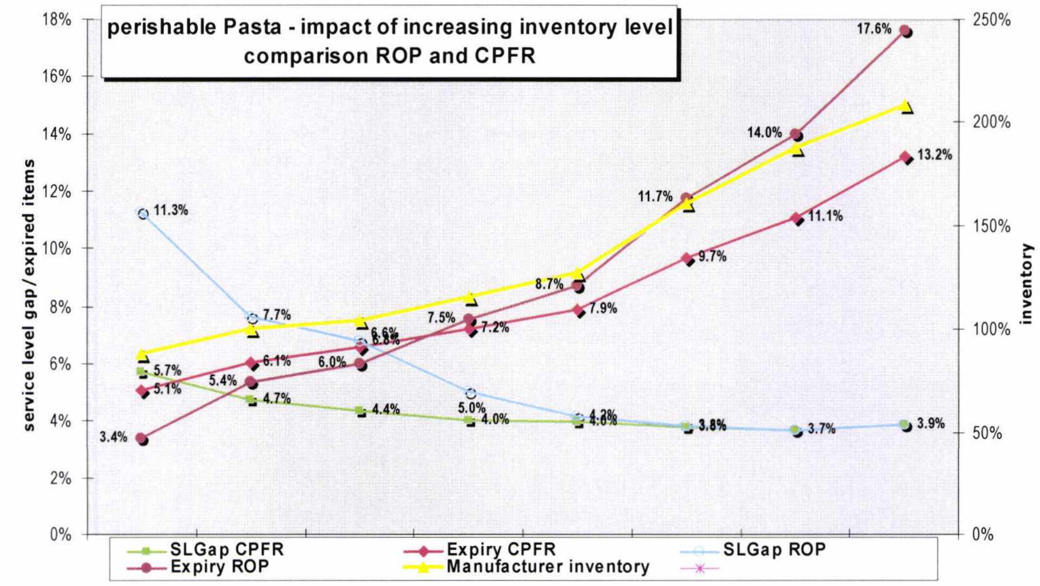


Figure 9.13: Cross comparison ROP and CPFR

Finally we compare key performance metrics outcome of collaboration and non-collaboration contexts. We can see that the ROP environment performs much worse within low inventory cases whilst service level outcomes are virtually the same for both once inventory is raised beyond 25%. The CPFR environment does not seem to substantially benefit from increased inventory. Considering the percentage of expired items CPFR seems to have a significant edge over ROP. This gap seems to widen the more inventory is expanded. Finally, both frameworks reach the best service level outcome at around +80% additional inventory. This would nevertheless come at a much higher price (expired items) in case of ROP than within a collaboration enabled system.

9.4.2 The Impact of partial collaboration

Apart from the performance improvements achieved by changing the entire distribution system from non-collaborative order fulfilment to a collaborative replenishment, we also investigate what impact partial implementation of collaboration has. Therefore we evaluate various cases with just 1 or 2 out of the four customers engaging in CPFR and compare the improvement with the default ROP and the full scope CPFR settings.

		Default ROP	CPFR C2 only	CPFR C3 only	CPFR C2&3	CPFR C1&4	CPFR C1&2	CPFR C3&4	CPFR C1&3	CPFR C2&4	All CPFR
Global	Manufacturer Inventory	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Combined SL gap	7.7%	5.7%	6.0%	4.9%	6.4%	5.2%	5.7%	5.5%	5.3%	4.7%
	Order lead-time	2.2	1.5	1.7	1.2	1.1	1.1	1.2	1.2	1.1	1.1
	% of expired products	5.4%	5.7%	5.7%	6.1%	5.9%	6.1%	5.9%	5.7%	6.3%	6.0%
Delivery	Delayed by Manufacturer	72%	57%	60%	50%	43%	44%	46%	46%	43%	49%
	Critical delayed by Manuf	33%	17%	21%	10%	12%	10%	11%	11%	9%	8%
	Overall Fill-rate	79%	83%	82%	85%	82%	85%	84%	83%	85%	85%
	Overall delayed by DCs	27%	14%	18%	10%	14%	11%	11%	12%	10%	9%
Individual	SL Gap C1	7%	5%	5%	5%	1%	2%	5%	1%	5%	3%
	SL Gap C2	7%	4%	9%	4%	9%	4%	9%	9%	4%	5%
	SL Gap C3	7%	8%	3%	3%	9%	8%	3%	3%	8%	5%
	SL Gap C4	10%	7%	8%	7%	3%	6%	3%	6%	3%	4%
	critical delayed C1	40%	21%	27%	15%	1%	1%	20%	1%	17%	7%
	critical delayed C2	22%	1%	25%	4%	21%	2%	23%	22%	2%	9%
	critical delayed C3	28%	20%	1%	6%	26%	19%	2%	2%	18%	10%
	critical delayed C4	45%	24%	31%	14%	1%	17%	2%	20%	2%	8%

Table 9.6: Selected partial collaboration scenarios

The investigation results presented in the table reveal remarkable benefits that can be achieved even within a partial collaboration framework. If even only one of the two major customers (C2 & 3) engages in collaborative replenishment, most overall performance metrics are improved noticeably. Particularly the two small customers C1 & 4 benefit from any kind of additional collaboration whilst the remaining large customer experiences some shortcomings. Amongst all 2 out 4 customers engaged in CPFR scenarios, all achieve an evident degree of improvement. The cases of C2&3, C1&2 and C2&4 seem to be particularly beneficial. Therefore a strong recommendation can be made to involve at least customer 2 in collaborative replenishment and if possible a second customer.

9.4.3 Sensitivity analysis of expiration control schemes

In this section we investigate how sensitively the system reacts to changes within expiration timetables. To analyse this matter we adjust the default expiry timings at various stages of the supply chain. By default, items are taken out of the flow of goods and being declared expired if they are older than 7 days and have not left the manufacturer's storage facility. Furthermore, only items younger than 16 days are forwarded by the DCs to the retail outlets which in turn take products out of their shelves if they are older than 20 days. Within the default ROP scenario this leads to about 6% of total produced items to be declared obsolete due to premature expiry. From these items 4% are taken out of the flow of goods by the manufacturer, 9% at the retailers' distribution centres and 87% at the retail outlets.

Sensitivity analysis for expiry scheme at manufacturer's storage facility

At this stage, we investigat the impact on the system if the original 7 days age limit that determined expiry at this supply chain echelon was altered to be in between 3 and 10 days.

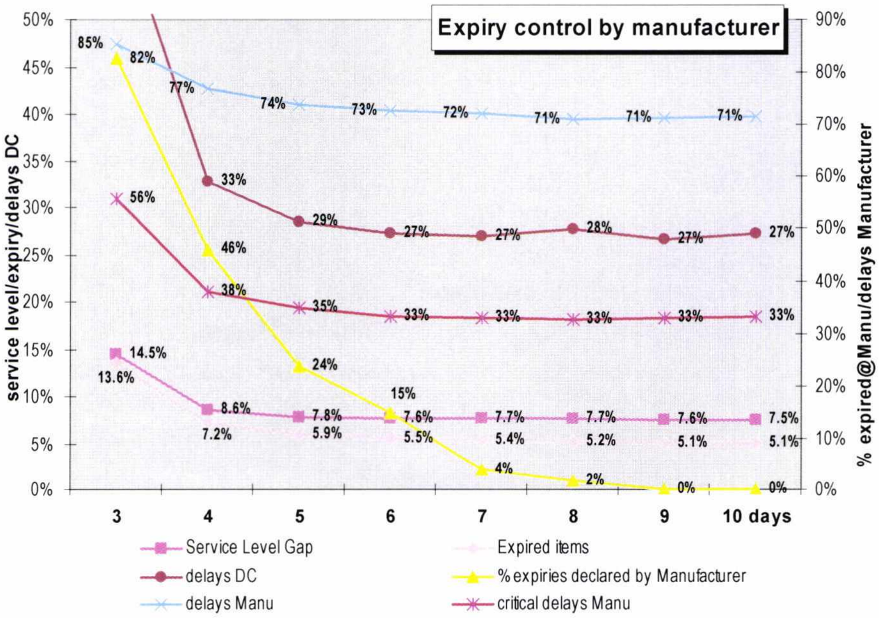


Figure 9.14: Impact of different expiry age limit at manufacturer's storage – no collaboration

Altogether it seems that the default 7 days age limit chosen by the manufacturer to declare items expired prematurely and prevent them from being shipped out is a reasonably good choice. There is altogether no other option that would result in significantly better overall performance. If the age limit would be increased to 9 days or above there would be virtually no products to be taken out by the manufacturer. On the other hand one could argue that it is advantageous to take products with a high risk to expire prematurely out of the flow of goods as early as possible. Therefore a considerable option for the manufacturer would be to decrease the age limit to e.g. 5 or 6 days. As a result of that the number of overall expired products would not increase noticeably and key performance metrics would remain virtually unchanged as well. On the positive side 15% to 25% of to be expired products could already be taken out at the manufacturer's echelon and would not need to be forwarded to subsequent echelons which would incur unnecessary cost. In an extreme case the limit could even be set down to 4 days which would result in only 50% of the overall expired products to be declared at other echelons (distributions centres and retail outlets) whilst performance remains acceptable. Any setting below 4 days would not be reasonable due to vastly increased number of expired items and significantly reduced performance metrics. The overall recommendation would thus be to either increase the age limit up to 10 days which would make carrying out expiration checks virtually unnecessary or to reduce the age limit to 5 or 6 days which would save cost for unnecessary forwarding.

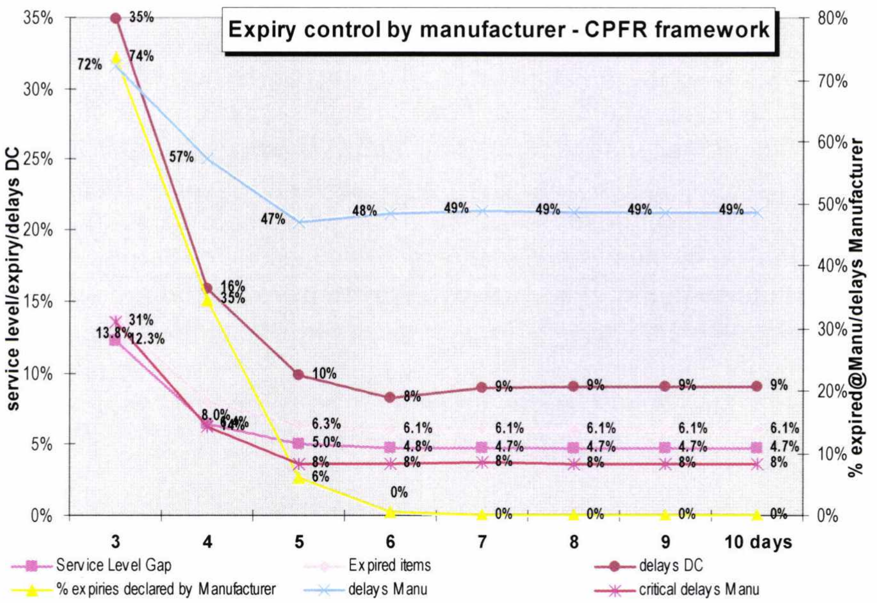


Figure 9.15: Impact of different expiry age limit at manufacturer's storage – CPFR framework

The sensitivity analysis within a collaborative replenishment framework reveals very similar outcomes. If collaboration is introduced there are virtually no items with an age of 6 days or above. The optimal setting would thus be either to withdraw expiry checks by the manufacturer or lower the age limit to 5 days.

<u>Sensitivity analysis for the expiry scheme at retailers' distribution centres</u>

Assuming manufacturer expiry age remains at 7 days, we now evaluate possible expiration time adjustments at the following echelon.

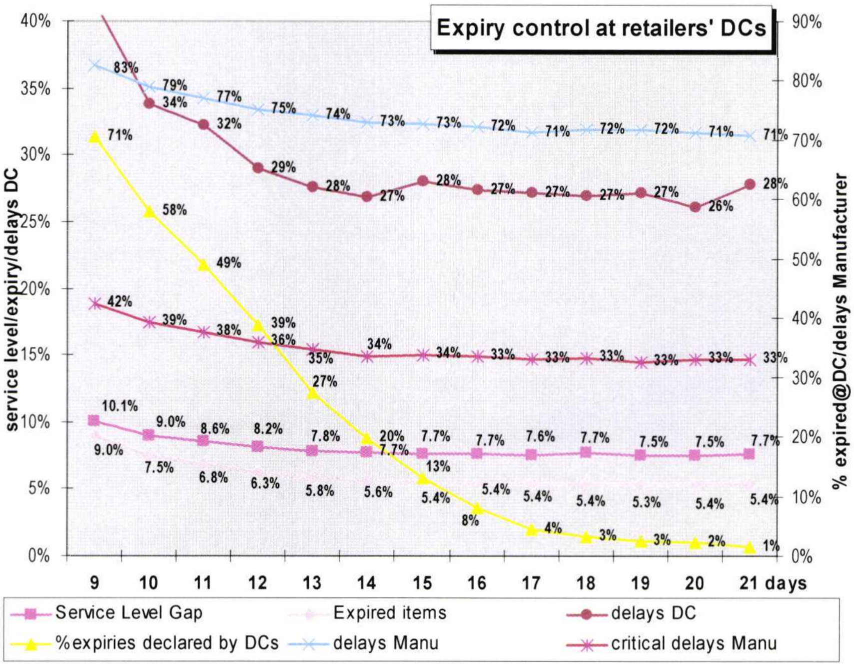


Figure 9.16: Impact of different expiry age limit at retailers' DC storage – no collaboration

Figure 9.16 shows 13 scenarios with expiry age limits ranging from 9 to 21 days. The default age limit of maximum 16 days leads to 8% of the total expired products to be taken out at this echelon. Although the differences are rather small, increasing this limit to 19 or 20 days could result in slightly better service level and less expired items. Once again it could also be argued to lower the limit down to 13 days since performance impact is minimal but the amount of items being declared expired at distribution centre echelon is substantially increased, thus avoiding unnecessary forwarding.

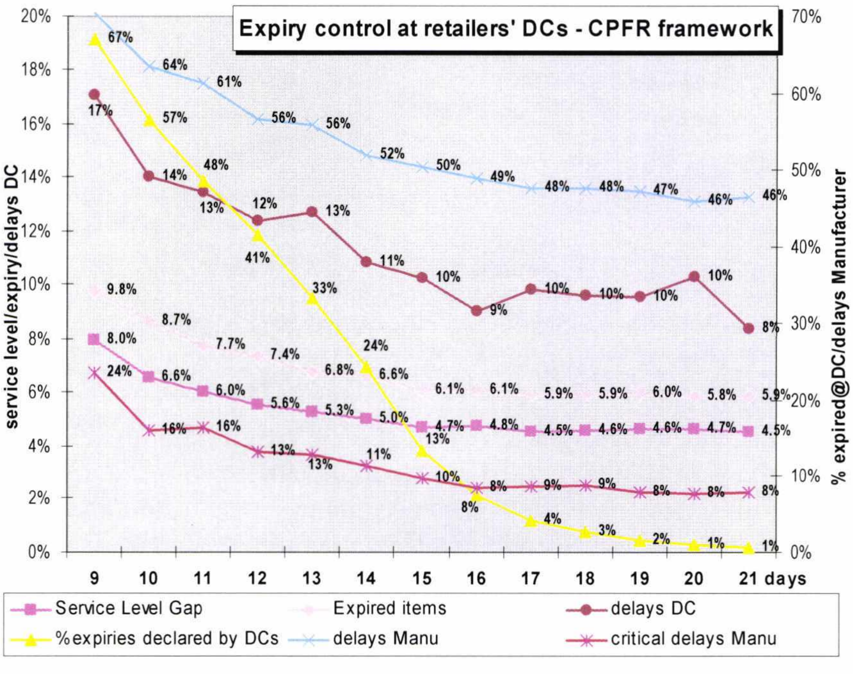


Figure 9.17: Impact of different expiry age limit at retailers' DC storage – CPFR framework

The outcome of the sensitivity analysis within the CPFR framework results in similar conclusions as the non-collaboration case. Overall expiration control at this echelon does not seem to be overly important to obtain low expiry and service level gaps. If such control schemes were put in place it would most likely be more reasonable to shift the age limit down to 14 or 15 days since the percentage of overall prematurely expired products taken out at this stage of the supply chain would be considerably larger compared to the default policy.

Sensitivity analysis for expiry scheme at retail outlets

In case the manufacturer expiry age remains at 7 days and DC echelon expiry age at 16 days we finally evaluate possible expiration time adjustments at the retail outlet echelon.

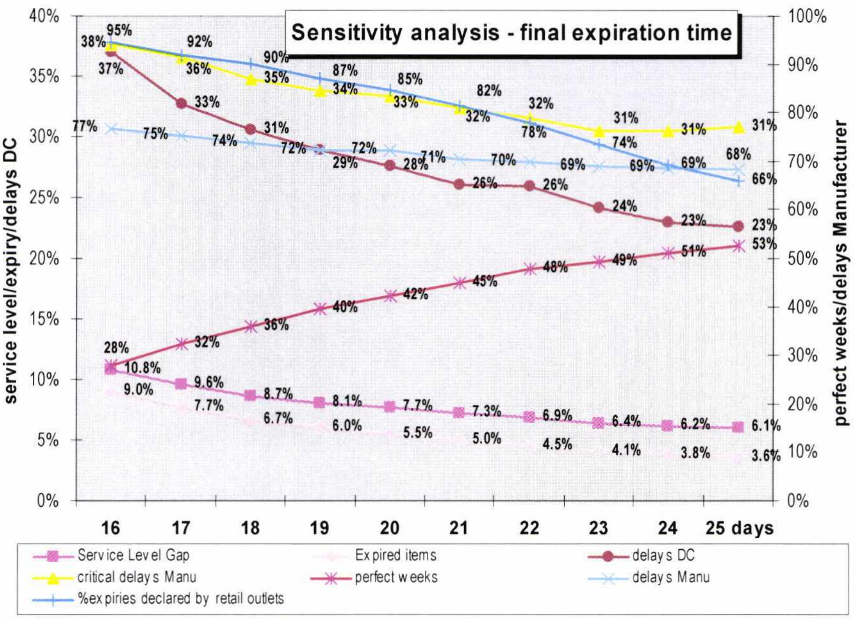


Figure 9.18: Impact of different expiry age limit at retail outlets

This scenario analysis investigates the impact on the system if the default 20 days expiry age at retail outlets was altered to be in between 16 to 25 days. We clearly see that adjusting the final expiration time of the product has an immediate effect on key performance metrics. If for example products were to be taken out of the shelves 2 days earlier than usually due to e.g. extended customer convenience, the number of expired products would increase by over 20%. As a result of that, unsatisfied demand would increase by a similar amount as the overall service level gap increases from 5.5% to 6.7%. If on the other hand the time until expiration could be extended by 2 days, 1% more items could be sold since expired items would diminish to about 80% of the default situation and unsatisfied demand could be reduced by a similar amount. The outcome of the collaborative replenishment context results in very similar findings and is thus not stated here.

Simultaneous adjustments at manufacturer and retailers' DC expiration control schemes

Finally, we take the findings from the investigations above and evaluate various expiration schedule scenarios that include simultaneous changes of expiration age at manufacturers and retailers' distribution centres. The expiration age at the retail outlet echelon has not been varied since in practice this value is most likely pre-determined.

		Non-collaborative replenishment (ROP)						Collaborative replenishment (CPFR)					
	Expiry age at manufacturer	7d	none	6d	5d	4d	3d	7d	none	5d	5d	4d	3d
	Expiry age at DCs	16d	none	14d	13d	12d	10d	16d	none	15d	14d	13d	12d
	Expiry age at retail outlets	20d	20d	20d	20d	20d	20d	20d	20d	20d	20d	20d	20d
Misc. global	Manufacturer Inventory	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Combined SL gap	7.7%	7.7%	7.9%	8.0%	9.3%	15.5%	4.8%	4.5%	4.9%	5.0%	7.2%	13.5%
	Perfect supply weeks	43%	41%	42%	42%	40%	32%	56%	59%	59%	59%	57%	54%
	Order lead-time	2.2	2.1	2.2	2.3	2.5	3.2	1.1	1.1	1.2	1.2	1.8	2.9
	% of expired products	5.4%	5.0%	5.7%	5.9%	7.5%	13.7%	6.1%	5.8%	6.4%	6.7%	8.6%	15.0%
	% expired at Manufacturer	8%	0%	8%	13%	35%	71%	0%	0%	6%	3%	32%	69%
	% expired at DCs	8%	0%	21%	22%	21%	15%	8%	0%	12%	22%	22%	13%
	% expired at retail outlets	85%	100%	71%	66%	44%	14%	92%	100%	82%	75%	47%	18%
	Product age at POS	11.0	11.2	10.8	10.6	10.2	9.2	11.4	11.5	11.2	11.0	10.4	9.4
Delivery	Delayed by Manufacturer	72%	71%	74%	74%	79%	88%	49%	48%	50%	51%	61%	74%
	Critical delayed by Manuf	33%	32%	34%	35%	38%	56%	8%	9%	10%	10%	18%	34%
	Overall Fill-rate	79%	79%	78%	78%	77%	74%	85%	85%	84%	84%	80%	74%
	Overall delayed by DCs	27%	27%	29%	30%	36%	65%	9%	10%	11%	11%	18%	37%

Table 9.7: Various scenarios featuring distinct expiration control schemes

Within both non-collaborative and collaborative replenishment frameworks we can see that the best outcome considering service level and expired items is to abandon expiration control at manufacturer and retailers' DCs altogether. This is somewhat surprising since initially we expected a positive overall impact if inventory was declared expired earlier within the supply chain process. If the overall target is nevertheless shifted towards saving transportation cost and increasing customer convenience alternative scenarios become more interesting. This would be even more apparent within situations where manufacturers are charged for disposing their expired goods or retailers assign this responsibility to the manufacturer altogether. If there was a choice, a retailer would always prefer not having to deal with expired products as much as possible. Apart from that, freshness of the products sold is an issue as customer convenience is increased if products have an extended shelf life. Considering such issues, the other proposed scenarios above which include more restrictive expiry control at manufacturer and retailers' DCs echelon become more valuable to pursue. If for example the expiry schedule within the ROP framework was changed to 6d/14d/20d or 5d/14d/20d within the CPFR context, service level would slightly suffer but about 30% of expired items would be dealt with before they reach the shops and product age at sale would diminish as well. In a somewhat more extreme case (ROP-4d/12d/20d and CPFR-4d/13d/20d) more than 50% of expiries would be taken out of the flow of goods before they reach the store and age of products at point of sale would be evidentially lower. To be fair it needs to be mentioned that within these cases the overall amount of expired products increases noticeably which makes extended shifting somewhat pointless.

