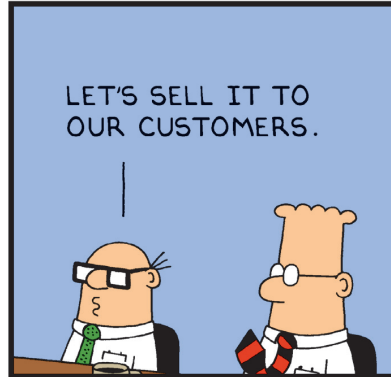


PIET VAN DER VLIST

Synchronizing the Retail Supply Chain



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Synchronizing the Retail Supply Chain

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Synchroniseer de retail supply chain

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To survive ...

Paranimfen:
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Dr.ir. M.A.A.P. Verwijmeren

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Abstract

This thesis actually is a design, a design of a retail supply chain, better and cheaper than the usual one. The usual retail supply chain is shown in Figure 1. Straight from produc-

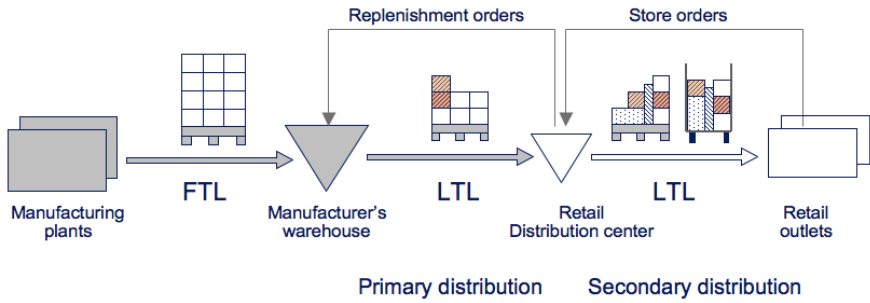


Figure 1: Current retail supply chain

tion goods move in full homogeneous pallets in full truckload (FTL) to the manufacturer's warehouses. To produce efficiently, suppliers run large batches, resulting in relatively high levels of cycle stock in their warehouses. To keep their inventory levels low, retailers order frequently in small quantities. As a consequence retail distribution centers (RDC's) are replenished with (manually assembled) mixed pallets in less than full truckloads (LTL). Also the stores re-order frequently. They receive the goods they order on pallets or rolling cages, containing articles from various manufacturers grouped per family so as to make filling the shelves easier.

But the retailers seem to have gone too far in inventories savings. A logistics costs breakdown at both supplier and retailer shows that at the supplier the costs of inventory and of picking the retail orders are ten times as high as the costs of inventory at the retail distribution centers. The focus on inventory reduction at the retailer is at the least questionable. Most of the supply chain inventory sits at the manufacturer, where it cannot fulfill urgent consumer needs; whereas at the retail distribution centers only limited amounts of inventory are available for immediate replenishment of the stores. So the goods are available, but at the wrong location.

This thesis is based on the hypothesis that to get a good retail supply chain, downstream processes should be synchronized to upstream processes, instead of the