9.4.4 Changes in inventory dispatch policies and delivery prioritisation

As within the investigation of product 1 earlier in this chapter, we first evaluate various changes within the inventory handling policies applied at certain stages of the supply chain and later on investigate issues arising from delivery prioritisation. The experienced default strategies were the same as before. In particular FIFO at a daily basis at manufacturer's inventory facility, FDFO (First delivered-first out) policy at distribution centres and a rather random throughput at the majority of retail outlets. The following tables 9.8 and 9.9 express the effect various inventory dispatch alterations would result in.

Possible improvement approaches

		Default ROP	Manuf FPFO	DCs FPFO	Retail FDFO	Retail FPFO	CPFR+ Retail FPFO
Misc.	Combined SL gap	7.6%	7.7%	7.6%	5.1%	4.8%	2.2%
	Order lead-time in days	2.2	2.1	2.2	2.0	1.9	1.1
	% of expired products	5.2%	5.3%	5.0%	2.3%	1.7%	1.4%
	Product age at POS in days	11.0	11.0	11.1	12.2	12.4	12.9
Delivery	Delayed by Manufacturer	72%	70%	71%	67%	66%	46%
	Critical delayed by Manuf	32%	32%	34%	30%	29%	8%
	Overall Fill-rate	79%	79%	79%	80%	81%	86%
	Overall delayed by DCs	26%	28%	27%	24%	22%	11%

Table 9.8: Various alternative dispatch scenarios I

The first of the improvement scenarios implies changing the first produced-first out dispatch policy at the manufacturer's storage facility from a daily based to an hourly based system. Thus products are loaded not just according to day but also hour of production. As within the previous case, this does not seem to result in any noticeable improvement. The next improvement scenario implies changing the dispatch process at the retailers' distribution centres from a first delivered-first out to a first produced-first out system. Once again this policy does not seem to result in any significant improvements over the default system.

The remaining three scenarios which imply changes at the retail outlets clearly seem to have a much bigger impact. As mentioned earlier the actual reality within stores was found to be modelled best by a random approach that suggested the likelihood of a product being sold to be almost independent of the production date or the date of arrival at the outlet. If this could be adjusted towards an FDFO (first delivered-first out) or even FPFO (first produced-first out) policy, substantial improvements would be possible regarding service level as well as amount of expired products. Besides its obvious positive effect, implementing such policies is commonly very difficult to accomplish. Even if inventory at stores was handled in that way we can see that there would still be a substantial amount of expired items. The reason for this is inadequate production and delivery planning which can be remedied by introducing collaborative replenishment as we can see from the final improvement scenario. Combining advanced inventory dispatching and CPFR would apart from other improvements leave only a fraction of initially unsatisfied demand and would make the issue of expired products practically irrelevant.

Further possible dispatch scenarios

		Default ROP	Manuf LIFO	Manuf SIRO	DCs LIFO	DCs SIRO	Retailer LIFO	All LIFO	All SIRO
Misc.	Combined SL gap	7.6%	10.9%	10.0%	9.6%	9.2%	9.1%	13.9%	11.7%
	Order lead-time in days	2.2	2.7	2.6	2.6	2.5	2.1	3.0	2.7
	% of expired products	5.2%	9.1%	8.0%	7.9%	7.3%	6.6%	12.4%	10.0%
	Product age at POS in days	11.0	9.9	10.2	9.6	10.0	10.8	8.8	9.3
Delivery	Delayed by Manufacturer	72%	80%	79%	80%	79%	70%	85%	82%
	Critical delayed by Manuf	32%	45%	42%	41%	38%	32%	52%	46%
	Overall Fill-rate	79%	76%	77%	76%	77%	79%	74%	75%
	Overall delayed by DCs	26%	45%	40%	37%	36%	28%	56%	48%

Table 9.9: Various alternative dispatch scenarios II

The scenarios stated in Table 9.9 are meant for demonstration purposes and should by no means be understood as proposed improvement settings. The adjustment cases imply a range of inferior but practically possible and often realistic inventory throughput policies.

Adjustments include dispatching inventory either on a random basis (SIRO) or even worse, a last in-first out policy. Although such policies should not be in operation it might be of interest to see their actual impact on the system. The results do not surprise since any considered case leads to severe shortcomings with performance outcome being far inferior to even the default system setup. Altogether the results demonstrate what devastating effect negligence of suitable inventory dispatch policies can have within a perishable goods environment.

Adjusting delivery fulfilment prioritisation policies

Within this part we change the prioritisation of incoming orders that have to cope with insufficient quantity of available products.

		Various replenishment prioritisation policies					
		Default	random prio	C2 prio	C3 prio	C2&C3 prio	C1&C4 prio
Misc. global	Manufacturer Inventory	100%	100%	100%	100%	100%	100%
	Combined SL gap	**7.7%**	**9.1%**	**8.3%**	**8.2%**	**7.9%**	**9.5%**
	typical SL gap	10.7%	11.8%	13.6%	12.7%	14.3%	11.3%
	Order lead-time	2.2	1.6	2.0	1.9	2.2	1.3
	% of expired products	**5.4%**	**6.4%**	**5.9%**	**5.8%**	**5.5%**	**6.7%**
Delivery	Delayed by Manufacturer	**72%**	**55%**	**60%**	**60%**	**69%**	**45%**
	Critical delayed by Manuf	**33%**	**18%**	**25%**	**24%**	**27%**	**15%**
	Overall Fill-rate	79%	80%	82%	82%	80%	81%
	Overall delayed by DCs	**27%**	**21%**	**26%**	**27%**	**29%**	**18%**
Individual	SL Gap C1	7%	4%	8%	9%	11%	1%
	SL Gap C2	7%	13%	3%	12%	6%	14%
	SL Gap C3	7%	9%	12%	3%	5%	11%
	SL Gap C4	10%	6%	12%	12%	17%	3%
	critical delayed C1	40%	10%	33%	32%	39%	1%
	critical delayed C2	22%	23%	2%	31%	16%	27%
	critical delayed C3	28%	22%	32%	1%	16%	27%
	critical delayed C4	45%	11%	37%	37%	41%	1%
	Expired products C1	5%	8%	6%	6%	5%	10%
	Expired products C2	5%	5%	6%	4%	5%	4%
	Expired products C3	4%	5%	4%	7%	5%	4%
	Expired products C4	6%	9%	7%	7%	6%	11%

Table 9.10: Selected scenarios for adjusted replenishment prioritisation policies

The default scenario assigns delivery priorities according to a first come first served policy where incoming orders are queued due to their arrival. However, by default the major two customers receive some sort of special treatment as their orders jump the queue if the waiting time of the queued orders does not already exceed a certain time limit. A similar system named FCFS-advantaged was described in section 8.3. As a result of this, service level and expired items are rather evenly distributed amongst all customers whilst critical delivery delay figures are clearly inferior for the small customers C1 and C4. Within the first tested scenario we changed this prioritisation system to a random approach where order fulfilment is independent of waiting time, urgency, customer's importance etc. This seems to result in reduced service level and more expired products but deliveries tend to be less delayed in such a system. It is particularly the small customers that would benefit from such a change. Within the next two scenarios customers 2 and 3 are given sole priority under any circumstances. As a result of that they each improve their performance metrics significantly but on a global basis there is no performance improvement noticeable. A similar outcome was recorded in case both large customers receive unrestricted priority

treatment. Here both somewhat improve their scores at the expense of the two smaller customers. Finally, the last scenario tests possible implications if the two small customers were prioritised. As expected, their performance improves drastically at the expense of the larger customers. However, delivery performance indicators improve significantly on a global basis as well.
Overall changing the prioritisation policy does not seem to result in any significant global benefit. Depending on the particular policy chosen, shortcomings are only shifted in between particular customers. The FCFS policy operated by default seems to be most fair considering the interests of all market participants.

9.4.5 Recommended overall improvement settings

Based on the outcome of previous analyses we suggested six improvement scenarios to the companies within this supply chain framework. The recommendations are combinations of previously considered issues and derive around improved throughput at store level, an increase of average inventory held and partial or full introduction of collaborative replenishment. Each of the presented six scenarios has particular strengths and areas of significant improvement compared to the initial case. Generally an increase in throughput efficiency at store level is once again of major importance. Since a genuine FPFO process is rather implausible considering real-life practice at retail outlets, the goal needs to be to improve the actual rather random dispatch sales situation to achieve at least a FDFO practice. This way of advancement is thus included in each proposed scenario. Apart from that we changed the expiry control scheme to an expiry age of 5 days at manufacturer, 14 days at DCs and 20 days at retail outlets in order to comply with manufacturer's request to reduce the percentage and absolute number of expired items at the retail outlet echelon.

		Default ROP	ROP +20%inv	ROP +40%inv	C2 CPFR	C2 & C3 CPFR	all CPFR	all CPFR +10%inv +no EC
Misc. global	Manufacturer Inventory	100%	120%	140%	100%	100%	100%	110%
	Combined DC Inventory	100%	131%	149%	125%	135%	130%	141%
	Combined Retail Inventory	100%	107%	109%	106%	108%	107%	108%
	Combined SL gap	**7.7%**	**2.6%**	**2.0%**	**2.8%**	**2.1%**	**2.1%**	**1.9%**
	Perfect supply weeks	43%	74%	78%	76%	82%	82%	80%
	Order lead-time	2.2	1.2	0.7	1.2	0.9	1.0	0.7
	% of expired products	**5.4%**	**4.0%**	**5.4%**	**2.4%**	**2.1%**	**2.2%**	**2.3%**
	% expired at Manufacturer	8%	31%	31%	6%	1%	1%	0%
	% expired at DCs	8%	30%	32%	49%	50%	55%	0%
	% expired at retail outlets	85%	39%	37%	45%	48%	44%	100%
Delivery	Overall DC deliveries	123%	116%	113%	113%	107%	104%	104%
	Delayed by Manufacturer	**72%**	**47%**	**32%**	**46%**	**40%**	**39%**	**29%**
	Critical delayed by Manuf	**33%**	**13%**	**7%**	**12%**	**6%**	**6%**	**3%**
	Overall Fill-rate	79%	86%	90%	86%	88%	88%	90%
	Overall delayed by DCs	**27%**	**10%**	**7%**	**10%**	**7%**	**8%**	**7%**
Individual	SL Gap C1	7%	2%	1%	2%	2%	1%	1%
	SL Gap C2	7%	3%	2%	2%	2%	3%	3%
	SL Gap C3	7%	2%	2%	4%	1%	2%	2%
	SL Gap C4	10%	3%	2%	3%	3%	2%	2%
	critical delayed deliveries C1	40%	16%	9%	15%	8%	7%	3%
	critical delayed deliveries C2	22%	8%	4%	1%	3%	8%	5%
	critical delayed deliveries C3	28%	11%	7%	15%	3%	9%	3%
	critical delayed deliveries C4	45%	18%	9%	17%	11%	6%	2%
	Expired products C1	5%	3%	4%	2%	2%	3%	3%
	Expired products C2	5%	2%	3%	2%	2%	1%	2%
	Expired products C3	4%	2%	3%	1%	2%	2%	1%
	Expired products C4	6%	6%	7%	4%	5%	5%	6%

Table 9.11: Selected improvement settings for the supply chain framework of product 2

Overall there are two suggested scenarios based on a purely non-collaborative replenishment context whilst the other four include collaboration to a partial or full scale. All the scenarios manage to reduce the service level gap to below 3%. The ultimate target set out by the manufacturer was 2% which is reached by either increasing inventory held by 40% or introducing CPFR. This is in addition to earlier outlined adjustments which where implemented in all scenarios (improved dispatch policies and expiration schedule). If the level of inventory held by the manufacturer cannot be expanded, it seems that the target performance level can only be reached by introducing collaboration. The number of expired items is significantly lower within all collaboration settings due to improved production and delivery forecasting and lower inventory held. As a result of the improved overall system, inventory at distribution centres will necessarily increase due to fewer shortages. Order lead time which here expresses the time between an order being placed and the departure of the loaded lorries (assuming fixed delivery time) also diminishes noticeably from over 2 days to less than one day on average. Apart from that, delivery delays are diminished remarkably which results in only 1 out of 10 deliveries to be remarkably delayed instead of 1 out of 3 as it was the case initially. Considering the distribution of product expiries amongst the three supply chain echelons, adjusted expiry schedules resulted in the number of expiries to be remarkably diminished at retail outlets due to an overall shift towards expiry control at preceding echelons and improved dispatch at retail-outlets. Taking the all CPFR scenario as an example this leads to a reduction of expired items at retail outlets by as much as 80%. The final column within the table states the outcome for an all CPFR scenario with slightly increased inventory held and expiration control (EC) only at retail outlets. This scenario was put in to demonstrate improvements possible within a reduced expiry control framework which was also requested by the manufacturer. Altogether, the investigation clearly showed how much potential there is for improvement of various aspects within a perishable goods supply chain environment. Successful implementation of any one of the recommended scenarios should resolve specific performance shortcomings identified by management of the involved companies and remarkably advance operational performance supply chain wide.

9.5 Aggregation of obtained findings

During the previous investigations of two perishable products within two distinct supply chain frameworks we clearly identified a variety of issues that constitute peculiarities within supply chain management research. The perishable nature of the investigated products opens a wide range of investigation opportunities that are substantially different from a default research perspective. Throughout the analyses, simulation modelling of the supply chain networks has turned out to be extremely useful to evaluate hundreds of practically highly relevant altered scenarios to identify possible areas of improvement. In the following section we sum up the most interesting points that stand out from findings within previous sections based on both perishable goods investigation frameworks.

The influence of increasing inventory level

This part of the analysis investigated the outcome of key performance metrics at a particular level of average inventory held by the manufacturer. Within a low inventory context, collaborative replenishment seems to have a clear advantage over ROP systems since for example service level scores are significantly superior. This advantage tapers off whilst inventory level is increased and eventually vanishes altogether. Additionally, within extensive inventory scenarios, CPFR driven systems lead to significantly fewer expired items. The gap between ROP and CPFR in this respect widens as inventory expands. Depending on the inventory situation of a particular company or product, collaborative replenishment thus leads to either improved service level or diminished expiries but commonly not both.

Expiration control schemes

Altogether it has been shown that expiration control schemes do have a remarkable influence towards the supply chain performance of perishable products. Selecting a particular age limit for items to be declared obsolete at various stages does not just influence the total quantity of products taken out of the flow of goods but also customer service level, delivery reliability, transportation cost, dispatching cost, customer convenience etc. Considering the various stages of expiration control, retailers' distribution centres could play a more important role in regulating the amount of product that is declared obsolete. The goal must be to find an optimal cost/benefit ratio to optimise the amount of goods taken out of the flow before they are shipped to retail outlets. This ratio should depend on the costs saved by avoiding unnecessary dispatching, shipping, handling and disposing goods at retail outlets on one hand and additional number of expired items and inventory control cost at distribution centres on the other. In optimising this procedure, non-collaborative replenishment systems seem to bear more potential for improvement in this respect than CPFR enabled replenishment. Within this process of establishing the right policy it needs to be determined if inventory control activities altogether should be kept at a minimum which would mean not to carry them out at all up to the retail shelves or in the opposite to carry them out at each echelon and prevent a substantial amount of soon to be expired items from being unnecessarily transported. Particularly the expiration control by the manufacturer appears to be of less value and improvement potential at this echelon is rather low. However, a decision on whether expiration control should be carried out at a particular echelon has to be made not only based on the number of expected expired items but also as a part of quality control management. Within the investigated supply chain frameworks expiry checks are also used to identify damaged boxes, insufficient cooling systems or visual quality inspections. Although the default control schemes put in place proved to be considerably effective, some fine-tuning as recommended within the individual case analyses should most likely improve overall performance. Altogether there should be a substantial cost saving potential within this subject. Prior to carrying out the analysis, there was a general wondering about to what degree frequent expiry checks and thus up to date information about expired items would lead to more timely updated orders and thus improved overall performance. Altogether there seems to be no evidence of this kind of effect since excellent service level and other key performance metrics improvements could also be achieved with expiry control solely executed at retail outlets.
A further issue within this area is setting the ultimate expiration date at retail outlets. As the previous analyses show, there is a lot of potential revenue to be lost or gained if expiration age is only altered by one single day. In both frameworks, a day more or less in expiry age accounts for about ±10% of total expired items and about 0.5% drop or gain of service level. A possible expansion of expiration time would therefore be highly beneficial. This should nevertheless be done via production enhancements or transportation/storage improvements and not at the cost of product quality and customers' convenience.

Order fulfilment prioritisation

Regarding prioritisation strategies to fulfil simultaneously incoming orders requesting a scarce product, the analysis suggests a standard first come first served queuing system as optimal. Giving fulfilment preference to any individual or group of customers leads to inferior global outcome. This is independent of a distribution system including either a group of equally important or individually dominant customers. However, in practice major customers often demand special treatment and manufacturers will be more eager to please their major business partner instead of less significant clients. Overall a trade-off has to be found to set up a prioritisation policy that aims for the best global outcome to serve the interest of the manufacturer but on the other hand does not upset customers. Such issues are much less cumbersome within a collaborative replenishment context since due to increased demand visibility, replenishment can be much better optimised to serve global and individual performance targets. Within a non-collaborative replenishment system implying poor demand visibility at best, both investigated perishable goods manufacturers operate a first come first served system with adjustments for the major customers. These policies prioritise order fulfilments to key customers only in case already existing orders would not be delayed by too much or are not already queuing beyond a certain time limit. This policy setup achieves overall performance outcome comparable to a pure FCFS system but balances replenishment as not to disadvantage major customers.

Inventory dispatch policies

Inventory dispatch policies proved to be a major factor within supply chain performance improvement as the previous investigations showed. Within both supply chain frameworks key performance targets could be achieved already only by optimising the inventory throughput strategies. Considering the two investigated frameworks, stock handling was already carried out at an advanced level except within retail outlets. The shortcomings within this echelon were to some extent due to ineffective product handling i.e. LIFO or SIRO (random) handling of new arrivals at in-store storage facilities or NTO (new on top of old) shelf packing. Apart from such issues which varied greatly in between individual outlets, other reasons for insufficient in-store product throughput arose out of day by day practical issues like multiple in store sales placements, item-displacement by customers, freshness seeking smart-shoppers that dig for freshest items etc. Altogether there is a whole bunch of activities needed to achieve an improvement of in-store product handling. Nevertheless, the investigation results show how much potential there is for increased sales, customer convenience and lower expired items. The inventory dispatch analysis also revealed how much a supply system for perishable goods can be affected in case advanced dispatch policies are disregarded within individual echelons of the chain. Inconsiderate LIFO or random dispatching by the manufacturer and/or retailers' DCs could for example easily double or triple the amount of obsolete items.

9.6 Final comments

Depending on the individual objectives set out by a given company, a wide range of possible improvements is available to enhance supply chain efficiency in a perishable goods delivery environment. The investigated cases considered already numerous factors but are by no means exhaustive. Altogether we can say that initiating further engagement in collaborative replenishment seems to be most worthwhile. It seems to be the only way to improve all significant performance metrics while avoiding additional safety inventory. The investigation also revealed that substantial achievements can be obtained even by incorporating only a limited range of customers in a collaboration driven replenishment process. Thus improvements should be possible even without supply chain wide collaboration. Moreover it was demonstrated how much potential there is within an advanced way of inventory throughput handling. This should surely put pressure behind the introduction of new methods and technologies that make it easier to move closer towards most favourable FPFO dispatching. Technologies such as RFID tags can make it possible to monitor expiry times of individual product items even within large storage facilities or at a shop floor wide level and thus allow optimisation of forwarding or repacking schedules to avoid unnecessary expiries.

We believe the research succeeded in providing further insights in the distribution process of perishable goods environments and revealed various sources of improvement. This should overall lead to better service levels, less expired products and lower inventories, thus higher supply chain efficiency. Even though the applied supply chain model was customised for the companies under investigation, reported outcome and recommendations can be used in similar distribution environments although the level of achievement may somewhat differ in case of other companies or within different industries.

The presented analysis can – beyond the recommendations for the involved companies – give a certain degree of thought about what could work to what extent in what way. The simulation study has been much appreciated by the participating parties and proved to be very useful to evaluate a wide range of policy adjustments within their supply chains. Apart from the manufacturers' interest in inventory sensitivity analysis, the retail companies found it particularly useful to gain further insights into expiration control strategies. As a result, the timings to declare a product obsolete (prematurely) at various stages of the supply chain have been successfully optimised.

10. Summary and conclusion

Within the final chapter we summarise the main results of the study and evaluate theoretical and practical contributions. Furthermore we look at the relevance of the study by discussing practical and managerial implications of the obtained outcomes. Finally, we also look at validity and reliability of the results, limitations and directions for future research.

10.1 The central outcomes of the study

What was set out to be done?

The main target of our research was to reveal further insights regarding the impact of enhanced coordination and scheduling of production and distribution in the light of various levels of collaboration within retail supply chains of SME manufacturers. Within this context of investigation we aimed to support a group of companies with practically feasible solutions about how they can improve their businesses. The focus of the analysis was thus centred on the scenarios that arose from the investigated supply chain frameworks. Moreover, a major target of the research was the development of a sophisticated simulation model to enable and foster a profound analysis to the degree of detail necessary to address numerous issues raised by the participating companies as well as academic literature. Both of these two main goals were formulated in the two main objectives within Chapter 3.

What was found out?

Overall, the study revealed a multitude of insights that on one hand address the objectives set out to move ahead academic research within the outlined field and on the other hand lead to direct benefits for the companies that participated in the research. The individual contributions will hereafter be outlined in more detail.

10.1.1 Methodological contribution

The first research objective was to develop an appropriate simulation framework to allow investigating the proposed ideas and areas of interest. According to this, a sophisticated simulation model was created that was not just capable of supporting the actual investigation of issues raised within the investigation context, but also addressed various issues that were somewhat neglected by previous simulation approaches.

To begin with, the research addressed a multitude of multi-echelon supply chain decision making implications such as delivery prioritisation, shortage gaming, data sharing, collaborative forecasting, expiration scheduling, inventory throughput policies etc. Many of these issues have not been previously investigated based on a discrete event simulation study to such detail and for supply chain frameworks as within this study.

Furthermore, an investigation of three stages of collaboration (ROP, VMI and CPFR) within the same simulation model running within mixed settings simultaneously has not been attempted beforehand to our knowledge.

Finally, the incorporation of a highly adjustable and adaptable forecasting system based on exponential smoothing and regression analysis to form the basis of a collaborative planning forecasting and replenishment system has not been carried out to a comparable extent within any other academic study that we are aware of.

Apart from these main findings there were numerous smaller contributions that were based on earlier supply chain modelling approaches and enhance the used methodology as suggested by literature.

The second research objective was to utilise the developed simulation model in order to investigate the impact of enhanced coordination and scheduling of production and distribution in the light of various levels of collaboration within retail supply chains of several SME manufacturers. Apart from addressing many practical concerns of the involved companies, a variety of previously unconsidered academic matters have been tackled. The most important of these issues is the impact of various stages of collaboration on the performance of particular supply chain echelons and their individual members. Significant attention within this topic was given to evaluate the impact of emerging collaboration on non-collaborating customers. The analysis revealed that full scale implementation of collaborative replenishment does lead to improved overall supply chain performance but the degree of improvement heavily depends on the distribution circumstances of each supplier, the targeted inventory levels and the kind of collaboration (VMI/CPFR). Whilst global metrics improve, the actual level of progress for each individual customer varies greatly and there is a genuine threat that particular customers experience a performance decline although being engaged in collaboration. A second major finding was that partial implementation of collaboration can be remarkably beneficial for the supplier, the involved customer and remaining customers but the level of improvement even more depends on each individual case and there is a substantial risk that collaboration will not be beneficial or even lead to a drop amongst various performance metrics. Apart from that, individual customers not participating in collaboration initiatives can be substantially disadvantaged as a result of other customers engaging in collaborative replenishment. Considering furthermore the ratio between improvement on one side and implementation and maintenance effort on the other, heterogeneous settings would have to be recommended over full implementation cases in virtually all possible frameworks.

Finally, we found that early adopters' superior degree of improvement together with a strong correlation between performance improvement and percentage of demand supplied via collaborative replenishment could initiate intense pressure from either supplier or individual customers not to extend collaboration beyond individual key customers. There is a genuine possibility that a full scale collaboration framework would neither be preferred by the manufacturer due to disproportional cost of integrating small customers nor by key customers due to early adopters' superior performance and competition with other retail customers.

A second major issue addressed by the study was investigating the impact of enhanced coordination and collaboration within perishable goods environments. This seemingly has not been much considered within publicly available previous research studies. Within this framework we focused particularly on the influence of collaborative replenishment, increasing inventory levels, expiry control schemes, order fulfilment prioritisation and various inventory dispatch policies. It was found that depending on the individual goals set out by a given company, a wide range of possible improvements is available to enhance supply chain efficiency in a perishable goods delivery environment. Altogether we can state that further engagement in collaborative replenishment seems to be most worthwhile. It seems to be the only way to improve all significant performance metrics while avoiding additional safety inventory. The investigation revealed also that substantial achievements can be obtained even by incorporating only a limited range of customers in a collaboration driven replenishment process. Thus improvements should be possible even without supply chain wide collaboration. Moreover, it was demonstrated how much potential there is within an advanced way of inventory throughput handling.

This should encourage the introduction of new methods and technologies that make it easier to move closer towards most favourable first produced-first out dispatching within all supply chain echelons. We believe the research succeeded in providing further insights in the distribution process of a perishable goods environment and revealed various possible sources of improvement. These should overall lead to better service levels, less expired products and low inventory, thus higher supply chain efficiency.

10.1.2 Dissemination of the research

The outcomes of the research have already been disseminated through numerous presentations and publications within journals, working paper series, conferences and research seminars. In the following we give a short overview about major topics and occasions as well as direct references to which parts of the thesis they relate to.
A summary of initial research findings was presented in a working paper called "Opportunities and Vulnerabilities of Demand Forecasting Approaches prior to and after Implementation into Computer Simulation Models". It was presented at the 2nd Industrial Simulation Conference in Malaga, Spain, in June 2004 and released as a working paper (Thron *et al.*, 2004). The content is based on the investigations within Chapter 5.
Within the stage of exploring the research framework, exploiting the obtained information and addressing particular issues outlined by the companies involved in the research project, further presentations and publications were made. In particular these included an article about the "Impact of Various Delivery Prioritization Strategies in heterogeneous Supply Chain Environments" which was submitted, peer reviewed and presented at the 3rd Industrial Simulation Conference 2005, Berlin, Germany. It was also published within the ISC'2005 conference proceedings (Thron *et al.*, 2005). The content of the paper can be directly linked to the analysis in section 8.2. Another paper based on the investigations in section 8.1 was entitled "Impact of Fill-rate Dependent Reordering Behaviour on Supply Chains under Varying Levels of Demand Transparency". It was peer reviewed and presented at the International Conference on Information Systems, Logistics and Supply Chain (ILS'06), Lyon, France and subsequently published within the ILS 2006 conference proceedings (Thron *et al.*, 2006a). Moreover, an article about the "Distinct Influence of Various CPFR Components on Overall Supply-Chain Performance", was presented at the Industrial Simulation Conference 2006, Palermo, Italy and published within the ISC'2006 proceedings (Thron *et al.*, 2006b). After an extensive evaluation by eight independent peer-reviewers the paper entered the conference's best paper award and became second best which was also awarded with a £300 price equivalent. The paper was drafted from the findings reflected in section 7.3. Moreover, an article about "Diverse Allocation Strategies within the Process of Distributing Scarce Products amongst Traditional and Collaboratively Replenished Customers" was presented at the International Conference on Industrial Engineering and Systems Management (IESM'2007), Beijing, China and published within IESM 2007 conference proceedings (Thron *et al.*, 2007a). The paper is based on an extended investigation of the issues outlined within section 8.1.
As the research reached a somewhat more matured stage, a more conclusive overview about the research context was published in two reputable journals. The "Impact of increasing demand visibility on order fulfilment and service level in heterogeneous ROP/CPFR environments" was published in the International Journal of Physical Distribution & Logistics Management (Thron *et al.*, 2006c). The content of this paper describes roughly the assumptions and findings presented in Chapter 7. Another article drafted from the analyses represented in Chapter 9 was called "Evaluating alternative

supply chain structures for perishable products" and is published in the most recent issue of the International Journal of Logistics Management (Thron *et al.*, 2007b).
Apart from the occasions mentioned above, results of the research have been presented at numerous other conferences, research seminars or workshops which however did not include a formal peer review or attached publication. The instant feedback resulting from such sessions were nevertheless invaluable for testing the value and credibility of the research in direct dialogue with subject matter experts.

10.1.3 Contributions of the study to support participating companies

Altogether, the research resulted in a multitude of benefits for the participating companies. The main beneficiaries were clearly the three SME manufacturers. By participating in the study, they gained valuable knowledge about how their distribution processes are interlinked with their customer demand, production planning as well as their supply of raw materials. Apart from that, retail companies and 3PL (3rd party logistics) service providers showed considerable interest and appreciation of presenting them the outcome of the study. The most appreciated feature was clearly the simulation model that made it possible to run through a multitude of what-if scenarios to investigate potential adjustments within the companies' production, order, distribution and delivery planning. It furthermore fostered understanding of how demand was placed by the retailers and why this happened in certain ways.
Apart from the gained knowledge about system dynamics within their supply chain framework, there were also clear tangible achievements such as improved seasonal sales deviation compensation, improved order forecasting, competing order prioritisation mitigation or perishable goods expiration scheduling.
The most tangible achievements for each manufacturer can be summarised as follows:

Manufacturer 1:

- improved demand seasonality anticipation and compensation
- an entirely new demand forecasting approach based on recommendations given in Chapter 5
- support within collaboration test phase including setup of new IT equipment
- instating a formal incoming order request fulfilment prioritisation policy

Manufacturer 2:

- improved demand seasonality anticipation and compensation
- adjusted perishable products expiration time setup
- set up improved communication scheme with customers to tackle "shortage gaming" behaviour

Manufacturer 3:

- improved demand seasonality anticipation and compensation
- setting up collaboration parameters for CPFR collaboration initiative with two major customers
- changed perishable product dispatch strategy
- adjusted perishable products expiration time setup

Common to all three companies was the improved awareness of a wide range of delivery performance measurement and metrics systems that were not much formalised beforehand. Additionally, throughout the study the companies were introduced to the various ways collaboration could be implemented into their existing systems and simulation test runs clearly revealed potential benefits. This was also very helpful to argue against numerous prejudices about collaboration such as losing negotiation power, giving away control or revealing crucial data.
Apart from these "hard" improvements which should directly impact on the day to day business of the companies, the main benefit of the study can most certainly be found in the improved understanding of the business and supply chain framework altogether. If the recommendations of this study find their way into the strategic decision making of the participating companies, future benefits should be much greater than the improvements resulting from the above mentioned directly tangible changes. Altogether, the business environment of small or medium sized enterprises often reveals a surprising amount of simple but effective improvement opportunities which most likely could not be found or tackled in the same fashion within larger corporations. This fact makes the analysis much more interesting to the researcher and more beneficial for the company which is a fact that should encourage further relationships between SME companies and academia.

10.2 Practical implications and relevance of the study

As can be seen from the previous considerations, the research results promise to have a very positive impact on the business of the participating companies. Altogether, a major part of the practical utility of this research was to provide a better understanding of business dynamics within the investigated supply chain environments and to provide tools for improved operative and strategic business planning and understanding. The simulation approach allowed the companies to investigate and understand their business framework from various new perspectives including suppliers, customers and competitors. The insights obtained throughout this process revealed strengths, weaknesses, opportunities and threats and clearly highlighted future capability needs. The beneficiaries of the research study were astonished and pleased about the demonstrated potential of simulation modeling for business strategy analyses as it was a business support tool they were previously entirely unaware of.

10.3 Evaluation of the research - Validity and Reliability

From the perspective of a case study research as it was carried out within this research undertaking, it is of great importance to combine emerging findings with existing literature to assure a sufficient level of internal and external research validity to foster the generalizability and transferability of obtained results. This is particularly important within in-depth case studies of individually engaged companies in specific business environments as they can lack external validity due to sacrificing an impartial external observer's point of view towards the investigated subjects. Within this research study, such threats were tried to be prevented via comparative research design based on three distinct frameworks, consulting supportive studies within existing literature and seeking out similar practical case studies as points of reference. Internal validity, as it is best obtained by establishing causal relationships and investigating their sanity (Yin, 1994), has been carried out by rigorous model validation and verification as was outlined earlier.

The validity of the research was further improved by seeking out multiple sources of information and quantitative as well as qualitative data collection methods. Quantitative data collection was carried out via utilisation of business data records and manual counting, timekeeping and observing. Qualitative data on the other hand were obtained via interviews that gave additional meaning to the "hard numbers" and confirmed findings derived from written documentation from various internal and external sources.
According to Voss *et al.* (2002), reliability is the extent to which a study's operations can be repeated. To assure a sufficient level of reliability, the entire research methodology has been documented to a very detailed degree including data preparation, framework assumptions, parameter settings, model layout and logic and numerical investigation output etc. The outline of the research proceedings are meant to provide a good level of transparency which should foster the reproducibility of obtained results and trustworthiness of drawn conclusions. Reliability was further increased by discussions with other researchers and experts internal and external to the research project. The suggestions developed in this research study should thus be generally applicable to similar companies and supply chain frameworks.

10.4 Limitations of the research and future directions

The limitations of this study have already been outlined at various stages throughout earlier proceedings. We will thus only state the most generic issues. Altogether, the main constraints can most likely be found in the choice of simulation modelling methodology and the focus on three particular supply chain frameworks. Due to limited resources and time, the research could until this point of time not be extended beyond the chosen supply chain frameworks as this would have required a substantial additional time commitment and would have further increased the complexity of result analyses. Due to those issues and the restricted availability of in-depth company support, the research outcome will most likely have a somewhat narrower applicability compared to a possible broader study including a wider range of supply chain frameworks with distinct demand, production and distribution patterns.
The investigated topics were thus very much focused on specific issues raised by the participating companies that could sufficiently be addressed by simulation modelling and at the same time contribute to ongoing academic research. Due to this focus, there is a wide range of other possible issues that remained unaddressed since they simply could not be suitably tackled by the applied research methodology or would have merely exceeded the research scope.
Due to these outlined limitations, the study leaves a wide range of possible extensions for future research. First of all the explored supply chain frameworks could be further investigated regarding implications of collaboration towards supply chain partnerships further upstream (e.g. suppliers of raw material, logistics service providers etc.). Apart from this there are a number of issues raised by the companies that could not be addressed so far. These issues include

- the effect of distinct or dynamic minimum load-level settings within the replenishment prioritization process
- investigating the impact of possible interruptions and breakdowns within several echelons/entities of the supply chain, time taken until recovery from breakdowns, strikes etc. and how best to distribute scarce products during phases of limited production

- possible production smoothing effects due to increased demand visibility
- quantification of performance improvements in monetary terms
- inventory effects such as average and peak inventory requirements in the light of several delivery approaches; effect of possible storage or production capacity extension; or efficacy improvements from including raw material suppliers into CPFR

Apart from these more specific issues it would be very interesting to investigate the applicability of the obtained results within supply chain networks of a much wider scale and level of complexity. It would be interesting for future research studies to conduct in-depth case comparisons with other supply chain frameworks that are in a phase of lower or higher degree of collaboration. It would also be valuable to investigate other industries to find support or differences to the findings of this study. This could lead to a more specific definition in which environments the recommendations of this study are applicable and appropriate. Ultimately, this would lead to strengthen the internal validity of the study and its wider generalizability.

Overall, we believe the research framework offers significant additional potential for further investigations and it will be an interesting task to explore them further within future research undertakings. The model and analysis framework presented within this study were most successful in providing a starting point to look at where the investigated companies are and what might lie ahead of them as well as providing a guide for further capability development of all involved market participants.
Altogether the research outcomes resulting from this study can already be considered as a great success since the obtained results have actively benefited the participating companies. At the same time certain gaps in literature that have commonly been neglected by current supply chain management research were identified, discussed and possible solutions proposed within this thesis and in various research papers.

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Thron, T., Nagy, G. and Wassan, N. (2006a), "The Impact of Fill-rate Dependent Reordering Behaviour on Supply Chains under Varying Levels of Demand Transparency", presented at International Conference on Information Systems, Logistics and Supply Chain (ILS'06), Lyon, France, *published within ILS 2006 conference proceedings,* pp. 423-430, ISSN: 90-77381-26-0

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Thron, T., Nagy, G. and Wassan, N. (2007a), "Diverse Allocation Strategies within the Process of Distributing Scarce Products amongst Traditional and Collaboratively Replenished Customers", presented at the International Conference on Industrial Engineering and Systems Management (IESM'2007), Beijing, China, published *within IESM 2007 conference proceedings*, pp. 257-27, ISBN: 978-7-302-15312-2

Thron, T., Nagy, G. and Wassan, N. (2007b), "Evaluating Various Supply Chain Advancements to Achieve Higher Efficiency in Environments with Perishable Products", *International Journal of Logistics Management*, Vol. 18, No. 3, pp. 364-384

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Appendix I: Publications

Journal articles:

Thron, T., Nagy, G. and Wassan, N. (2007b), "Evaluating Various Supply Chain Advancements to Achieve Higher Efficiency in Environments with Perishable Products", *International Journal of Logistics Management*, Vol. 18, No. 3

Thron, T., Nagy, G. and Wassan, N. (2006c), "The impact of increasing demand visibility on order fulfilment and service level in heterogeneous ROP/CPFR environments", *International Journal of Physical Distribution & Logistics Management*, Vol. 36, No. 8, pp. 596-620

Peer-reviewed conference papers:

Thron, T., Nagy, G. and Wassan, N. (2005), "The Impact of Various Delivery Prioritization Strategies in heterogeneous Supply Chain Environments", presented at Industrial Simulation Conference 2005, Berlin, Germany, *published within ISC2005 conference proceedings*, EUROSIS-ETI, pp. 262-268, ISSN: 90-77381-18-0

Thron, T., Nagy, G. and Wassan, N. (2006a), "The Impact of Fill-rate Dependent Reordering Behaviour on Supply Chains under Varying Levels of Demand Transparency", presented at International Conference on Information Systems, Logistics and Supply Chain (ILS'06), Lyon, France, *published within ILS 2006 conference proceedings*, pp. 423-430, ISSN: 90-77381-26-0

Thron, T., Nagy, G. and Wassan, N. (2006b), "The Distinct Influence of Various CPFR Components on Overall Supply-Chain Performance", presented at Industrial Simulation Conference 2006, Palermo, Italy, *published within ISC2006 proceedings*, EUROSIS-ETI, pp. 1234-1247, ISSN: 2-930294-18-3 - **awarded as second best conference paper**

Thron, T., Nagy, G. and Wassan, N. (2007a), "Diverse Allocation Strategies within the Process of Distributing Scarce Products amongst Traditional and Collaboratively Replenished Customers", presented at the International Conference on Industrial Engineering and Systems Management (IESM'2007), Beijing, China, published *within IESM 2007 conference proceedings*, pp. 257-27, ISBN: 978-7-302-15312-2

Working papers:

Thron, T. (2004), "Opportunities and Vulnerabilities of Demand Forecasting Approaches prior to and after Implementation into Computer Simulation Models", Working Paper, Kent Business School

Appendix II: Simulation model parameter settings

Factor settings		Mustard	PASTA	Pickles
std_demand	**units**	5000/6000/5000/4000	5000/9000/4000/2000	3000/7000/7000/3000
	setup	25%,30%,25%,20%	25%,45%,20%,10%	15%,35%,35%,15%
	actual	25.2%,29.9%,25.1%,19.8%	25.1%,45.5%,19.8%,9.6%	14.8%,35.9%,33.9%,15.4
ROP delivery	**option1**	F/Tu/m/m	f/F/f/f	w1Tu/Th/Tu/w2Th
	option2	D/D/D/D	D/D/D/D	D/D/D/D
Forecast values	**trend-alpha**	0.3DES	0.25DES	0.15 DES
Production	**setup when?**	Monday morning	Monday morning	Monday morning
	Horizont	3 weeks smoothing	3 weeks smoothing	3 weeks smoothing
	FC	arvg +1,+2,+3 weeks ahead	avrg +0,+1,+2 weeks ahead	avrg +1,+2,+3 weeks ahea
Productionrate	**standard**	2.4	2.4	2.4
	max	1.6 (+50% above normal)	1.75 (+37% above normal)	1.6 (+50% above normal)
	min	no lower limit	no lower limit	no lower limit
	overutilise	<1.8	<2.0	<1.8
	underutilise	>3.2	>3.0	>3.2
	production time	8am-16pm Mo-Fri	8am-16pm Mo-Fri	8am-16pm Mo-Fri
	distribution	fixed	fixed	fixed
FC	**VMI**	monthly SF*Promo*market promo uncertainty adjusted	monthly SF*Promo*market promo uncertainty adjusted	monthly SF*Promo*marke promo uncertainty adjuste
uncertainty factor	**promo adj**	80%-110%	80%-110%	85%-115%
	promo level	>1.24	>1.34	>1.39
		market=biannual adjustment to sales	market=biannual adjustment to sales	market=biannual adjustment sales
FC	**CPFR**	weeklySF*Promo*Trend DES	weeklySF*Promo*Trend DES	weeklySF*Promo*Trend DES
ROP adjustment	**rewe**	3.11	3.19	3.13
	kaufland	3.1	3.18	3.22
(promo+market trend)	**edeka**	3.1	3.11	3.16
	walmart	3.11	3.04	3.19
ROP seasonal F	**increase**	Dec,Apr,May,Jun +10%	Nov, Dec, Jan +10%	Dec,Jan +33%
	decrease	Aug,Sep,Oct,Nov -10%	Jun, Jul, Aug -10%	Jun,Jul,Aug,Sep -16.6%
Inventory level	**upper 1st limit**	600	400	600
(avrg daily inv after delivery)	**diminish**	-15%	-15%	-15%
	upper 2nd limit	900	400	1000
	diminish	-30%	-30%	-30%
	promo interrupt	following 3 weeks	following 3 weeks	following 3 weeks
	interruption trigger	3.16	3.4 ~ top25% demand weeks	3.46
	lower limit	200	100	250
	increase	5%	5%	10%
	target inventory	500	400	500
	excessive inv	1000	1000	1000

Manu-DC Delivery	**when?**	everyday at 6am	everyday at 6am	everyday at 6am
	reorder trigger	default day/reorder barrier	default day/reorder barrier	default day/reorder barrie
	reorder barrier ROP	DC inv<0.67forecasted weeks	DC inv<1forecasted weeks	DC inv<0.67/1 forecasted we
	reorder barrier CPFR	DC inv<0.5forecasted weeks	DC inv<0.67forecasted weeks	DC inv<0.5/0.67 forecaste weeks
	FC	VMI or CPFR	VMI or CPFR	VMI or CPFR
	reorder Quantity ROP fix	FC 4th-18th day from pt of FC-DCinv+0.5std_demand	FC 4th-18th day from pt of FC-DCinv+0.5std_demand	FC 4th-18th day from pt of F DCinv+0.5std_demand
	reorder Quantity ROP flex	FC 4th-18th day from pt of FC	FC 4th-18th day from pt of FC	FC following2weeks*0.5/FC 18th day
	reorder Quantity CPFR	FC 4th-18th day from pt of FC-DCinv	FC 4th-18th day from pt of FC-DCinv	FC following2weeks*0.5-Dcinv+2d_safety stock
	safety inventory level	0d-VMI/CPFR,3.5daysROPfix,3.67daysROPflex	0d-VMI/CPFR,3.5daysROPffix,6days ROPflex	2d-VMI, 2dCPFR 3.67d-ROP 3.5d-ROPfix
	min loadlevel	70% of order	70% of order	70% of order
	reorder intervall	ca 2 weeks	ca 2 weeks	ca 1 week/2weeks
	transportation time	1 day (1400mins)	1 day (1400mins)	1 day (1400mins)
	special case	Q evtl loadlevel adjusted	Q evtl loadlevel adjusted	Q evtl loadlevel adjusted
Availability	**>70% reqest avail**	same ratio for all orders	same ratio for all orders	same ratio for all orders
	<70% request avail	prioritisation	prioritisation	prioritisation
Prioritisation	**ROP**	fixed/random	fixed/random	fixed/random
	ROP override	max waiting time/ CPFR&VMI delivery	max waiting time/ CPFR&VMI delivery	max waiting time/ CPFR&V delivery
	Customer preference	none	C2 if WT min1day&no>3dWT of C1/C3/C4	C2/C3 if WT min1day&no>3c of C1/C4
	VMI/CPFR	DCinv/FC 2 weeks ahead	DCinv/FC 2 weeks ahead	DCinv/FC 1week ahead
	avrg inv ratio CPFR	0.15-0.4(medium inv)	0.3-0.6(low inv)	0.2-0.5(2weeks),0.05-0.3(1week)(medinv)
	Avrg inv ratio VMI	0.2-0.4(medium inv)	0.2-0.5(low inv)	0.2-0.5(2weeks),0.05-0.25(1week)(medinv)
DC-Retail Delivery	**when?**	everyday at 6am	everyday at 6am	everyday at 6am
	reorder trigger	Reorder barrier	reorder barrier	reorder barrier
	reorder barrier	outlet inv<3 days FC	outlet inv<3 days FC	outlet inv<2.5/**3** days FC
	FC	CPFR	CPFR	CPFR
	reorder Quantity	FC demand 1 week	FC demand 1 week	FC demand 1 week
	reorder intervall	ca 1 week	ca 1 week	ca 1 week
	transportation time	1 day (1400mins)	1 day (1400mins)	1 day (1400mins)
Availability	**>70% reqest avail**	same ratio for all orders	same ratio for all orders	same ratio for all orders
	<70% request avail	prioritisation	prioritisation	prioritisation
Prioritisation		lowest outlet-inventory	lowest outlet-inventory	lowest outlet-inventory
Demand distribution	**distribution type**	exponential E(x)	exponential E(x)	exponential E(x)
	setup - Rewe	daily - Mo/Tu -20%, Fr/Sa +20%	daily - Mo/Tu -20%, Fr/Sa +20%	daily - Mo/Tu -20%, Fr/Sa +2
	setup - Kaufland	daily - Mo/Tu -30%, Fr/Sa +30%	daily - Mo/Tu -30%, Fr/Sa +30%	daily - Mo/Tu -30%, Fr/Sa +3
	setup- Edeka	daily - Mo/Tu -20%, Fr/Sa +20%	daily - Mo/Tu -20%, Fr/Sa +20%	daily - Mo/Tu -20%, Fr/Sa +2
	setup- Walmart	daily - Mo/Tu -30%, Fr/Sa +30%	daily - Mo/Tu -30%, Fr/Sa +30%	daily - Mo/Tu -30%, Fr/Sa +3

Appendix III: Simulation model – logic code

```
VL SECTION: Time Check Logic
 IF Simulation Time = 0
  (Disabled) Open Dialog   VMI Setup
  (Disabled) Open Dialog   Start Menue
  SET VMI_DC_Rewe = 2
  SET VMI_Retail_Rewe = 2
  '------------- S E T T I N G S ---------
  SET alpha = 0.15
  (Disabled) SET CPFR_Rewe = 2
  (Disabled) SET CPFR_Kaufland = 2
  (Disabled) SET CPFR_Edeka = 2
  (Disabled) SET CPFR_WalMart = 2
  SET inventory1 = 600
  SET inventory2 = 1000
  SET inventory3 = 325
  SET inventory4 = 0.925
  SET vmi_uncertainty = 1.39
  SET safetyinv = 5
  SET manu_expiration_time = 201600
  SET DC_expiration_time = 201600
  SET retail_expiration_time = 201600
  SET std_demand_rewe = 3000
  SET std_demand_kaufland = 7000
  SET std_demand_edeka = 7000
  SET std_demand_walmart = 3000
  SET Trend_rewe = 1
  SET Trend_kaufland = 1
  SET Trend_edeka = 1
  SET Trend_walmart = 1
 SET weektime = Simulation Time-[[WEEK[Simulation Time]-1]*10080]
 SET week = WEEK[Simulation Time]
 (Disabled) SET CPFR_Rewe = 0
 (Disabled) SET CPFR_Kaufland = 0
 (Disabled) SET CPFR_Edeka = 0
 (Disabled) SET CPFR_WalMart = 0
 IF week = 171
  IF weektime = 60
   UNTIL res_DCtotal_deliveries.Count Contents >= loading_success
    Add Work To Queue   Main Work Item Type , res_DCtotal_deliveries
   UNTIL res_DCtotal_failures.Count Contents >= loading_failures
    Add Work To Queue   Main Work Item Type , res_DCtotal_failures
   UNTIL res_DCRewe_delays.Count Contents >= long_waits_rewe
    Add Work To Queue   Main Work Item Type , res_DCRewe_delays
   UNTIL res_DCRewe_longdelays.Count Contents >= verylong_waits_rewe
    Add Work To Queue   Main Work Item Type , res_DCRewe_longdelays
   UNTIL res_DCKaufland_delays.Count Contents >= long_waits_kaufland
    Add Work To Queue   Main Work Item Type , res_DCKaufland_delays
   UNTIL res_DCKaufland_longdelays.Count Contents >= verylong_waits_kaufland
    Add Work To Queue   Main Work Item Type , res_DCKaufland_longdelays
   UNTIL res_DCEdeka_delays.Count Contents >= long_waits_edeka
    Add Work To Queue   Main Work Item Type , res_DCEdeka_delays
   UNTIL res_DCEdeka_longdelays.Count Contents >= verylong_waits_edeka
    Add Work To Queue   Main Work Item Type , res_DCEdeka_longdelays
   UNTIL res_DCWalMart_delays.Count Contents >= long_waits_walmart
    Add Work To Queue   Main Work Item Type , res_DCWalMart_delays
   UNTIL res_DCWalMart_longdelays.Count Contents >= verylong_waits_walmart
    Add Work To Queue   Main Work Item Type , res_DCWalMart_longdelays
   UNTIL res_RRewe_total_deliveries.Count Contents >= total_deliveries_retail_rewe
    Add Work To Queue   Main Work Item Type , res_RRewe_total_deliveries
   UNTIL res_RKaufland_total_deliveries.Count Contents >= total_deliveries_retail_kaufland
    Add Work To Queue   Main Work Item Type , res_RKaufland_total_deliveries
   UNTIL res_REdeka_total_deliveries.Count Contents >= total_deliveries_retail_edeka
    Add Work To Queue   Main Work Item Type , res_REdeka_total_deliveries
   UNTIL res_RWalMart_total_deliveries.Count Contents >= total_deliveries_retail_walmart
    Add Work To Queue   Main Work Item Type , res_RWalMart_total_deliveries
   UNTIL res_RRewe_total_failures.Count Contents >= loading_failures_retail_rewe
    Add Work To Queue   Main Work Item Type , res_RRewe_total_failures
   UNTIL res_RKaufland_total_failures.Count Contents >= loading_failures_retail_kaufland
    Add Work To Queue   Main Work Item Type , res_RKaufland_total_failures
   UNTIL res_REdeka_total_failures.Count Contents >= loading_failures_retail_edeka
    Add Work To Queue   Main Work Item Type , res_REdeka_total_failures
   UNTIL res_RWalMart_total_failures.Count Contents >= loading_failures_retail_walmart
```

```
  Add Work To Queue   Main Work Item Type , res_RWalMart_total_failures
UNTIL res_RRewe_delays.Count Contents >= longwaits_retail_Rewe
  Add Work To Queue   Main Work Item Type , res_RRewe_delays
UNTIL res_RKaufland_delays.Count Contents >= longwaits_retail_Kaufland
  Add Work To Queue   Main Work Item Type , res_RKaufland_delays
UNTIL res_REdeka_delays.Count Contents >= longwaits_retail_Edeka
  Add Work To Queue   Main Work Item Type , res_REdeka_delays
UNTIL res_RWalMart_delays.Count Contents >= longwaits_retail_WalMart
  Add Work To Queue   Main Work Item Type , res_RWalMart_delays
UNTIL res_RRewe_longdelays.Count Contents >= verylongwaits_Retail_Rewe
  Add Work To Queue   Main Work Item Type , res_RRewe_longdelays
UNTIL res_RKaufland_longdelays.Count Contents >= verylongwaits_Retail_Kaufland
  Add Work To Queue   Main Work Item Type , res_RKaufland_longdelays
UNTIL res_REdeka_longdelays.Count Contents >= verylongwaits_Retail_Edeka
  Add Work To Queue   Main Work Item Type , res_REdeka_longdelays
UNTIL res_RWalMart_longdelays.Count Contents >= verylongwaits_Retail_WalMart
  Add Work To Queue   Main Work Item Type , res_RWalMart_longdelays
SET loadlevel_DC_Rewe = [loadlevel_DC_Rewe/Transport_DC_Rewe.Completed]*1000
UNTIL loadlevel_deliveries_DC_Rewe.Count Contents >= loadlevel_DC_Rewe
  Add Work To Queue   Main Work Item Type , loadlevel_deliveries_DC_Rewe
SET loadlevel_DC_Kaufland = [loadlevel_DC_Kaufland/Transport_DC_Kaufland.Completed]*1000
UNTIL loadlevel_deliveries_DC_Kaufland.Count Contents >= loadlevel_DC_Kaufland
  Add Work To Queue   Main Work Item Type , loadlevel_deliveries_DC_Kaufland
SET loadlevel_DC_Edeka = [loadlevel_DC_Edeka/Transport_DC_Edeka.Completed]*1000
UNTIL loadlevel_deliveries_DC_Edeka.Count Contents >= loadlevel_DC_Edeka
  Add Work To Queue   Main Work Item Type , loadlevel_deliveries_DC_Edeka
SET loadlevel_DC_WalMart = [loadlevel_DC_WalMart/Transport_DC_WalMart.Completed]*1000
UNTIL loadlevel_deliveries_DC_WalMart.Count Contents >= loadlevel_DC_WalMart
  Add Work To Queue   Main Work Item Type , loadlevel_deliveries_DC_WalMart
SET loadlevel_retail_Rewe1 = [loadlevel_retail_Rewe1/Transport_Retail_Rewe 1.Completed]*1000
UNTIL loadlevel_deliveries_retail_Rewe1.Count Contents >= loadlevel_retail_Rewe1
  Add Work To Queue   Main Work Item Type , loadlevel_deliveries_retail_Rewe1
SET loadlevel_retail_Kaufland1 = [loadlevel_retail_Kaufland1/Transport_Retail_Kaufland 1.Completed]*1000
UNTIL loadlevel_deliveries_retail_Kaufland1.Count Contents >= loadlevel_retail_Kaufland1
  Add Work To Queue   Main Work Item Type , loadlevel_deliveries_retail_Kaufland1
SET loadlevel_retail_Edeka1 = [loadlevel_retail_Edeka1/Transport_Retail_Edeka 1.Completed]*1000
UNTIL loadlevel_deliveries_retail_Edeka1.Count Contents >= loadlevel_retail_Edeka1
  Add Work To Queue   Main Work Item Type , loadlevel_deliveries_retail_Edeka1
SET loadlevel_retail_WalMart1 = [loadlevel_retail_WalMart1/Transport_Retail_WalMart 1.Completed]*1000
UNTIL loadlevel_deliveries_retail_WalMart1.Count Contents >= loadlevel_retail_WalMart1
  Add Work To Queue   Main Work Item Type , loadlevel_deliveries_retail_WalMart1
IF slgap_rewe_count = 0
  SET slgap_rewe_count = 1
IF slgap_kaufland_count = 0
  SET slgap_kaufland_count = 1
IF slgap_edeka_count = 0
  SET slgap_edeka_count = 1
IF slgap_walmart_count = 0
  SET slgap_walmart_count = 1
SET slgap_overall_avrg =
[[[slgap_rewe_avrg+slgap_kaufland_avrg]+slgap_edeka_avrg]+slgap_walmart_avrg]/[[[slgap_rewe_count+slgap_kaufland_count]+slgap_edeka_count]
+slgap_walmart_count]
IF slgap_rewe_count <> 0
  SET slgap_rewe_avrg = slgap_rewe_avrg/slgap_rewe_count
SET slgap_rewe_count = 1-[slgap_rewe_count/157]
IF slgap_kaufland_count <> 0
  SET slgap_kaufland_avrg = slgap_kaufland_avrg/slgap_kaufland_count
SET slgap_kaufland_count = 1-[slgap_kaufland_count/157]
IF slgap_edeka_count <> 0
  SET slgap_edeka_avrg = slgap_edeka_avrg/slgap_edeka_count
SET slgap_edeka_count = 1-[slgap_edeka_count/157]
IF slgap_walmart_count <> 0
  SET slgap_walmart_avrg = slgap_walmart_avrg/slgap_walmart_count
SET slgap_walmart_count = 1-[slgap_walmart_count/157]
SET loadlevel_DC_Rewe_count = loadlevel_DC_Rewe_count/Transport_DC_Rewe.Completed
SET loadlevel_DC_Kaufland_count = loadlevel_DC_Kaufland_count/Transport_DC_Kaufland.Completed
SET loadlevel_DC_Edeka_count = loadlevel_DC_Edeka_count/Transport_DC_Edeka.Completed
SET loadlevel_DC_Walmart_count = loadlevel_DC_Walmart_count/Transport_DC_WalMart.Completed
SET fc_accuracy = fc_accuracy/158
SET order_leadtime_DC_rewe = order_leadtime_DC_rewe/Transport_DC_Rewe.Completed
SET order_leadtime_DC_kaufland = order_leadtime_DC_kaufland/Transport_DC_Kaufland.Completed
SET order_leadtime_DC_edeka = order_leadtime_DC_edeka/Transport_DC_Edeka.Completed
SET order_leadtime_DC_walmart = order_leadtime_DC_walmart/Transport_DC_WalMart.Completed
SET productionrate_avrg = productionrate_avrg/158
SET production_volatility = production_volatility/158
SET production_underutilisation = production_underutilisation/158
```

```
    SET production_overutilisation = production_overutilisation/158
    SET order_volatility_Rewe = order_volatility_Rewe/Transport_DC_Rewe.Completed
    SET order_volatility_Kaufland = order_volatility_Kaufland/Transport_DC_Kaufland.Completed
    SET order_volatility_Edeka = order_volatility_Edeka/Transport_DC_Edeka.Completed
    SET order_volatility_Walmart = order_volatility_Walmart/Transport_DC_WalMart.Completed
 IF Simulation Time-tmp_time = 43680
  SET month = month+1
  IF month = 13
   SET month = 1
  SET tmp_time = Simulation Time
 IF week > 13
  'Excessive INVENTORY METRIC
  IF HOUR[Simulation Time] = 1
   IF Inventory_Factory.Count Contents > 1000
    SET excessive_inv_time = excessive_inv_time+1
 IF weektime = 0
  SET loading_failures = [[loading_failures_rewe+loading_failures_kaufland]+loading_failures_edeka]+loading_failures_walmart
  'Define Demand
  SET demandrate_rewe = 92400/[output[28,week]*std_demand_rewe]
  SET demandrate_kaufland = 92400/[output[29,week]*std_demand_kaufland]
  SET demandrate_edeka = 92400/[output[30,week]*std_demand_edeka]
  SET demandrate_walmart = 92400/[output[31,week]*std_demand_walmart]
  Set Distribution Parameters   customerarrival_day_rewe , Exponential , demandrate_rewe , 0 , 0 , 0
  Set Distribution Parameters   customerarrival_day_kaufland , Exponential , demandrate_kaufland , 0 , 0 , 0
  Set Distribution Parameters   customerarrival_day_edeka , Exponential , demandrate_edeka , 0 , 0 , 0
  Set Distribution Parameters   customerarrival_day_walmart , Exponential , demandrate_walmart , 0 , 0 , 0
  'Output Production and Demand Data to Spreadsheet
  Get Result   total_production , Current Run , Inventory_Factory: Items Entered
  Get Result   total_demand_rewe , Current Run , Demand_Rewe: Number Entered
  Get Result   total_demand_kaufland , Current Run , Demand_Kaufland: Number Entered
  Get Result   total_demand_edeka , Current Run , Demand_Edeka: Number Entered
  Get Result   total_demand_walmart , Current Run , Demand_WalMart: Number Entered
  SET output[35,week] = [[[unsatisfied_demand_Rewe 1.Count Contents+unsatisfied_demand_Rewe 2.Count Contents]+unsatisfied_demand_Rewe
3.Count Contents]-lost_sales_rewe]/[total_demand_rewe-total_demand_rewe_tmp]
  SET output[36,week] = [[[unsatisfied_demand_Kaufland 1.Count Contents+unsatisfied_demand_Kaufland 2.Count
Contents]+unsatisfied_demand_Kaufland 3.Count Contents]-lost_sales_kaufland]/[total_demand_kaufland-total_demand_kaufland_tmp]
  SET output[37,week] = [[[unsatisfied_demand_Edeka 1.Count Contents+unsatisfied_demand_Edeka 2.Count
Contents]+unsatisfied_demand_Edeka 3.Count Contents]-lost_sales_edeka]/[total_demand_edeka-total_demand_edeka_tmp]
  SET output[38,week] = [[[unsatisfied_demand_WalMart 1.Count Contents+unsatisfied_demand_WalMart 2.Count
Contents]+unsatisfied_demand_WalMart 3.Count Contents]-lost_sales_walmart]/[total_demand_walmart-total_demand_walmart_tmp]
  'weekly SL GAP analysis
  IF week >= 15
   IF output[35,week] > 0
    SET slgap_rewe_avrg = slgap_rewe_avrg+output[35,week]
    SET slgap_rewe_count = slgap_rewe_count+1
    IF output[35,week] > slgap_rewe_highest
     SET slgap_rewe_highest = output[35,week]
   IF output[36,week] > 0
    SET slgap_kaufland_avrg = slgap_kaufland_avrg+output[36,week]
    SET slgap_kaufland_count = slgap_kaufland_count+1
    IF output[36,week] > slgap_kaufland_highest
     SET slgap_kaufland_highest = output[36,week]
   IF output[37,week] > 0
    SET slgap_edeka_avrg = slgap_edeka_avrg+output[37,week]
    SET slgap_edeka_count = slgap_edeka_count+1
    IF output[37,week] > slgap_edeka_highest
     SET slgap_edeka_highest = output[37,week]
   IF output[38,week] > 0
    SET slgap_walmart_avrg = slgap_walmart_avrg+output[38,week]
    SET slgap_walmart_count = slgap_walmart_count+1
    IF output[38,week] > slgap_walmart_highest
     SET slgap_walmart_highest = output[38,week]
  SET lost_sales_rewe = [unsatisfied_demand_Rewe 1.Count Contents+unsatisfied_demand_Rewe 2.Count Contents]+unsatisfied_demand_Rewe
3.Count Contents
  SET lost_sales_kaufland = [unsatisfied_demand_Kaufland 1.Count Contents+unsatisfied_demand_Kaufland 2.Count
Contents]+unsatisfied_demand_Kaufland 3.Count Contents
  SET lost_sales_edeka = [unsatisfied_demand_Edeka 1.Count Contents+unsatisfied_demand_Edeka 2.Count
Contents]+unsatisfied_demand_Edeka 3.Count Contents
  SET lost_sales_walmart = [unsatisfied_demand_WalMart 1.Count Contents+unsatisfied_demand_WalMart 2.Count
Contents]+unsatisfied_demand_WalMart 3.Count Contents
  SET output[2,week+1] = [total_production-total_production_tmp]*20
  SET output[3,week+1] = [total_demand_rewe-total_demand_rewe_tmp]*20
  SET output[4,week+1] = [total_demand_kaufland-total_demand_kaufland_tmp]*20
  SET output[5,week+1] = [total_demand_edeka-total_demand_edeka_tmp]*20
  SET output[6,week+1] = [total_demand_walmart-total_demand_walmart_tmp]*20
  IF VMI_DC_Rewe = 2
```

```
IF week < 4
 SET LES_FC_rewe = std_demand_rewe
 SET LES_FC_kaufland = std_demand_kaufland
 SET LES_FC_edeka = std_demand_edeka
 SET LES_FC_walmart = std_demand_walmart
IF week >= 2
 'output de-promo+de-seasonalised demand
 SET output[7,week+1] = ROUND[output[3,week+1]/[[output[17,week-1]*output[18,week-1]]*output[26,week-1]]]
 SET output[8,week+1] = ROUND[output[4,week+1]/[[output[19,week-1]*output[20,week-1]]*output[26,week-1]]]
 SET output[9,week+1] = ROUND[output[5,week+1]/[[output[21,week-1]*output[22,week-1]]*output[26,week-1]]]
 SET output[10,week+1] = ROUND[output[6,week+1]/[[output[23,week-1]*output[24,week-1]]*output[26,week-1]]]
IF week >= 4
 SET S1 = [alpha*output[7,week+1]]+[[1-alpha]*output[50,week+1]]
 SET S2 = [alpha*S1]+[[1-alpha]*output[51,week+1]]
 SET LES_FC_rewe = [[2*S1]-S2]+[[S1-S2]*[alpha/[1-alpha]]]
 SET output[50,week+2] = S1
 SET output[51,week+2] = S2
 (Disabled) SET LES_FC_rewe = [alpha*output[7,week+1]]+[[1-alpha]*output[11,week+1]]
 SET S1 = [alpha*output[8,week+1]]+[[1-alpha]*output[52,week+1]]
 SET S2 = [alpha*S1]+[[1-alpha]*output[53,week+1]]
 SET LES_FC_kaufland = [[2*S1]-S2]+[[S1-S2]*[alpha/[1-alpha]]]
 SET output[52,week+2] = S1
 SET output[53,week+2] = S2
 (Disabled) SET LES_FC_kaufland = [alpha*output[8,week+1]]+[[1-alpha]*output[12,week+1]]
 SET S1 = [alpha*output[9,week+1]]+[[1-alpha]*output[54,week+1]]
 SET S2 = [alpha*S1]+[[1-alpha]*output[55,week+1]]
 SET LES_FC_edeka = [[2*S1]-S2]+[[S1-S2]*[alpha/[1-alpha]]]
 SET output[54,week+2] = S1
 SET output[55,week+2] = S2
 (Disabled) SET LES_FC_edeka = [alpha*output[9,week+1]]+[[1-alpha]*output[13,week+1]]
 SET S1 = [alpha*output[10,week+1]]+[[1-alpha]*output[56,week+1]]
 SET S2 = [alpha*S1]+[[1-alpha]*output[57,week+1]]
 SET LES_FC_walmart = [[2*S1]-S2]+[[S1-S2]*[alpha/[1-alpha]]]
 SET output[56,week+2] = S1
 SET output[57,week+2] = S2
 (Disabled) SET LES_FC_walmart = [alpha*output[10,week+1]]+[[1-alpha]*output[14,week+1]]
 SET Trend_rewe = LES_FC_rewe/std_demand_rewe
 SET Trend_kaufland = LES_FC_kaufland/std_demand_kaufland
 SET Trend_edeka = LES_FC_edeka/std_demand_edeka
 SET Trend_walmart = LES_FC_walmart/std_demand_walmart
SET output[11,week+2] = LES_FC_rewe
SET output[12,week+2] = LES_FC_kaufland
SET output[13,week+2] = LES_FC_edeka
SET output[14,week+2] = LES_FC_walmart
IF Simulation Time = Warm Up Period
 SET total_production_tmp = 0
 SET total_demand_rewe_tmp = 0
 SET total_demand_kaufland_tmp = 0
 SET total_demand_edeka_tmp = 0
 SET total_demand_walmart_tmp = 0
 SET lost_sales_rewe = 0
 SET lost_sales_kaufland = 0
 SET lost_sales_edeka = 0
 SET lost_sales_walmart = 0
 SET loading_failures = 0
 SET loading_success = 0
 SET loading_failures_rewe = 0
 SET loading_failures_kaufland = 0
 SET loading_failures_edeka = 0
 SET loading_failures_walmart = 0
 SET loading_failures_retail_rewe = 0
 SET loading_failures_retail_kaufland = 0
 SET loading_failures_retail_edeka = 0
 SET loading_failures_retail_walmart = 0
 SET long_waits_rewe = 0
 SET long_waits_kaufland = 0
 SET long_waits_edeka = 0
 SET long_waits_walmart = 0
 SET longwaits_retail_Rewe = 0
 SET longwaits_retail_Kaufland = 0
 SET longwaits_retail_Edeka = 0
 SET longwaits_retail_WalMart = 0
 SET verylong_waits_rewe = 0
 SET verylong_waits_kaufland = 0
 SET verylong_waits_edeka = 0
 SET verylong_waits_walmart = 0
```

```
   SET verylongwaits_Retail_Rewe = 0
   SET verylongwaits_Retail_Kaufland = 0
   SET verylongwaits_Retail_Edeka = 0
   SET verylongwaits_Retail_WalMart = 0
   SET total_deliveries_retail_rewe = 0
   SET total_deliveries_retail_kaufland = 0
   SET total_deliveries_retail_edeka = 0
   SET total_deliveries_retail_walmart = 0
   SET loadlevel_DC_Rewe = 0
   SET loadlevel_DC_Kaufland = 0
   SET loadlevel_DC_Edeka = 0
   SET loadlevel_DC_WalMart = 0
   SET loadlevel_retail_Rewe1 = 0
   SET loadlevel_retail_Kaufland1 = 0
   SET loadlevel_retail_Edeka1 = 0
   SET loadlevel_retail_WalMart1 = 0
   SET loadlevel_DC_Rewe_count = 0
   SET loadlevel_DC_Kaufland_count = 0
   SET loadlevel_DC_Edeka_count = 0
   SET loadlevel_DC_Walmart_count = 0
  ELSE
   SET total_production_tmp = total_production
   SET total_demand_rewe_tmp = total_demand_rewe
   SET total_demand_kaufland_tmp = total_demand_kaufland
   SET total_demand_edeka_tmp = total_demand_edeka
   SET total_demand_walmart_tmp = total_demand_walmart
IF HOUR[Simulation Time] = 0
  'DAILY DEMAND VARIATION SETUP
  Set Distribution Parameters   customerarrival_day_rewe , Exponential , demandrate_rewe , 0 , 0 , 0
  Set Distribution Parameters   customerarrival_day_kaufland , Exponential , demandrate_kaufland , 0 , 0 , 0
  Set Distribution Parameters   customerarrival_day_edeka , Exponential , demandrate_edeka , 0 , 0 , 0
  Set Distribution Parameters   customerarrival_day_walmart , Exponential , demandrate_walmart , 0 , 0 , 0
  IF DAY[Simulation Time] <= 2
   Set Distribution Parameters   customerarrival_day_rewe , Exponential , demandrate_rewe*1.25 , 0 , 0 , 0
   Set Distribution Parameters   customerarrival_day_kaufland , Exponential , demandrate_kaufland*1.43 , 0 , 0 , 0
   Set Distribution Parameters   customerarrival_day_edeka , Exponential , demandrate_edeka*1.25 , 0 , 0 , 0
   Set Distribution Parameters   customerarrival_day_walmart , Exponential , demandrate_walmart*1.43 , 0 , 0 , 0
  IF DAY[Simulation Time] >= 5
   IF DAY[Simulation Time] <= 6
    Set Distribution Parameters   customerarrival_day_rewe , Exponential , demandrate_rewe*0.83 , 0 , 0 , 0
    Set Distribution Parameters   customerarrival_day_kaufland , Exponential , demandrate_kaufland*0.77 , 0 , 0 , 0
    Set Distribution Parameters   customerarrival_day_edeka , Exponential , demandrate_edeka*0.83 , 0 , 0 , 0
    Set Distribution Parameters   customerarrival_day_walmart , Exponential , demandrate_walmart*0.77 , 0 , 0 , 0
SET blockroute_DC_rewe = 1
SET blockroute_DC_kaufland = 1
SET blockroute_DC_edeka = 1
SET blockroute_DC_walmart = 1
SET blockroute_Retail_Rewe 1 = 1
SET blockroute_Retail_Rewe 2 = 1
SET blockroute_Retail_Rewe 3 = 1
SET blockroute_Retail_kaufland 1 = 1
SET blockroute_Retail_kaufland 2 = 1
SET blockroute_Retail_kaufland 3 = 1
SET blockroute_Retail_edeka 1 = 1
SET blockroute_Retail_edeka 2 = 1
SET blockroute_Retail_edeka 3 = 1
SET blockroute_Retail_WalMart 1 = 1
SET blockroute_Retail_WalMart 2 = 1
SET blockroute_Retail_WalMart 3 = 1
'
'------------------------------------DEFINE P R O D U C T I O N --------------------------------------
'
IF HOUR[Simulation Time] = 7
  SET avrg_inv_factory = avrg_inv_factory+Inventory_Factory.Count Contents
IF weektime = 0
  SET output[15,week+1] = ROUND[avrg_inv_factory/7]
  SET avrg_inv_factory = 0
  IF VMI_DC_Rewe = 2
   (Disabled) IF Trend_rewe < 1
    SET Trend_rewe = ABS[[[1-Trend_rewe]*0.75]-1]
   (Disabled) IF Trend_rewe > 1
    SET Trend_rewe = [[Trend_rewe-1]*1.25]+1
   IF CPFR_Rewe = 1
    'FC CPFR Rewe
    SET fc_actweek = ROUND[[[output[26,week]*output[17,week]]*output[18,week]]*LES_FC_rewe]
    SET fc_nxtweek = ROUND[[[output[26,week+1]*output[17,week+1]]*output[18,week+1]]*LES_FC_rewe]
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  SET fc_secnextweek = ROUND[[[output[26,week+2]*output[17,week+2]]*output[18,week+2]]*LES_FC_rewe]
  SET fc_3rdnextweek = ROUND[[[output[26,week+3]*output[17,week+3]]*output[18,week+3]]*LES_FC_rewe]
  SET fc_3weeks_rewe = [[fc_nxtweek+fc_secnextweek]+fc_3rdnextweek]
 IF CPFR_Rewe = 2
  'FC VMI REWE
  IF output[17,week]*output[18,week] > vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_actweek = [[[output[33,week]*output[17,week]]*output[18,week]]*uncertainty_factor]
  IF output[17,week+1]*output[18,week+1] > vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_nxtweek = [[[output[33,week+1]*output[17,week+1]]*output[18,week+1]]*uncertainty_factor]
  IF output[17,week+2]*output[18,week+2] > vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_secnextweek = [[[output[33,week+2]*output[17,week+2]]*output[18,week+2]]*uncertainty_factor]
  IF output[17,week+3]*output[18,week+3] > vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_3rdnextweek = [[[output[33,week+3]*output[17,week+3]]*output[18,week+3]]*uncertainty_factor]
  SET fc_3weeks_rewe = ROUND[[[fc_3rdnextweek+fc_nxtweek]+fc_secnextweek]*std_demand_rewe]*output[34,week]
 IF CPFR_Kaufland = 1
  'FC CPFR Kaufland
  SET fc_actweek = ROUND[[[output[26,week]*output[19,week]]*output[20,week]]*LES_FC_kaufland]
  SET fc_nxtweek = ROUND[[[output[26,week+1]*output[19,week+1]]*output[20,week+1]]*LES_FC_kaufland]
  SET fc_secnextweek = ROUND[[[output[26,week+2]*output[19,week+2]]*output[20,week+2]]*LES_FC_kaufland]
  SET fc_3rdnextweek = ROUND[[[output[26,week+3]*output[19,week+3]]*output[20,week+3]]*LES_FC_kaufland]
  SET fc_3weeks_kaufland = [fc_3rdnextweek+fc_nxtweek]+fc_secnextweek
 IF CPFR_Kaufland = 2
  'FC VMI Kaufland
  IF output[19,week]*output[20,week] > vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_actweek = [[[output[33,week]*output[19,week]]*output[20,week]]*uncertainty_factor]
  IF output[19,week+1]*output[20,week+1] > vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_nxtweek = [[[output[33,week+1]*output[19,week+1]]*output[20,week+1]]*uncertainty_factor]
  IF output[19,week+2]*output[20,week+2] > vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_secnextweek = [[[output[33,week+2]*output[19,week+2]]*output[20,week+2]]*uncertainty_factor]
  IF output[19,week+3]*output[20,week+3] > vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_3rdnextweek = [[[output[33,week+3]*output[19,week+3]]*output[20,week+3]]*uncertainty_factor]
  SET fc_3weeks_kaufland = ROUND[[[fc_3rdnextweek+fc_nxtweek]+fc_secnextweek]*std_demand_kaufland]*output[34,week]
 IF CPFR_Edeka = 1
  'FC CPFR Edeka
  SET fc_actweek = ROUND[[[output[26,week]*output[21,week]]*output[22,week]]*LES_FC_edeka]
  SET fc_nxtweek = ROUND[[[output[26,week+1]*output[21,week+1]]*output[22,week+1]]*LES_FC_edeka]
  SET fc_secnextweek = ROUND[[[output[26,week+2]*output[21,week+2]]*output[22,week+2]]*LES_FC_edeka]
  SET fc_3rdnextweek = ROUND[[[output[26,week+3]*output[21,week+3]]*output[22,week+3]]*LES_FC_edeka]
  SET fc_3weeks_edeka = [fc_3rdnextweek+fc_nxtweek]+fc_secnextweek
 IF CPFR_Edeka = 2
  'FC VMI Edeka
  IF output[21,week]*output[22,week] >= vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_actweek = [[[output[33,week]*output[21,week]]*output[22,week]]*uncertainty_factor]
  IF output[21,week+1]*output[22,week+1] >= vmi_uncertainty
   SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
  ELSE
   SET uncertainty_factor = 1
  SET fc_nxtweek = [[[output[33,week+1]*output[21,week+1]]*output[22,week+1]]*uncertainty_factor]
  IF output[21,week+2]*output[22,week+2] >= vmi_uncertainty
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      SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
     ELSE
      SET uncertainty_factor = 1
     SET fc_secnextweek = [[[output[33,week+2]*output[21,week+2]]*output[22,week+2]]*uncertainty_factor]
     IF output[21,week+3]*output[22,week+3] >= vmi_uncertainty
      SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
     ELSE
      SET uncertainty_factor = 1
     SET fc_3rdnextweek = [[[output[33,week+3]*output[21,week+3]]*output[22,week+3]]*uncertainty_factor]
     SET fc_3weeks_edeka = ROUND[[[fc_3rdnextweek+fc_nxtweek]+fc_secnextweek]*std_demand_edeka]*output[34,week]
    IF CPFR_WalMart = 1
     'FC CPFR WalMart
     SET fc_actweek = ROUND[[[output[26,week]*output[23,week]]*output[24,week]]*LES_FC_walmart]
     SET fc_nxtweek = ROUND[[[output[26,week+1]*output[23,week+1]]*output[24,week+1]]*LES_FC_walmart]
     SET fc_secnextweek = ROUND[[[output[26,week+2]*output[23,week+2]]*output[24,week+2]]*LES_FC_walmart]
     SET fc_3rdnextweek = ROUND[[[output[26,week+3]*output[23,week+3]]*output[24,week+3]]*LES_FC_walmart]
     SET fc_3weeks_walmart = [fc_3rdnextweek+fc_nxtweek]+fc_secnextweek
    IF CPFR_WalMart = 2
     'FC VMI WalMart
     IF output[23,week]*output[24,week] > vmi_uncertainty
      SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
     ELSE
      SET uncertainty_factor = 1
     SET fc_actweek = [[[output[33,week]*output[23,week]]*output[24,week]]*uncertainty_factor]
     IF output[23,week+1]*output[24,week+1] > vmi_uncertainty
      SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
     ELSE
      SET uncertainty_factor = 1
     SET fc_nxtweek = [[[output[33,week+1]*output[23,week+1]]*output[24,week+1]]*uncertainty_factor]
     IF output[23,week+2]*output[24,week+2] > vmi_uncertainty
      SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
     ELSE
      SET uncertainty_factor = 1
     SET fc_secnextweek = [[[output[33,week+2]*output[23,week+2]]*output[24,week+2]]*uncertainty_factor]
     IF output[23,week+3]*output[24,week+3] > vmi_uncertainty
      SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
     ELSE
      SET uncertainty_factor = 1
     SET fc_3rdnextweek = [[[output[33,week+3]*output[23,week+3]]*output[24,week+3]]*uncertainty_factor]
     SET fc_3weeks_walmart = ROUND[[[fc_3rdnextweek+fc_nxtweek]+fc_secnextweek]*std_demand_walmart]*output[34,week]
    'Total Production
    SET simple_SF = 1
    IF CPFR_Rewe = 0
     (Disabled) SET fc_3weeks_rewe =
LES_FC_rewe*[[[output[17,week]*output[18,week]]+[output[17,week+1]*output[18,week+1]]]+[output[17,week+2]*output[18,week+2]]]
     IF RANDOM[0] < 2
      (Disabled) SET fc_3weeks_rewe = [[3.17*LES_FC_rewe]*[[output[26,week]+output[26,week+1]]+output[26,week+2]]]/3
      (Disabled) SET fc_3weeks_rewe = 3.2171*LES_FC_rewe
      SET fc_3weeks_rewe = std_demand_rewe*3.13
     IF simple_SF = 1
      IF [month = 12] | [month = 1] = 1
       SET fc_3weeks_rewe = fc_3weeks_rewe*1.33
      IF [month = 6] | [month = 7] | [month = 8] | [month = 9] = 1
       SET fc_3weeks_rewe = fc_3weeks_rewe*0.83
    IF CPFR_Kaufland = 0
     (Disabled) SET fc_3weeks_kaufland =
LES_FC_kaufland*[[[output[19,week]*output[20,week]]+[output[19,week+1]*output[20,week+1]]]+[output[19,week+2]*output[20,week+2]]]
     IF RANDOM[0] < 2
      (Disabled) SET fc_3weeks_kaufland = [[3.2076*LES_FC_kaufland]*[[output[26,week]+output[26,week+1]]+output[26,week+2]]]/3
      (Disabled) SET fc_3weeks_kaufland = 3.2076*LES_FC_kaufland
      SET fc_3weeks_kaufland = std_demand_kaufland*3.22
     IF simple_SF = 1
      IF [month = 12] | [month = 1] = 1
       SET fc_3weeks_rewe = fc_3weeks_rewe*1.33
      IF [month = 6] | [month = 7] | [month = 8] | [month = 9] = 1
       SET fc_3weeks_rewe = fc_3weeks_rewe*0.83
    IF CPFR_Edeka = 0
     (Disabled) SET fc_3weeks_edeka =
LES_FC_edeka*[[[output[21,week]*output[22,week]]+[output[21,week+1]*output[22,week+1]]]+[output[21,week+2]*output[22,week+2]]]
     IF RANDOM[0] < 2
      (Disabled) SET fc_3weeks_edeka = [[3.143*LES_FC_edeka]*[[output[26,week]+output[26,week+1]]+output[26,week+2]]]/3
      (Disabled) SET fc_3weeks_edeka = 3.143*LES_FC_edeka
      SET fc_3weeks_edeka = std_demand_edeka*3.16
      IF simple_SF = 1
       IF [month = 12] | [month = 1] = 1
        SET fc_3weeks_rewe = fc_3weeks_rewe*1.33
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      IF [month = 6] | [month = 7] | [month = 8] | [month = 9] = 1
       SET fc_3weeks_rewe = fc_3weeks_rewe*0.83
   IF CPFR_WalMart = 0
    (Disabled) SET fc_3weeks_walmart =
LES_FC_walmart*[[[output[23,week]*output[24,week]]+[output[23,week+1]*output[24,week+1]]]+[output[23,week+2]*output[24,week+2]]]
     IF RANDOM[0] < 2
      (Disabled) SET fc_3weeks_walmart = [[3.0714*LES_FC_walmart]*[[output[26,week]+output[26,week+1]]+output[26,week+2]]]/3
      (Disabled) SET fc_3weeks_walmart = 3.0714*LES_FC_walmart
      SET fc_3weeks_walmart = std_demand_walmart*3.19
     IF simple_SF = 1
      IF [month = 12] | [month = 1] = 1
       SET fc_3weeks_rewe = fc_3weeks_rewe*1.33
      IF [month = 6] | [month = 7] | [month = 8] | [month = 9] = 1
       SET fc_3weeks_rewe = fc_3weeks_rewe*0.83
   SET fc_3weeks_total = [[fc_3weeks_rewe+fc_3weeks_kaufland]+fc_3weeks_edeka]+fc_3weeks_walmart
   SET productionrate = 144000/fc_3weeks_total
   'Accuracy metrics
   SET fc_3weeks_rewe = [output[28,week+1]+output[28,week+2]]+output[28,week+3]
   SET fc_3weeks_kaufland = [output[29,week+1]+output[29,week+2]]+output[29,week+3]
   SET fc_3weeks_edeka = [output[30,week+1]+output[30,week+2]]+output[30,week+3]
   SET fc_3weeks_walmart = [output[31,week+1]+output[31,week+2]]+output[31,week+3]
   SET demand_3weeks_total =
[[[std_demand_rewe*fc_3weeks_rewe]+[std_demand_kaufland*fc_3weeks_kaufland]]+[std_demand_edeka*fc_3weeks_edeka]]+[std_demand_walmart
*fc_3weeks_walmart]
   IF WEEK[Simulation Time] >= 14
    SET fc_accuracy = fc_accuracy+[ABS[fc_3weeks_total-demand_3weeks_total]/demand_3weeks_total]
   'Promo Information ?
   SET prodlimit = 20
   IF [[CPFR_Rewe+CPFR_Kaufland]+CPFR_Edeka]+CPFR_WalMart >= 3
    SET prodlimit = 3.46
   '********************************** I N V E N T O R Y  L E V E L  S E T U P ********************************************
   IF output[15,week+1] > inventory1
    IF [output[25,week+1]+output[25,week+2]]+output[25,week+3] <= prodlimit
     SET productionrate = productionrate*1.15
     IF output[15,week+1] > inventory2
      SET productionrate = productionrate*1.13
   IF output[15,week+1] <= inventory3
    SET productionrate = productionrate*inventory4
   IF productionrate < 1.6
    SET productionrate = 1.6
   '********************************** I N V E N T O R Y  L E V E L  S E T U P ********************************************
   Set Distribution Parameters   factory_production , Fixed , productionrate , 0 , 0 , 0
  SET output[1,week+2] = productionrate
  SET production_volatility = production_volatility+[[ABS[productionrate-2.4]]/2.4]
  IF week > 13
   SET productionrate_avrg = productionrate_avrg+productionrate
   IF productionrate > 3.2
    SET production_underutilisation = production_underutilisation+1
   IF productionrate < 1.8
    SET production_overutilisation = production_overutilisation+1
 '
 '---------------------------------MANUFACTURER -> DC  D E L I V E R Y ----------------------------------------
 '
 IF HOUR[Simulation Time] = 6
  'FC Rewe
  IF CPFR_Rewe <= 1
   SET fc_actweek_rewe = ROUND[[[output[26,week]*output[17,week]]*output[18,week]]*LES_FC_rewe]
   SET fc_nxtweek = ROUND[[[output[26,week+1]*output[17,week+1]]*output[18,week+1]]*LES_FC_rewe]
   SET fc_secnextweek_rewe = ROUND[[[output[26,week+2]*output[17,week+2]]*output[18,week+2]]*LES_FC_rewe]
   SET fc_1week_rewe = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_rewe]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
   SET fc_2weeks_rewe = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_rewe]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_rewe]]
   (Disabled) SET output[45,week] = fc_2weeks_rewe
  IF CPFR_Rewe = 2
   IF output[17,week]*output[18,week] > vmi_uncertainty
    SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
   ELSE
    SET uncertainty_factor = 1
   SET fc_actweek_rewe = [[[[output[33,week]*output[17,week]]*output[18,week]]*uncertainty_factor]*std_demand_rewe]*output[34,week]
   IF output[17,week+1]*output[18,week+1] > vmi_uncertainty
    SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
   ELSE
    SET uncertainty_factor = 1
   SET fc_nxtweek = [[[[output[33,week+1]*output[17,week+1]]*output[18,week+1]]*uncertainty_factor]*std_demand_rewe]*output[34,week]
   IF output[17,week+2]*output[18,week+2] > vmi_uncertainty
    SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
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    ELSE
     SET uncertainty_factor = 1
    SET fc_secnextweek_rewe =
[[[[output[33,week+2]*output[17,week+2]]*output[18,week+2]]*uncertainty_factor]*std_demand_rewe]*output[34,week]
    SET fc_1week_rewe = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_rewe]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
    SET fc_2weeks_rewe = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_rewe]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_rewe]]
    (Disabled) SET output[45,week] = fc_2weeks_rewe
   'FC Kaufland
   IF CPFR_Kaufland <= 1
    SET fc_actweek_kaufland = ROUND[[[output[26,week]*output[19,week]]*output[20,week]]*LES_FC_kaufland]
    SET fc_nxtweek = ROUND[[[output[26,week+1]*output[19,week+1]]*output[20,week+1]]*LES_FC_kaufland]
    SET fc_secnextweek_kaufland = ROUND[[[output[26,week+2]*output[19,week+2]]*output[20,week+2]]*LES_FC_kaufland]
    SET fc_1week_kaufland = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_kaufland]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
    SET fc_2weeks_kaufland = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_kaufland]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_kaufland]]
   IF CPFR_Kaufland = 2
    'FC VMI Kaufland
    IF output[19,week]*output[20,week] > vmi_uncertainty
     SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
    ELSE
     SET uncertainty_factor = 1
    SET fc_actweek_kaufland = [[[[output[33,week]*output[19,week]]*output[20,week]]*uncertainty_factor]*std_demand_kaufland]*output[34,week]
    IF output[19,week+1]*output[20,week+1] > vmi_uncertainty
     SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
    ELSE
     SET uncertainty_factor = 1
    SET fc_nxtweek = [[[[output[33,week+1]*output[19,week+1]]*output[20,week+1]]*uncertainty_factor]*std_demand_kaufland]*output[34,week]
    IF output[19,week+2]*output[20,week+2] > vmi_uncertainty
     SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
    ELSE
     SET uncertainty_factor = 1
    SET fc_secnextweek_kaufland =
[[[[output[33,week+2]*output[19,week+2]]*output[20,week+2]]*uncertainty_factor]*std_demand_kaufland]*output[34,week]
    SET fc_1week_kaufland = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_kaufland]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
    SET fc_2weeks_kaufland = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_kaufland]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_kaufland]]
   'FC Edeka
   IF CPFR_Edeka <= 1
    SET fc_actweek_edeka = ROUND[[[output[26,week]*output[21,week]]*output[22,week]]*LES_FC_edeka]
    SET fc_nxtweek = ROUND[[[output[26,week+1]*output[21,week+1]]*output[22,week+1]]*LES_FC_edeka]
    SET fc_secnextweek_edeka = ROUND[[[output[26,week+2]*output[21,week+2]]*output[22,week+2]]*LES_FC_edeka]
    SET fc_1week_edeka = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_edeka]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
    SET fc_2weeks_edeka = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_edeka]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_edeka]]
   IF CPFR_Edeka = 2
    'FC VMI Edeka
    IF output[21,week]*output[22,week] >= vmi_uncertainty
     SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
    ELSE
     SET uncertainty_factor = 1
    SET fc_actweek_edeka = [[[[output[33,week]*output[21,week]]*output[22,week]]*uncertainty_factor]*std_demand_edeka]*output[34,week]
    IF output[21,week+1]*output[22,week+1] >= vmi_uncertainty
     SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
    ELSE
     SET uncertainty_factor = 1
    SET fc_nxtweek = [[[[output[33,week+1]*output[21,week+1]]*output[22,week+1]]*uncertainty_factor]*std_demand_edeka]*output[34,week]
    IF output[21,week+2]*output[22,week+2] >= vmi_uncertainty
     SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
    ELSE
     SET uncertainty_factor = 1
    SET fc_secnextweek_edeka =
[[[[output[33,week+2]*output[21,week+2]]*output[22,week+2]]*uncertainty_factor]*std_demand_edeka]*output[34,week]
    SET fc_1week_edeka = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_edeka]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
    SET fc_2weeks_edeka = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_edeka]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_edeka]]
   'FC WalMart
   IF CPFR_WalMart <= 1
    SET fc_actweek_walmart = ROUND[[[output[26,week]*output[23,week]]*output[24,week]]*LES_FC_walmart]
    SET fc_nxtweek = ROUND[[[output[26,week+1]*output[23,week+1]]*output[24,week+1]]*LES_FC_walmart]
    SET fc_secnextweek_walmart = ROUND[[[output[26,week+2]*output[23,week+2]]*output[24,week+2]]*LES_FC_walmart]
    SET fc_1week_walmart = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_walmart]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
    SET fc_2weeks_walmart = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_walmart]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_walmart]]
   IF CPFR_WalMart = 2
    'FC VMI WalMart
```

```
    IF output[23,week]*output[24,week] > vmi_uncertainty
     SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
    ELSE
     SET uncertainty_factor = 1
    SET fc_actweek_walmart = [[[[output[33,week]*output[23,week]]*output[24,week]]*uncertainty_factor]*std_demand_walmart]*output[34,week]
    IF output[23,week+1]*output[24,week+1] > vmi_uncertainty
     SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
    ELSE
     SET uncertainty_factor = 1
    SET fc_nxtweek = [[[[output[33,week+1]*output[23,week+1]]*output[24,week+1]]*uncertainty_factor]*std_demand_walmart]*output[34,week]
    IF output[23,week+2]*output[24,week+2] > vmi_uncertainty
     SET uncertainty_factor = [[RANDOM[0]*30]+85]/100
    ELSE
     SET uncertainty_factor = 1
    SET fc_secnextweek_walmart =
[[[[output[33,week+2]*output[23,week+2]]*output[24,week+2]]*uncertainty_factor]*std_demand_walmart]*output[34,week]
    SET fc_1week_walmart = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_walmart]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
    SET fc_2weeks_walmart = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_walmart]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_walmart]]
   'Delivery Scheduling Module Factory-DC
   IF VMI_DC_Rewe = 2
    SET Order_DC_Rewe = 0
    SET Order_DC_Kaufland = 0
    SET Order_DC_Edeka = 0
    SET Order_DC_WalMart = 0
    SET DC_rewe_inv_ratio = 6
    SET DC_Kaufland_inv_ratio = 6
    SET DC_edeka_inv_ratio = 6
    SET DC_WalMart_inv_ratio = 6
    'DC DELIVERY ALL SCENARIOS
    (Disabled) SET CPFR_Rewe = 1
    (Disabled) SET CPFR_Kaufland = 1
    (Disabled) SET CPFR_Edeka = 1
    (Disabled) SET CPFR_WalMart = 1
    SET CPFR_order = 0
    'FLEXIBLE ROP DELIVERY?
    SET DC_Rewe_ROPflex_Delivery = 1
    SET DC_Kaufland_ROPflex_Delivery = 1
    SET DC_Edeka_ROPflex_Delivery = 1
    SET DC_Walmart_ROPflex_Delivery = 1
    IF [CPFR_Rewe+CPFR_Kaufland]+CPFR_Edeka <= 10
     IF [CPFR_Rewe = 0] & [DC_Rewe_ROPflex_Delivery = 0] = 1
      IF DAY[Simulation Time] = 2
       IF WEEK[Simulation Time]/2 = TRUNC[WEEK[Simulation Time]/2]
        SET Order_DC_Rewe = ROUND[[[[[[[fc_2weeks_rewe+[fc_secnextweek_rewe*0.5]]-[fc_actweek_rewe*0.5]]]/20]-Inventory_DC_Rewe.Count
Contents]+[[safetyinv*fc_actweek_rewe]/140]]*[1/loadlevel_DC_Rewe_act]]
        IF waitingtime_rewe <> 2000000
         SET Order_DC_Rewe = requested_order_DC_Rewe
        SET requested_order_DC_Rewe = Order_DC_Rewe
      IF waitingtime_rewe <> 2000000
       SET Order_DC_Rewe = requested_order_DC_Rewe
     IF [CPFR_Rewe = 0] & [DC_Rewe_ROPflex_Delivery = 1] = 1
      IF Inventory_DC_Rewe.Count Contents < fc_2weeks_rewe/40
       SET Order_DC_Rewe = ROUND[[[[[fc_2weeks_rewe+[fc_secnextweek_rewe*0.5]]-[fc_actweek_rewe*0.5]]/20]]*[1/loadlevel_DC_Rewe_act]]
       IF waitingtime_rewe <> 2000000
        SET Order_DC_Rewe = requested_order_DC_Rewe
       SET requested_order_DC_Rewe = Order_DC_Rewe
     IF CPFR_Rewe > 0
      IF Inventory_DC_Rewe.Count Contents < fc_2weeks_rewe/60
       SET Order_DC_Rewe = ROUND[[[[[[fc_2weeks_rewe+[fc_secnextweek_rewe*0.5]]-[fc_actweek_rewe*0.5]]/20]-Inventory_DC_Rewe.Count
Contents]+[fc_actweek_rewe/47]]*[1/loadlevel_DC_Rewe_act]]
       SET requested_order_DC_Rewe = Order_DC_Rewe
       SET DC_rewe_inv_ratio = [[Inventory_DC_Rewe.Count Contents*20]/[fc_2weeks_rewe*0.5]]
       (Disabled) SET output[47,week] = Order_DC_Rewe
       SET CPFR_order = 1
     IF [CPFR_Kaufland = 0] & [DC_Kaufland_ROPflex_Delivery = 0] = 1
      IF DAY[Simulation Time] = 4
       IF WEEK[Simulation Time]/2 = [WEEK[Simulation Time]/2]
        SET Order_DC_Kaufland = ROUND[[[[[fc_2weeks_kaufland*0.5]/20]-Inventory_DC_Kaufland.Count
Contents]+[[safetyinv*fc_actweek_kaufland]/140]]*[1/loadlevel_DC_Kaufland_act]]
        IF waitingtime_kaufland <> 2000000
         SET Order_DC_Kaufland = requested_order_DC_Kaufland
        SET requested_order_DC_Kaufland = Order_DC_Kaufland
      IF waitingtime_kaufland <> 2000000
       SET Order_DC_Kaufland = requested_order_DC_Kaufland
     IF [CPFR_Kaufland = 0] & [DC_Kaufland_ROPflex_Delivery = 1] = 1
```

```
        IF Inventory_DC_Kaufland.Count Contents < fc_2weeks_kaufland/60
          SET Order_DC_Kaufland = ROUND[[[fc_2weeks_kaufland*0.5]/20]*[1/loadlevel_DC_Kaufland_act]]
          IF waitingtime_kaufland <> 2000000
            SET Order_DC_Kaufland = requested_order_DC_Kaufland
          SET requested_order_DC_Kaufland = Order_DC_Kaufland
      IF CPFR_Kaufland > 0
        IF Inventory_DC_Kaufland.Count Contents < fc_2weeks_kaufland/80
          SET Order_DC_Kaufland = ROUND[[[[[fc_2weeks_kaufland*0.5]/20]-Inventory_DC_Kaufland.Count
Contents]+[fc_actweek_kaufland/70]]*[1/loadlevel_DC_Kaufland_act]]
          SET requested_order_DC_Kaufland = Order_DC_Kaufland
          SET DC_Kaufland_inv_ratio = [[Inventory_DC_Kaufland.Count Contents*20]/[fc_2weeks_kaufland*0.5]]
          SET CPFR_order = 1
      IF [CPFR_Edeka = 0] & [DC_Edeka_ROPflex_Delivery = 0] = 1
        IF DAY[Simulation Time] = 2
          IF WEEK[Simulation Time]/2 = [WEEK[Simulation Time]/2]
            SET Order_DC_Edeka = ROUND[[[[[fc_2weeks_edeka*0.5]/20]-Inventory_DC_Edeka.Count
Contents]+[[safetyinv*fc_actweek_edeka]/140]]*[1/loadlevel_DC_Edeka_act]]
            IF waitingtime_edeka <> 2000000
              SET Order_DC_Edeka = requested_order_DC_Edeka
            SET requested_order_DC_Edeka = Order_DC_Edeka
        IF waitingtime_edeka <> 2000000
          SET Order_DC_Edeka = requested_order_DC_Edeka
      IF [CPFR_Edeka = 0] & [DC_Edeka_ROPflex_Delivery = 1] = 1
        IF Inventory_DC_Edeka.Count Contents < fc_2weeks_edeka/60
          SET Order_DC_Edeka = ROUND[[[fc_2weeks_edeka*0.5]/20]*[1/loadlevel_DC_Edeka_act]]
          IF waitingtime_edeka <> 2000000
            SET Order_DC_Edeka = requested_order_DC_Edeka
          SET requested_order_DC_Edeka = Order_DC_Edeka
      IF CPFR_Edeka > 0
        IF Inventory_DC_Edeka.Count Contents < fc_2weeks_edeka/80
          SET Order_DC_Edeka = ROUND[[[[[fc_2weeks_edeka*0.5]/20]-Inventory_DC_Edeka.Count
Contents]+[fc_actweek_edeka/70]]*[1/loadlevel_DC_Edeka_act]]
          SET requested_order_DC_Edeka = Order_DC_Edeka
          SET DC_edeka_inv_ratio = [[Inventory_DC_Edeka.Count Contents*20]/[fc_2weeks_edeka*0.5]]
          SET CPFR_order = 1
      IF [CPFR_WalMart = 0] & [DC_Walmart_ROPflex_Delivery = 0] = 1
        IF DAY[Simulation Time] = 4
          IF WEEK[Simulation Time]/2 = TRUNC[WEEK[Simulation Time]/2]
            SET Order_DC_WalMart = ROUND[[[[[[fc_2weeks_walmart+[fc_secnextweek_walmart*0.5]]-[fc_actweek_walmart*0.5]]]/20]-
Inventory_DC_WalMart.Count Contents]+[[safetyinv*fc_actweek_walmart]/140]]*[1/loadlevel_DC_Walmart_act]]
            IF waitingtime_walmart <> 2000000
              SET Order_DC_WalMart = requested_order_DC_Walmart
            SET requested_order_DC_Walmart = Order_DC_WalMart
        IF waitingtime_walmart <> 2000000
          SET Order_DC_WalMart = requested_order_DC_Walmart
      IF [CPFR_WalMart = 0] & [DC_Walmart_ROPflex_Delivery = 1] = 1
        IF Inventory_DC_WalMart.Count Contents < fc_2weeks_walmart/40
          SET Order_DC_WalMart = ROUND[[[[[[fc_2weeks_walmart+[fc_secnextweek_walmart*0.5]]-
[fc_actweek_walmart*0.5]]/20]]]*[1/loadlevel_DC_Walmart_act]]
          IF waitingtime_walmart <> 2000000
            SET Order_DC_WalMart = requested_order_DC_Walmart
          SET requested_order_DC_Walmart = Order_DC_WalMart
      IF CPFR_WalMart > 0
        IF Inventory_DC_WalMart.Count Contents < fc_2weeks_walmart/60
          SET Order_DC_WalMart = ROUND[[[[[[fc_2weeks_walmart+[fc_secnextweek_walmart*0.5]]-[fc_actweek_walmart*0.5]]/20]-
Inventory_DC_WalMart.Count Contents]+[fc_actweek_walmart/47]]*[1/loadlevel_DC_Walmart_act]]
          SET requested_order_DC_Walmart = Order_DC_WalMart
          SET DC_WalMart_inv_ratio = [[Inventory_DC_WalMart.Count Contents*20]/[fc_2weeks_walmart*0.5]]
          SET CPFR_order = 1
      (Disabled) SET output[40,week] = DC_rewe_inv_ratio
      (Disabled) SET output[41,week] = DC_Kaufland_inv_ratio
      (Disabled) SET output[42,week] = DC_edeka_inv_ratio
      (Disabled) SET output[43,week] = DC_WalMart_inv_ratio
      (Disabled) SET CPFR_order = 0
      (Disabled) SET DC_rewe_inv_ratio = DC_rewe_inv_ratio+2
      (Disabled) SET DC_Kaufland_inv_ratio = DC_Kaufland_inv_ratio+2
      (Disabled) SET DC_edeka_inv_ratio = DC_edeka_inv_ratio+2
      (Disabled) SET DC_WalMart_inv_ratio = DC_WalMart_inv_ratio+2
      SET total_DC_request = [[Order_DC_Rewe+Order_DC_Kaufland]+Order_DC_Edeka]+Order_DC_WalMart
      IF Inventory_Factory.Count Contents < total_DC_request
        SET Factory_request_ratio = Inventory_Factory.Count Contents/total_DC_request
        IF Factory_request_ratio >= 0.7
          SET Order_DC_Rewe = TRUNC[Factory_request_ratio*Order_DC_Rewe]
          SET Order_DC_Kaufland = TRUNC[Factory_request_ratio*Order_DC_Kaufland]
          SET Order_DC_Edeka = TRUNC[Factory_request_ratio*Order_DC_Edeka]
          SET Order_DC_WalMart = TRUNC[Factory_request_ratio*Order_DC_WalMart]
```

```
IF Factory_request_ratio < 0.7
 'CPFR ALL SCENARIO
 IF CPFR_Rewe = 0
  IF Order_DC_Rewe > 0
   SET DC_rewe_inv_ratio = 0.41
   SET DC_rewe_inv_ratio = [[RANDOM[0]+41]/100]
   SET DC_rewe_inv_ratio = [[RANDOM[0]*3]/10]+0.4
   SET DC_rewe_inv_ratio = [[RANDOM[0]+70]/100]
   IF waitingtime_rewe < 2000000
    IF waitingtime_rewe < waitingtime_kaufland
     IF waitingtime_rewe <= waitingtime_edeka
      IF waitingtime_rewe <= waitingtime_walmart
       IF CPFR_order = 0
        SET DC_rewe_inv_ratio = 0.1
 IF CPFR_Kaufland = 0
  IF Order_DC_Kaufland > 0
   SET DC_Kaufland_inv_ratio = 0.4
   SET DC_Kaufland_inv_ratio = [[RANDOM[0]+41]/100]
   SET DC_Kaufland_inv_ratio = [[RANDOM[0]+70]/100]
   IF waitingtime_kaufland < 2000000
    IF waitingtime_kaufland <= waitingtime_rewe
     IF waitingtime_kaufland <= waitingtime_edeka
      IF waitingtime_kaufland <= waitingtime_walmart
       IF CPFR_order = 0
        SET DC_Kaufland_inv_ratio = 0.1
    IF CPFR_order = 0
     IF Simulation Time-waitingtime_rewe < 5000
      IF Simulation Time-waitingtime_edeka < 5000
       IF Simulation Time-waitingtime_walmart < 5000
        SET DC_Kaufland_inv_ratio = 0.09
 IF CPFR_Edeka = 0
  IF Order_DC_Edeka > 0
   SET DC_edeka_inv_ratio = 0.42
   SET DC_edeka_inv_ratio = [[RANDOM[0]+41]/100]
   SET DC_edeka_inv_ratio = [[RANDOM[0]+70]/100]
   IF waitingtime_edeka < 2000000
    IF waitingtime_edeka < waitingtime_rewe
     IF waitingtime_edeka < waitingtime_kaufland
      IF waitingtime_edeka <= waitingtime_walmart
       IF CPFR_order = 0
        SET DC_edeka_inv_ratio = 0.1
    IF CPFR_order = 0
     IF Simulation Time-waitingtime_rewe < 5000
      IF waitingtime_edeka < waitingtime_kaufland
       IF Simulation Time-waitingtime_walmart < 5000
        SET DC_edeka_inv_ratio = 0.088
 IF CPFR_WalMart = 0
  IF Order_DC_WalMart > 0
   SET DC_WalMart_inv_ratio = 0.43
   SET DC_WalMart_inv_ratio = [[RANDOM[0]+41]/100]
   SET DC_WalMart_inv_ratio = [[RANDOM[0]+70]/100]
   IF waitingtime_walmart < 2000000
    IF waitingtime_walmart < waitingtime_rewe
     IF waitingtime_walmart < waitingtime_kaufland
      IF waitingtime_walmart < waitingtime_edeka
       IF CPFR_order = 0
        SET DC_WalMart_inv_ratio = 0.1
 IF Order_DC_Rewe > 0
  IF DC_rewe_inv_ratio <= DC_Kaufland_inv_ratio
   IF DC_rewe_inv_ratio < DC_edeka_inv_ratio
    IF DC_rewe_inv_ratio < DC_WalMart_inv_ratio
     IF Inventory_Factory.Count Contents >= 0.7*Order_DC_Rewe
      SET Order_DC_Rewe = TRUNC[0.7*Order_DC_Rewe]
      IF Order_DC_Kaufland > 0
       SET loading_failures_kaufland = loading_failures_kaufland+1
       IF waitingtime_kaufland = 2000000
        SET waitingtime_kaufland = Simulation Time
       SET Order_DC_Kaufland = 0
      IF Order_DC_Edeka > 0
       SET loading_failures_edeka = loading_failures_edeka+1
       IF waitingtime_edeka = 2000000
        SET waitingtime_edeka = Simulation Time
       SET Order_DC_Edeka = 0
      IF Order_DC_WalMart > 0
       SET loading_failures_walmart = loading_failures_walmart+1
       IF waitingtime_walmart = 2000000
```

```
        SET waitingtime_walmart = Simulation Time
       SET Order_DC_WalMart = 0
      SET Factory_request_ratio = 0
     (Disabled) ELSE
      SET DC_rewe_inv_ratio = 6
IF Order_DC_Kaufland > 0
 IF DC_Kaufland_inv_ratio <= DC_rewe_inv_ratio
  IF DC_Kaufland_inv_ratio < DC_edeka_inv_ratio
   IF DC_Kaufland_inv_ratio < DC_WalMart_inv_ratio
    IF Inventory_Factory.Count Contents >= 0.7*Order_DC_Kaufland
     SET Order_DC_Kaufland = TRUNC[0.7*Order_DC_Kaufland]
     IF Order_DC_Rewe > 0
      SET loading_failures_rewe = loading_failures_rewe+1
      IF waitingtime_rewe = 2000000
       SET waitingtime_rewe = Simulation Time
      SET Order_DC_Rewe = 0
     IF Order_DC_Edeka > 0
      SET loading_failures_edeka = loading_failures_edeka+1
      IF waitingtime_edeka = 2000000
       SET waitingtime_edeka = Simulation Time
      SET Order_DC_Edeka = 0
     IF Order_DC_WalMart > 0
      SET loading_failures_walmart = loading_failures_walmart+1
      IF waitingtime_walmart = 2000000
       SET waitingtime_walmart = Simulation Time
      SET Order_DC_WalMart = 0
     SET Factory_request_ratio = 0
    (Disabled) ELSE
     SET DC_Kaufland_inv_ratio = 6
IF Order_DC_Edeka > 0
 IF DC_edeka_inv_ratio <= DC_rewe_inv_ratio
  IF DC_edeka_inv_ratio < DC_Kaufland_inv_ratio
   IF DC_edeka_inv_ratio < DC_WalMart_inv_ratio
    IF Inventory_Factory.Count Contents >= 0.7*Order_DC_Edeka
     SET Order_DC_Edeka = TRUNC[0.7*Order_DC_Edeka]
     IF Order_DC_Rewe > 0
      SET loading_failures_rewe = loading_failures_rewe+1
      IF waitingtime_rewe = 2000000
       SET waitingtime_rewe = Simulation Time
      SET Order_DC_Rewe = 0
     IF Order_DC_Kaufland > 0
      SET loading_failures_kaufland = loading_failures_kaufland+1
      IF waitingtime_kaufland = 2000000
       SET waitingtime_kaufland = Simulation Time
      SET Order_DC_Kaufland = 0
     IF Order_DC_WalMart > 0
      SET loading_failures_walmart = loading_failures_walmart+1
      IF waitingtime_walmart = 2000000
       SET waitingtime_walmart = Simulation Time
      SET Order_DC_WalMart = 0
     SET Factory_request_ratio = 0
    (Disabled) ELSE
     SET DC_edeka_inv_ratio = 6
IF Order_DC_WalMart > 0
 IF DC_WalMart_inv_ratio <= DC_rewe_inv_ratio
  IF DC_WalMart_inv_ratio < DC_Kaufland_inv_ratio
   IF DC_WalMart_inv_ratio < DC_edeka_inv_ratio
    IF Inventory_Factory.Count Contents >= 0.7*Order_DC_WalMart
     SET Order_DC_WalMart = TRUNC[0.7*Order_DC_WalMart]
     IF Order_DC_Rewe > 0
      SET loading_failures_rewe = loading_failures_rewe+1
      IF waitingtime_rewe = 2000000
       SET waitingtime_rewe = Simulation Time
      SET Order_DC_Rewe = 0
     IF Order_DC_Kaufland > 0
      SET loading_failures_kaufland = loading_failures_kaufland+1
      IF waitingtime_kaufland = 2000000
       SET waitingtime_kaufland = Simulation Time
      SET Order_DC_Kaufland = 0
     IF Order_DC_Edeka > 0
      SET loading_failures_edeka = loading_failures_edeka+1
      IF waitingtime_edeka = 2000000
       SET waitingtime_edeka = Simulation Time
      SET Order_DC_Edeka = 0
     SET Factory_request_ratio = 0
    (Disabled) ELSE
```

```
          SET DC_WalMart_inv_ratio = 6
     IF Factory_request_ratio <> 0
      IF Order_DC_Rewe > 0
       SET loading_failures_rewe = loading_failures_rewe+1
       IF waitingtime_rewe = 2000000
        SET waitingtime_rewe = Simulation Time
       SET Order_DC_Rewe = 0
      IF Order_DC_Kaufland > 0
       SET loading_failures_kaufland = loading_failures_kaufland+1
       IF waitingtime_kaufland = 2000000
        SET waitingtime_kaufland = Simulation Time
       SET Order_DC_Kaufland = 0
      IF Order_DC_Edeka > 0
       SET loading_failures_edeka = loading_failures_edeka+1
       IF waitingtime_edeka = 2000000
        SET waitingtime_edeka = Simulation Time
       SET Order_DC_Edeka = 0
      IF Order_DC_WalMart > 0
       SET loading_failures_walmart = loading_failures_walmart+1
       IF waitingtime_walmart = 2000000
        SET waitingtime_walmart = Simulation Time
       SET Order_DC_WalMart = 0
IF Order_DC_Rewe > 0
 IF Inventory_Factory.Count Contents >= Order_DC_Rewe-Transport_DC_Rewe.Count Contents
  SET Transport_DC_Rewe.Label Batching Max = Order_DC_Rewe
  SET Transport_DC_Rewe.Label Batching Min = Order_DC_Rewe
  SET loading_success = loading_success+1
  SET loadlevel_DC_Rewe_act = Order_DC_Rewe/requested_order_DC_Rewe
  IF loadlevel_DC_Rewe_act > 0.999
   SET loadlevel_DC_Rewe_count = loadlevel_DC_Rewe_count+1
  SET loadlevel_DC_Rewe = loadlevel_DC_Rewe+loadlevel_DC_Rewe_act
  SET order_volatility_Rewe = order_volatility_Rewe+[ABS[[20*Order_DC_Rewe]-[2*std_demand_rewe]]/[2*std_demand_rewe]]
  'If CPFR set LLact=1 / deactivate if flexible loadlevel
  SET loadlevel_DC_Rewe_act = 1
  (Disabled) SET loadlevel_DC_Rewe_act = loadlevel_DC_Rewe/[Transport_DC_Rewe.Completed+1]
  IF Simulation Time-waitingtime_rewe > 1000
   IF waitingtime_rewe <> 2000000
    SET long_waits_rewe = long_waits_rewe+1
    IF Simulation Time-waitingtime_rewe > 5000
     SET verylong_waits_rewe = verylong_waits_rewe+1
  IF week > 13
   IF waitingtime_rewe <> 2000000
    SET order_leadtime_DC_rewe = order_leadtime_DC_rewe+[[Simulation Time-waitingtime_rewe]/60]
  SET waitingtime_rewe = 2000000
  (Disabled) SET output[45,loading_success] = fc_2weeks_rewe
  (Disabled) SET output[46,loading_success] = requested_order_DC_Rewe
  (Disabled) SET output[47,loading_success] = Order_DC_Rewe
  SET blockroute_DC_rewe = 0
IF Order_DC_Kaufland > 0
 IF Inventory_Factory.Count Contents >= Order_DC_Kaufland-Transport_DC_Kaufland.Count Contents
  SET Transport_DC_Kaufland.Label Batching Max = Order_DC_Kaufland
  SET Transport_DC_Kaufland.Label Batching Min = Order_DC_Kaufland
  SET loading_success = loading_success+1
  SET loadlevel_DC_Kaufland_act = Order_DC_Kaufland/requested_order_DC_Kaufland
  IF loadlevel_DC_Kaufland_act > 0.999
   SET loadlevel_DC_Kaufland_count = loadlevel_DC_Kaufland_count+1
  SET loadlevel_DC_Kaufland = loadlevel_DC_Kaufland+loadlevel_DC_Kaufland_act
  SET order_volatility_Kaufland = order_volatility_Kaufland+[ABS[[20*Order_DC_Kaufland]-std_demand_kaufland]/std_demand_kaufland]
  'If CPFR set LLact=1 / deactivate if flexible loadlevel
  SET loadlevel_DC_Kaufland_act = 1
  (Disabled) SET loadlevel_DC_Kaufland_act = loadlevel_DC_Kaufland/[Transport_DC_Kaufland.Completed+1]
  IF Simulation Time-waitingtime_kaufland > 1000
   IF waitingtime_kaufland <> 2000000
    SET long_waits_kaufland = long_waits_kaufland+1
    IF Simulation Time-waitingtime_kaufland > 5000
     SET verylong_waits_kaufland = verylong_waits_kaufland+1
  IF week > 13
   IF waitingtime_kaufland <> 2000000
    SET order_leadtime_DC_kaufland = order_leadtime_DC_kaufland+[[Simulation Time-waitingtime_kaufland]/60]
  SET waitingtime_kaufland = 2000000
  SET blockroute_DC_kaufland = 0
IF Order_DC_Edeka > 0
 IF Inventory_Factory.Count Contents >= Order_DC_Edeka-Transport_DC_Edeka.Count Contents
  SET Transport_DC_Edeka.Label Batching Max = Order_DC_Edeka
  SET Transport_DC_Edeka.Label Batching Min = Order_DC_Edeka
  SET loading_success = loading_success+1
```

```
      SET loadlevel_DC_Edeka_act = Order_DC_Edeka/requested_order_DC_Edeka
      IF loadlevel_DC_Edeka_act > 0.999
       SET loadlevel_DC_Edeka_count = loadlevel_DC_Edeka_count+1
      SET loadlevel_DC_Edeka = loadlevel_DC_Edeka+loadlevel_DC_Edeka_act
      SET order_volatility_Edeka = order_volatility_Edeka+[ABS[[20*Order_DC_Edeka]-std_demand_edeka]/std_demand_edeka]
      'If CPFR set LLact=1 / deactivate if flexible loadlevel
      SET loadlevel_DC_Edeka_act = 1
      (Disabled) SET loadlevel_DC_Edeka_act = loadlevel_DC_Edeka/[Transport_DC_Edeka.Completed+1]
      IF Simulation Time-waitingtime_edeka > 1000
       IF waitingtime_edeka <> 2000000
        SET long_waits_edeka = long_waits_edeka+1
        IF Simulation Time-waitingtime_edeka > 5000
         SET verylong_waits_edeka = verylong_waits_edeka+1
      IF week > 13
       IF waitingtime_edeka <> 2000000
        SET order_leadtime_DC_edeka = order_leadtime_DC_edeka+[[Simulation Time-waitingtime_edeka]/60]
      SET waitingtime_edeka = 2000000
      SET blockroute_DC_edeka = 0
    IF Order_DC_WalMart > 0
     IF Inventory_Factory.Count Contents >= Order_DC_WalMart-Transport_DC_WalMart.Count Contents
      SET Transport_DC_WalMart.Label Batching Max = Order_DC_WalMart
      SET Transport_DC_WalMart.Label Batching Min = Order_DC_WalMart
      SET loading_success = loading_success+1
      SET loadlevel_DC_Walmart_act = Order_DC_WalMart/requested_order_DC_Walmart
      IF loadlevel_DC_Walmart_act > 0.999
       SET loadlevel_DC_Walmart_count = loadlevel_DC_Walmart_count+1
      SET loadlevel_DC_WalMart = loadlevel_DC_WalMart+loadlevel_DC_Walmart_act
      SET order_volatility_Walmart = order_volatility_Walmart+[ABS[[20*Order_DC_WalMart]-[2*std_demand_walmart]]/[2*std_demand_walmart]]
      'If CPFR set LLact=1 / deactivate if flexible loadlevel
      SET loadlevel_DC_Walmart_act = 1
      (Disabled) SET loadlevel_DC_Walmart_act = loadlevel_DC_WalMart/[Transport_DC_WalMart.Completed+1]
      IF Simulation Time-waitingtime_walmart > 1000
       IF waitingtime_walmart <> 2000000
        SET long_waits_walmart = long_waits_walmart+1
        IF Simulation Time-waitingtime_walmart > 5000
         SET verylong_waits_walmart = verylong_waits_walmart+1
      IF week > 13
       IF waitingtime_walmart <> 2000000
        SET order_leadtime_DC_walmart = order_leadtime_DC_walmart+[[Simulation Time-waitingtime_walmart]/60]
      SET waitingtime_walmart = 2000000
      SET blockroute_DC_walmart = 0
  '
  '------------------------------------------------ DC - RETAIL OUTLET  D E L I V E R Y------------------------------------------------
  '
  SET reorder_barrier_retail_Rewe = 3
  SET reorder_barrier_retail_Kaufland = 2.5
  SET reorder_barrier_retail_Edeka = 2.5
  SET reorder_barrier_retail_Walmart = 3
  SET fc_actweek_rewe = ROUND[[[output[26,week]*output[17,week]]*output[18,week]]*LES_FC_rewe]
  SET fc_nxtweek = ROUND[[[output[26,week+1]*output[17,week+1]]*output[18,week+1]]*LES_FC_rewe]
  SET fc_secnextweek_rewe = ROUND[[[output[26,week+2]*output[17,week+2]]*output[18,week+2]]*LES_FC_rewe]
  SET fc_1week_rewe = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_rewe]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
  SET fc_2weeks_rewe = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_rewe]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_rewe]]
  SET fc_actweek_kaufland = ROUND[[[output[26,week]*output[19,week]]*output[20,week]]*LES_FC_kaufland]
  SET fc_nxtweek = ROUND[[[output[26,week+1]*output[19,week+1]]*output[20,week+1]]*LES_FC_kaufland]
  SET fc_secnextweek_kaufland = ROUND[[[output[26,week+2]*output[19,week+2]]*output[20,week+2]]*LES_FC_kaufland]
  SET fc_1week_kaufland = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_kaufland]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
  SET fc_2weeks_kaufland = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_kaufland]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_kaufland]]
  SET fc_actweek_edeka = ROUND[[[output[26,week]*output[21,week]]*output[22,week]]*LES_FC_edeka]
  SET fc_nxtweek = ROUND[[[output[26,week+1]*output[21,week+1]]*output[22,week+1]]*LES_FC_edeka]
  SET fc_secnextweek_edeka = ROUND[[[output[26,week+2]*output[21,week+2]]*output[22,week+2]]*LES_FC_edeka]
  SET fc_1week_edeka = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_edeka]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
  SET fc_2weeks_edeka = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_edeka]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_edeka]]
  SET fc_actweek_walmart = ROUND[[[output[26,week]*output[23,week]]*output[24,week]]*LES_FC_walmart]
  SET fc_nxtweek = ROUND[[[output[26,week+1]*output[23,week+1]]*output[24,week+1]]*LES_FC_walmart]
  SET fc_secnextweek_walmart = ROUND[[[output[26,week+2]*output[23,week+2]]*output[24,week+2]]*LES_FC_walmart]
  SET fc_1week_walmart = ROUND[[[[8-DAY[Simulation Time]]*fc_actweek_walmart]/7]+[[[DAY[Simulation Time]-1]/7]*fc_nxtweek]]
  SET fc_2weeks_walmart = ROUND[[[[[8-DAY[Simulation Time]]*fc_actweek_walmart]/7]+fc_nxtweek]+[[[DAY[Simulation Time]-
1]/7]*fc_secnextweek_walmart]]
  'CPFR Retail Rewe
  IF VMI_Retail_Rewe = 2
   SET Order_Retail_Rewe 1 = 0
   SET Order_Retail_Rewe 2 = 0
```

```
SET Order_Retail_Rewe 3 = 0
IF Inventory_Retail_Rewe 1.Count Contents/[fc_1week_rewe/420] <= reorder_barrier_retail_Rewe
 SET Order_Retail_Rewe 1 = ROUND[fc_1week_rewe/60]
IF Inventory_Retail_Rewe 2.Count Contents/[fc_1week_rewe/420] <= reorder_barrier_retail_Rewe
 SET Order_Retail_Rewe 2 = ROUND[fc_1week_rewe/60]
IF Inventory_Retail_Rewe 3.Count Contents/[fc_1week_rewe/420] <= reorder_barrier_retail_Rewe
 SET Order_Retail_Rewe 3 = ROUND[fc_1week_rewe/60]
SET total_DC_request = [Order_Retail_Rewe 1+Order_Retail_Rewe 2]+Order_Retail_Rewe 3
IF Inventory_DC_Rewe.Count Contents < total_DC_request
 SET DC_request_ratio = Inventory_DC_Rewe.Count Contents/total_DC_request
 IF DC_request_ratio >= 0.7
  SET Order_Retail_Rewe 1 = TRUNC[DC_request_ratio*Order_Retail_Rewe 1]
  SET Order_Retail_Rewe 2 = TRUNC[DC_request_ratio*Order_Retail_Rewe 2]
  SET Order_Retail_Rewe 3 = TRUNC[DC_request_ratio*Order_Retail_Rewe 3]
 IF DC_request_ratio < 0.7
  IF Order_Retail_Rewe 1 > 0
   IF Inventory_Retail_Rewe 1.Count Contents <= Inventory_Retail_Rewe 2.Count Contents
    IF Inventory_Retail_Rewe 1.Count Contents <= Inventory_Retail_Rewe 3.Count Contents
     IF Inventory_DC_Rewe.Count Contents >= 0.7*Order_Retail_Rewe 1
      SET Order_Retail_Rewe 1 = TRUNC[0.7*Order_Retail_Rewe 1]
      IF Order_Retail_Rewe 2 > 0
       SET loading_failures_retail_rewe = loading_failures_retail_rewe+1
       IF waitingtime_retail_rewe 2 = -1
        SET waitingtime_retail_rewe 2 = Simulation Time
       SET Order_Retail_Rewe 2 = 0
      IF Order_Retail_Rewe 3 > 0
       SET loading_failures_retail_rewe = loading_failures_retail_rewe+1
       IF waitingtime_retail_rewe 3 = -1
        SET waitingtime_retail_rewe 3 = Simulation Time
       SET Order_Retail_Rewe 3 = 0
      SET DC_request_ratio = 0
     ELSE
      SET Order_Retail_Rewe 1 = 0
  IF Order_Retail_Rewe 2 > 0
   IF Inventory_Retail_Rewe 2.Count Contents < Inventory_Retail_Rewe 3.Count Contents
    IF Inventory_DC_Rewe.Count Contents >= 0.7*Order_Retail_Rewe 2
     SET Order_Retail_Rewe 2 = TRUNC[0.7*Order_Retail_Rewe 2]
     IF Order_Retail_Rewe 1 > 0
      SET loading_failures_retail_rewe = loading_failures_retail_rewe+1
      IF waitingtime_retail_rewe 1 = -1
       SET waitingtime_retail_rewe 1 = Simulation Time
      SET Order_Retail_Rewe 1 = 0
     IF Order_Retail_Rewe 3 > 0
      SET loading_failures_retail_rewe = loading_failures_retail_rewe+1
      IF waitingtime_retail_rewe 3 = -1
       SET waitingtime_retail_rewe 3 = Simulation Time
      SET Order_Retail_Rewe 3 = 0
     SET DC_request_ratio = 0
    ELSE
     SET Order_Retail_Rewe 2 = 0
  IF Order_Retail_Rewe 3 > 0
   IF Inventory_DC_Rewe.Count Contents >= 0.7*Order_Retail_Rewe 3
    SET Order_Retail_Rewe 3 = TRUNC[0.7*Order_Retail_Rewe 3]
    IF Order_Retail_Rewe 1 > 0
     SET loading_failures_retail_rewe = loading_failures_retail_rewe+1
     IF waitingtime_retail_rewe 1 = -1
      SET waitingtime_retail_rewe 1 = Simulation Time
     SET Order_Retail_Rewe 1 = 0
    IF Order_Retail_Rewe 2 > 0
     SET loading_failures_retail_rewe = loading_failures_retail_rewe+1
     IF waitingtime_retail_rewe 2 = -1
      SET waitingtime_retail_rewe 2 = Simulation Time
     SET Order_Retail_Rewe 2 = 0
    SET DC_request_ratio = 0
   ELSE
    SET Order_Retail_Rewe 3 = 0
  IF DC_request_ratio <> 0
   IF Order_Retail_Rewe 1 > 0
    SET loading_failures_retail_rewe = loading_failures_retail_rewe+1
    IF waitingtime_retail_rewe 1 = -1
     SET waitingtime_retail_rewe 1 = Simulation Time
    SET Order_Retail_Rewe 1 = 0
   IF Order_Retail_Rewe 2 > 0
    SET loading_failures_retail_rewe = loading_failures_retail_rewe+1
    IF waitingtime_retail_rewe 2 = -1
     SET waitingtime_retail_rewe 2 = Simulation Time
```

```
        SET Order_Retail_Rewe 2 = 0
      IF Order_Retail_Rewe 3 > 0
        SET loading_failures_retail_rewe = loading_failures_retail_rewe+1
        IF waitingtime_retail_rewe 3 = -1
          SET waitingtime_retail_rewe 3 = Simulation Time
        SET Order_Retail_Rewe 3 = 0
  IF Order_Retail_Rewe 1 > 0
    IF Inventory_DC_Rewe.Count Contents >= Order_Retail_Rewe 1-Transport_Retail_Rewe 1.Count Contents
      SET Transport_Retail_Rewe 1.Label Batching Max = Order_Retail_Rewe 1
      SET Transport_Retail_Rewe 1.Label Batching Min = Order_Retail_Rewe 1
      SET total_deliveries_retail_rewe = total_deliveries_retail_rewe+1
      SET loadlevel_retail_Rewe1 = loadlevel_retail_Rewe1+[Order_Retail_Rewe 1/ROUND[fc_1week_rewe/60]]
      IF Simulation Time-waitingtime_retail_rewe 1 > 1000
        IF waitingtime_retail_rewe 1 <> -1
          SET longwaits_retail_Rewe = longwaits_retail_Rewe+1
          IF Simulation Time-waitingtime_retail_rewe 1 > 5000
            SET verylongwaits_Retail_Rewe = verylongwaits_Retail_Rewe+1
      SET waitingtime_retail_rewe 1 = -1
      SET blockroute_Retail_Rewe 1 = 0
  IF Order_Retail_Rewe 2 > 0
    IF Inventory_DC_Rewe.Count Contents >= Order_Retail_Rewe 2-Transport_Retail_Rewe 2.Count Contents
      SET Transport_Retail_Rewe 2.Label Batching Max = Order_Retail_Rewe 2
      SET Transport_Retail_Rewe 2.Label Batching Min = Order_Retail_Rewe 2
      SET total_deliveries_retail_rewe = total_deliveries_retail_rewe+1
      (Disabled) SET loadlevel_retail_Kaufland1 = loadlevel_retail_Kaufland1+[Order_Retail_Rewe 2/ROUND[fc_1week_rewe/60]]
      IF Simulation Time-waitingtime_retail_rewe 2 > 1000
        IF waitingtime_retail_rewe 2 <> -1
          SET longwaits_retail_Rewe = longwaits_retail_Rewe+1
          IF Simulation Time-waitingtime_retail_rewe 2 > 5000
            SET verylongwaits_Retail_Rewe = verylongwaits_Retail_Rewe+1
      SET waitingtime_retail_rewe 2 = -1
      SET blockroute_Retail_Rewe 2 = 0
  IF Order_Retail_Rewe 3 > 0
    IF Inventory_DC_Rewe.Count Contents >= Order_Retail_Rewe 3-Transport_Retail_Rewe 3.Count Contents
      SET Transport_Retail_Rewe 3.Label Batching Max = Order_Retail_Rewe 3
      SET Transport_Retail_Rewe 3.Label Batching Min = Order_Retail_Rewe 3
      SET total_deliveries_retail_rewe = total_deliveries_retail_rewe+1
      (Disabled) SET loadlevel_retail_Edeka1 = loadlevel_retail_Edeka1+[Order_Retail_Rewe 3/ROUND[fc_1week_rewe/60]]
      IF Simulation Time-waitingtime_retail_rewe 3 > 1000
        IF waitingtime_retail_rewe 3 <> -1
          SET longwaits_retail_Rewe = longwaits_retail_Rewe+1
          IF Simulation Time-waitingtime_retail_rewe 3 > 5000
            SET verylongwaits_Retail_Rewe = verylongwaits_Retail_Rewe+1
      SET waitingtime_retail_rewe 3 = -1
      SET blockroute_Retail_Rewe 3 = 0
'CPFR Retail Kaufland
IF VMI_Retail_Rewe = 2
  SET Order_Retail_Kaufland 1 = 0
  SET Order_Retail_Kaufland 2 = 0
  SET Order_Retail_Kaufland 3 = 0
  IF Inventory_Retail_Kaufland 1.Count Contents/[fc_1week_kaufland/420] <= reorder_barrier_retail_Kaufland
    SET Order_Retail_Kaufland 1 = ROUND[fc_1week_kaufland/60]
  IF Inventory_Retail_Kaufland 2.Count Contents/[fc_1week_kaufland/420] <= reorder_barrier_retail_Kaufland
    SET Order_Retail_Kaufland 2 = ROUND[fc_1week_kaufland/60]
  IF Inventory_Retail_Kaufland 3.Count Contents/[fc_1week_kaufland/420] <= reorder_barrier_retail_Kaufland
    SET Order_Retail_Kaufland 3 = ROUND[fc_1week_kaufland/60]
  SET total_DC_request = [Order_Retail_Kaufland 1+Order_Retail_Kaufland 2]+Order_Retail_Kaufland 3
  IF Inventory_DC_Kaufland.Count Contents < total_DC_request
    SET DC_request_ratio = Inventory_DC_Kaufland.Count Contents/total_DC_request
    IF DC_request_ratio >= 0.7
      SET Order_Retail_Kaufland 1 = TRUNC[DC_request_ratio*Order_Retail_Kaufland 1]
      SET Order_Retail_Kaufland 2 = TRUNC[DC_request_ratio*Order_Retail_Kaufland 2]
      SET Order_Retail_Kaufland 3 = TRUNC[DC_request_ratio*Order_Retail_Kaufland 3]
    IF DC_request_ratio < 0.7
      IF Order_Retail_Kaufland 1 > 0
        IF Inventory_Retail_Kaufland 1.Count Contents <= Inventory_Retail_Kaufland 2.Count Contents
          IF Inventory_Retail_Kaufland 1.Count Contents <= Inventory_Retail_Kaufland 3.Count Contents
            IF Inventory_DC_Kaufland.Count Contents >= 0.7*Order_Retail_Kaufland 1
              SET Order_Retail_Kaufland 1 = TRUNC[0.7*Order_Retail_Kaufland 1]
              IF Order_Retail_Kaufland 2 > 0
                SET loading_failures_retail_kaufland = loading_failures_retail_kaufland+1
                IF waitingtime_retail_kaufland 2 = -1
                  SET waitingtime_retail_kaufland 2 = Simulation Time
                SET Order_Retail_Kaufland 2 = 0
              IF Order_Retail_Kaufland 3 > 0
                SET loading_failures_retail_kaufland = loading_failures_retail_kaufland+1
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```
        IF waitingtime_retail_kaufland 3 = -1
         SET waitingtime_retail_kaufland 3 = Simulation Time
        SET Order_Retail_Kaufland 3 = 0
       SET DC_request_ratio = 0
      ELSE
       SET Order_Retail_Kaufland 1 = 0
   IF Order_Retail_Kaufland 2 > 0
    IF Inventory_Retail_Kaufland 2.Count Contents < Inventory_Retail_Kaufland 3.Count Contents
     IF Inventory_DC_Kaufland.Count Contents >= 0.7*Order_Retail_Kaufland 2
      SET Order_Retail_Kaufland 2 = TRUNC[0.7*Order_Retail_Kaufland 2]
      IF Order_Retail_Kaufland 1 > 0
       SET loading_failures_retail_kaufland = loading_failures_retail_kaufland+1
       IF waitingtime_retail_kaufland 1 = -1
        SET waitingtime_retail_kaufland 1 = Simulation Time
       SET Order_Retail_Kaufland 1 = 0
      IF Order_Retail_Kaufland 3 > 0
       SET loading_failures_retail_kaufland = loading_failures_retail_kaufland+1
       IF waitingtime_retail_kaufland 3 = -1
        SET waitingtime_retail_kaufland 3 = Simulation Time
       SET Order_Retail_Kaufland 3 = 0
      SET DC_request_ratio = 0
     ELSE
      SET Order_Retail_Kaufland 2 = 0
   IF Order_Retail_Kaufland 3 > 0
    IF Inventory_DC_Kaufland.Count Contents >= 0.7*Order_Retail_Kaufland 3
     SET Order_Retail_Kaufland 3 = TRUNC[0.7*Order_Retail_Kaufland 3]
     IF Order_Retail_Kaufland 1 > 0
      SET loading_failures_retail_kaufland = loading_failures_retail_kaufland+1
      IF waitingtime_retail_kaufland 1 = -1
       SET waitingtime_retail_kaufland 1 = Simulation Time
      SET Order_Retail_Kaufland 1 = 0
     IF Order_Retail_Kaufland 2 > 0
      SET loading_failures_retail_kaufland = loading_failures_retail_kaufland+1
      IF waitingtime_retail_kaufland 2 = -1
       SET waitingtime_retail_kaufland 2 = Simulation Time
      SET Order_Retail_Kaufland 2 = 0
     SET DC_request_ratio = 0
    ELSE
     SET Order_Retail_Kaufland 3 = 0
   IF DC_request_ratio <> 0
    IF Order_Retail_Kaufland 1 > 0
     SET loading_failures_retail_kaufland = loading_failures_retail_kaufland+1
     IF waitingtime_retail_kaufland 1 = -1
      SET waitingtime_retail_kaufland 1 = Simulation Time
     SET Order_Retail_Kaufland 1 = 0
    IF Order_Retail_Kaufland 2 > 0
     SET loading_failures_retail_kaufland = loading_failures_retail_kaufland+1
     IF waitingtime_retail_kaufland 2 = -1
      SET waitingtime_retail_kaufland 2 = Simulation Time
     SET Order_Retail_Kaufland 2 = 0
    IF Order_Retail_Kaufland 3 > 0
     SET loading_failures_retail_kaufland = loading_failures_retail_kaufland+1
     IF waitingtime_retail_kaufland 3 = -1
      SET waitingtime_retail_kaufland 3 = Simulation Time
     SET Order_Retail_Kaufland 3 = 0
 IF Order_Retail_Kaufland 1 > 0
  IF Inventory_DC_Kaufland.Count Contents >= Order_Retail_Kaufland 1-Transport_Retail_Kaufland 1.Count Contents
   SET Transport_Retail_Kaufland 1.Label Batching Max = Order_Retail_Kaufland 1
   SET Transport_Retail_Kaufland 1.Label Batching Min = Order_Retail_Kaufland 1
   SET total_deliveries_retail_kaufland = total_deliveries_retail_kaufland+1
   SET loadlevel_retail_Kaufland1 = loadlevel_retail_Kaufland1+[Order_Retail_Kaufland 1/ROUND[fc_1week_kaufland/60]]
   IF Simulation Time-waitingtime_retail_kaufland 1 > 1000
    IF waitingtime_retail_kaufland 1 <> -1
     SET longwaits_retail_Kaufland = longwaits_retail_Kaufland+1
     IF Simulation Time-waitingtime_retail_kaufland 1 > 5000
      SET verylongwaits_Retail_Kaufland = verylongwaits_Retail_Kaufland+1
   SET waitingtime_retail_kaufland 1 = -1
   SET blockroute_Retail_kaufland 1 = 0
 IF Order_Retail_Kaufland 2 > 0
  IF Inventory_DC_Kaufland.Count Contents >= Order_Retail_Kaufland 2-Transport_Retail_Kaufland 2.Count Contents
   SET Transport_Retail_Kaufland 2.Label Batching Max = Order_Retail_Kaufland 2
   SET Transport_Retail_Kaufland 2.Label Batching Min = Order_Retail_Kaufland 2
   SET total_deliveries_retail_kaufland = total_deliveries_retail_kaufland+1
   IF Simulation Time-waitingtime_retail_kaufland 2 > 1000
    IF waitingtime_retail_kaufland 2 <> -1
     SET longwaits_retail_Kaufland = longwaits_retail_Kaufland+1
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      IF Simulation Time-waitingtime_retail_kaufland 2 > 5000
       SET verylongwaits_Retail_Kaufland = verylongwaits_Retail_Kaufland+1
    SET waitingtime_retail_kaufland 2 = -1
    SET blockroute_Retail_kaufland 2 = 0
  IF Order_Retail_Kaufland 3 > 0
   IF Inventory_DC_Kaufland.Count Contents >= Order_Retail_Kaufland 3-Transport_Retail_Kaufland 3.Count Contents
    SET Transport_Retail_Kaufland 3.Label Batching Max = Order_Retail_Kaufland 3
    SET Transport_Retail_Kaufland 3.Label Batching Min = Order_Retail_Kaufland 3
    SET total_deliveries_retail_kaufland = total_deliveries_retail_kaufland+1
    IF Simulation Time-waitingtime_retail_kaufland 3 > 1000
     IF waitingtime_retail_kaufland 3 <> -1
      SET longwaits_retail_Kaufland = longwaits_retail_Kaufland+1
      IF Simulation Time-waitingtime_retail_kaufland 3 > 5000
       SET verylongwaits_Retail_Kaufland = verylongwaits_Retail_Kaufland+1
    SET waitingtime_retail_kaufland 3 = -1
    SET blockroute_Retail_kaufland 3 = 0
'CPFR Retail Edeka
IF VMI_Retail_Rewe = 2
 SET Order_Retail_Edeka 1 = 0
 SET Order_Retail_Edeka 2 = 0
 SET Order_Retail_Edeka 3 = 0
 IF Inventory_Retail_Edeka 1.Count Contents/[fc_1week_edeka/420] <= reorder_barrier_retail_Edeka
  SET Order_Retail_Edeka 1 = ROUND[fc_1week_edeka/60]
 IF Inventory_Retail_Edeka 2.Count Contents/[fc_1week_edeka/420] <= reorder_barrier_retail_Edeka
  SET Order_Retail_Edeka 2 = ROUND[fc_1week_edeka/60]
 IF Inventory_Retail_Edeka 3.Count Contents/[fc_1week_edeka/420] <= reorder_barrier_retail_Edeka
  SET Order_Retail_Edeka 3 = ROUND[fc_1week_edeka/60]
 SET total_DC_request = [Order_Retail_Edeka 1+Order_Retail_Edeka 2]+Order_Retail_Edeka 3
 IF Inventory_DC_Edeka.Count Contents < total_DC_request
  SET DC_request_ratio = Inventory_DC_Edeka.Count Contents/total_DC_request
  IF DC_request_ratio >= 0.7
   SET Order_Retail_Edeka 1 = TRUNC[DC_request_ratio*Order_Retail_Edeka 1]
   SET Order_Retail_Edeka 2 = TRUNC[DC_request_ratio*Order_Retail_Edeka 2]
   SET Order_Retail_Edeka 3 = TRUNC[DC_request_ratio*Order_Retail_Edeka 3]
  IF DC_request_ratio < 0.7
   IF Order_Retail_Edeka 1 > 0
    IF Inventory_Retail_Edeka 1.Count Contents <= Inventory_Retail_Edeka 2.Count Contents
     IF Inventory_Retail_Edeka 1.Count Contents <= Inventory_Retail_Edeka 3.Count Contents
      IF Inventory_DC_Edeka.Count Contents >= 0.7*Order_Retail_Edeka 1
       SET Order_Retail_Edeka 1 = TRUNC[0.7*Order_Retail_Edeka 1]
       IF Order_Retail_Edeka 2 > 0
        SET loading_failures_retail_edeka = loading_failures_retail_edeka+1
        IF waitingtime_retail_edeka 2 = -1
         SET waitingtime_retail_edeka 2 = Simulation Time
        SET Order_Retail_Edeka 2 = 0
       IF Order_Retail_Edeka 3 > 0
        SET loading_failures_retail_edeka = loading_failures_retail_edeka+1
        IF waitingtime_retail_edeka 3 = -1
         SET waitingtime_retail_edeka 3 = Simulation Time
        SET Order_Retail_Edeka 3 = 0
       SET DC_request_ratio = 0
      ELSE
       SET Order_Retail_Edeka 1 = 0
   IF Order_Retail_Edeka 2 > 0
    IF Inventory_Retail_Edeka 2.Count Contents < Inventory_Retail_Edeka 3.Count Contents
     IF Inventory_DC_Edeka.Count Contents >= 0.7*Order_Retail_Edeka 2
      SET Order_Retail_Edeka 2 = TRUNC[0.7*Order_Retail_Edeka 2]
      IF Order_Retail_Edeka 1 > 0
       SET loading_failures_retail_edeka = loading_failures_retail_edeka+1
       IF waitingtime_retail_edeka 1 = -1
        SET waitingtime_retail_edeka 1 = Simulation Time
       SET Order_Retail_Edeka 1 = 0
      IF Order_Retail_Edeka 3 > 0
       SET loading_failures_retail_edeka = loading_failures_retail_edeka+1
       IF waitingtime_retail_edeka 3 = -1
        SET waitingtime_retail_edeka 3 = Simulation Time
       SET Order_Retail_Edeka 3 = 0
      SET DC_request_ratio = 0
     ELSE
      SET Order_Retail_Edeka 2 = 0
   IF Order_Retail_Edeka 3 > 0
    IF Inventory_DC_Edeka.Count Contents >= 0.7*Order_Retail_Edeka 3
     SET Order_Retail_Edeka 3 = TRUNC[0.7*Order_Retail_Edeka 3]
     IF Order_Retail_Edeka 1 > 0
      SET loading_failures_retail_edeka = loading_failures_retail_edeka+1
      IF waitingtime_retail_edeka 1 = -1
```

```
        SET waitingtime_retail_edeka 1 = Simulation Time
       SET Order_Retail_Edeka 1 = 0
      IF Order_Retail_Edeka 2 > 0
       SET loading_failures_retail_edeka = loading_failures_retail_edeka+1
       IF waitingtime_retail_edeka 2 = -1
        SET waitingtime_retail_edeka 2 = Simulation Time
       SET Order_Retail_Edeka 2 = 0
      SET DC_request_ratio = 0
     ELSE
      SET Order_Retail_Edeka 3 = 0
    IF DC_request_ratio <> 0
     IF Order_Retail_Edeka 1 > 0
      SET loading_failures_retail_edeka = loading_failures_retail_edeka+1
      IF waitingtime_retail_edeka 1 = -1
       SET waitingtime_retail_edeka 1 = Simulation Time
      SET Order_Retail_Edeka 1 = 0
     IF Order_Retail_Edeka 2 > 0
      SET loading_failures_retail_edeka = loading_failures_retail_edeka+1
      IF waitingtime_retail_edeka 2 = -1
       SET waitingtime_retail_edeka 2 = Simulation Time
      SET Order_Retail_Edeka 2 = 0
     IF Order_Retail_Edeka 3 > 0
      SET loading_failures_retail_edeka = loading_failures_retail_edeka+1
      IF waitingtime_retail_edeka 3 = -1
       SET waitingtime_retail_edeka 3 = Simulation Time
      SET Order_Retail_Edeka 3 = 0
  IF Order_Retail_Edeka 1 > 0
   IF Inventory_DC_Edeka.Count Contents >= Order_Retail_Edeka 1-Transport_Retail_Edeka 1.Count Contents
    SET Transport_Retail_Edeka 1.Label Batching Max = Order_Retail_Edeka 1
    SET Transport_Retail_Edeka 1.Label Batching Min = Order_Retail_Edeka 1
    SET total_deliveries_retail_edeka = total_deliveries_retail_edeka+1
    SET loadlevel_retail_Edeka1 = loadlevel_retail_Edeka1+[Order_Retail_Edeka 1/ROUND[fc_1week_edeka/60]]
    IF Simulation Time-waitingtime_retail_edeka 1 > 1000
     IF waitingtime_retail_edeka 1 <> -1
      SET longwaits_retail_Edeka = longwaits_retail_Edeka+1
      IF Simulation Time-waitingtime_retail_edeka 1 > 5000
       SET verylongwaits_Retail_Edeka = verylongwaits_Retail_Edeka+1
    SET waitingtime_retail_edeka 1 = -1
    SET blockroute_Retail_edeka 1 = 0
  IF Order_Retail_Edeka 2 > 0
   IF Inventory_DC_Edeka.Count Contents >= Order_Retail_Edeka 2-Transport_Retail_Edeka 2.Count Contents
    SET Transport_Retail_Edeka 2.Label Batching Max = Order_Retail_Edeka 2
    SET Transport_Retail_Edeka 2.Label Batching Min = Order_Retail_Edeka 2
    SET total_deliveries_retail_edeka = total_deliveries_retail_edeka+1
    IF Simulation Time-waitingtime_retail_edeka 2 > 1000
     IF waitingtime_retail_edeka 2 <> -1
      SET longwaits_retail_Edeka = longwaits_retail_Edeka+1
      IF Simulation Time-waitingtime_retail_edeka 2 > 5000
       SET verylongwaits_Retail_Edeka = verylongwaits_Retail_Edeka+1
    SET waitingtime_retail_edeka 2 = -1
    SET blockroute_Retail_edeka 2 = 0
  IF Order_Retail_Edeka 3 > 0
   IF Inventory_DC_Edeka.Count Contents >= Order_Retail_Edeka 3-Transport_Retail_Edeka 3.Count Contents
    SET Transport_Retail_Edeka 3.Label Batching Max = Order_Retail_Edeka 3
    SET Transport_Retail_Edeka 3.Label Batching Min = Order_Retail_Edeka 3
    SET total_deliveries_retail_edeka = total_deliveries_retail_edeka+1
    IF Simulation Time-waitingtime_retail_edeka 3 > 1000
     IF waitingtime_retail_edeka 3 <> -1
      SET longwaits_retail_Edeka = longwaits_retail_Edeka+1
      IF Simulation Time-waitingtime_retail_edeka 3 > 5000
       SET verylongwaits_Retail_Edeka = verylongwaits_Retail_Edeka+1
    SET waitingtime_retail_edeka 3 = -1
    SET blockroute_Retail_edeka 3 = 0
 'CPFR Retail WalMart
 IF VMI_Retail_Rewe = 2
  SET Order_Retail_WalMart 1 = 0
  SET Order_Retail_WalMart 2 = 0
  SET Order_Retail_WalMart 3 = 0
  IF Inventory_Retail_WalMart 1.Count Contents/[fc_1week_walmart/420] <= reorder_barrier_retail_Walmart
   SET Order_Retail_WalMart 1 = ROUND[fc_1week_walmart/60]
  IF Inventory_Retail_WalMart 2.Count Contents/[fc_1week_walmart/420] <= reorder_barrier_retail_Walmart
   SET Order_Retail_WalMart 2 = ROUND[fc_1week_walmart/60]
  IF Inventory_Retail_WalMart 3.Count Contents/[fc_1week_walmart/420] <= reorder_barrier_retail_Walmart
   SET Order_Retail_WalMart 3 = ROUND[fc_1week_walmart/60]
  SET total_DC_request = [Order_Retail_WalMart 1+Order_Retail_WalMart 2]+Order_Retail_WalMart 3
  IF Inventory_DC_WalMart.Count Contents < total_DC_request
```

```
SET DC_request_ratio = Inventory_DC_WalMart.Count Contents/total_DC_request
IF DC_request_ratio >= 0.7
 SET Order_Retail_WalMart 1 = TRUNC[DC_request_ratio*Order_Retail_WalMart 1]
 SET Order_Retail_WalMart 2 = TRUNC[DC_request_ratio*Order_Retail_WalMart 2]
 SET Order_Retail_WalMart 3 = TRUNC[DC_request_ratio*Order_Retail_WalMart 3]
IF DC_request_ratio < 0.7
 IF Order_Retail_WalMart 1 > 0
  IF Inventory_Retail_WalMart 1.Count Contents <= Inventory_Retail_WalMart 2.Count Contents
   IF Inventory_Retail_WalMart 1.Count Contents <= Inventory_Retail_WalMart 3.Count Contents
    IF Inventory_DC_WalMart.Count Contents >= 0.7*Order_Retail_WalMart 1
     SET Order_Retail_WalMart 1 = TRUNC[0.7*Order_Retail_WalMart 1]
     IF Order_Retail_WalMart 2 > 0
      SET loading_failures_retail_walmart = loading_failures_retail_walmart+1
      IF waitingtime_retail_walmart 2 = -1
       SET waitingtime_retail_walmart 2 = Simulation Time
      SET Order_Retail_WalMart 2 = 0
     IF Order_Retail_WalMart 3 > 0
      SET loading_failures_retail_walmart = loading_failures_retail_walmart+1
      IF waitingtime_retail_walmart 3 = -1
       SET waitingtime_retail_walmart 3 = Simulation Time
      SET Order_Retail_WalMart 3 = 0
     SET DC_request_ratio = 0
    ELSE
     SET Order_Retail_WalMart 1 = 0
 IF Order_Retail_WalMart 2 > 0
  IF Inventory_Retail_WalMart 2.Count Contents < Inventory_Retail_WalMart 3.Count Contents
   IF Inventory_DC_WalMart.Count Contents >= 0.7*Order_Retail_WalMart 2
    SET Order_Retail_WalMart 2 = TRUNC[0.7*Order_Retail_WalMart 2]
    IF Order_Retail_WalMart 1 > 0
     SET loading_failures_retail_walmart = loading_failures_retail_walmart+1
     IF waitingtime_retail_walmart 1 = -1
      SET waitingtime_retail_walmart 1 = Simulation Time
     SET Order_Retail_WalMart 1 = 0
    IF Order_Retail_WalMart 3 > 0
     SET loading_failures_retail_walmart = loading_failures_retail_walmart+1
     IF waitingtime_retail_walmart 3 = -1
      SET waitingtime_retail_walmart 3 = Simulation Time
     SET Order_Retail_WalMart 3 = 0
    SET DC_request_ratio = 0
   ELSE
    SET Order_Retail_WalMart 2 = 0
 IF Order_Retail_WalMart 3 > 0
  IF Inventory_DC_WalMart.Count Contents >= 0.7*Order_Retail_WalMart 3
   SET Order_Retail_WalMart 3 = TRUNC[0.7*Order_Retail_WalMart 3]
   IF Order_Retail_WalMart 1 > 0
    SET loading_failures_retail_walmart = loading_failures_retail_walmart+1
    IF waitingtime_retail_walmart 1 = -1
     SET waitingtime_retail_walmart 1 = Simulation Time
    SET Order_Retail_WalMart 1 = 0
   IF Order_Retail_WalMart 2 > 0
    SET loading_failures_retail_walmart = loading_failures_retail_walmart+1
    IF waitingtime_retail_walmart 2 = -1
     SET waitingtime_retail_walmart 2 = Simulation Time
    SET Order_Retail_WalMart 2 = 0
   SET DC_request_ratio = 0
  ELSE
   SET Order_Retail_WalMart 3 = 0
 IF DC_request_ratio <> 0
  IF Order_Retail_WalMart 1 > 0
   SET loading_failures_retail_walmart = loading_failures_retail_walmart+1
   IF waitingtime_retail_walmart 1 = -1
    SET waitingtime_retail_walmart 1 = Simulation Time
   SET Order_Retail_WalMart 1 = 0
  IF Order_Retail_WalMart 2 > 0
   SET loading_failures_retail_walmart = loading_failures_retail_walmart+1
   IF waitingtime_retail_walmart 2 = -1
    SET waitingtime_retail_walmart 2 = Simulation Time
   SET Order_Retail_WalMart 2 = 0
  IF Order_Retail_WalMart 3 > 0
   SET loading_failures_retail_walmart = loading_failures_retail_walmart+1
   IF waitingtime_retail_walmart 3 = -1
    SET waitingtime_retail_walmart 3 = Simulation Time
   SET Order_Retail_WalMart 3 = 0
IF Order_Retail_WalMart 1 > 0
 IF Inventory_DC_WalMart.Count Contents >= Order_Retail_WalMart 1-Transport_Retail_WalMart 1.Count Contents
  SET Transport_Retail_WalMart 1.Label Batching Max = Order_Retail_WalMart 1
```

```
    SET Transport_Retail_WalMart 1.Label Batching Min = Order_Retail_WalMart 1
    SET total_deliveries_retail_walmart = total_deliveries_retail_walmart+1
    SET loadlevel_retail_WalMart1 = loadlevel_retail_WalMart1+[Order_Retail_WalMart 1/ROUND[fc_1week_walmart/60]]
    IF Simulation Time-waitingtime_retail_walmart 1 > 1000
     IF waitingtime_retail_walmart 1 <> -1
      SET longwaits_retail_WalMart = longwaits_retail_WalMart+1
      IF Simulation Time-waitingtime_retail_walmart 1 > 5000
       SET verylongwaits_Retail_WalMart = verylongwaits_Retail_WalMart+1
    SET waitingtime_retail_walmart 1 = -1
    SET blockroute_Retail_WalMart 1 = 0
  IF Order_Retail_WalMart 2 > 0
   IF Inventory_DC_WalMart.Count Contents >= Order_Retail_WalMart 2-Transport_Retail_WalMart 2.Count Contents
    SET Transport_Retail_WalMart 2.Label Batching Max = Order_Retail_WalMart 2
    SET Transport_Retail_WalMart 2.Label Batching Min = Order_Retail_WalMart 2
    SET total_deliveries_retail_walmart = total_deliveries_retail_walmart+1
    IF Simulation Time-waitingtime_retail_walmart 2 > 1000
     IF waitingtime_retail_walmart 2 <> -1
      SET longwaits_retail_WalMart = longwaits_retail_WalMart+1
      IF Simulation Time-waitingtime_retail_walmart 2 > 5000
       SET verylongwaits_Retail_WalMart = verylongwaits_Retail_WalMart+1
    SET waitingtime_retail_walmart 2 = -1
    SET blockroute_Retail_WalMart 2 = 0
  IF Order_Retail_WalMart 3 > 0
   IF Inventory_DC_WalMart.Count Contents >= Order_Retail_WalMart 3-Transport_Retail_WalMart 3.Count Contents
    SET Transport_Retail_WalMart 3.Label Batching Max = Order_Retail_WalMart 3
    SET Transport_Retail_WalMart 3.Label Batching Min = Order_Retail_WalMart 3
    SET total_deliveries_retail_walmart = total_deliveries_retail_walmart+1
    IF Simulation Time-waitingtime_retail_walmart 3 > 1000
     IF waitingtime_retail_walmart 3 <> -1
      SET longwaits_retail_WalMart = longwaits_retail_WalMart+1
      IF Simulation Time-waitingtime_retail_walmart 3 > 5000
       SET verylongwaits_Retail_WalMart = verylongwaits_Retail_WalMart+1
    SET waitingtime_retail_walmart 3 = -1
    SET blockroute_Retail_WalMart 3 = 0
```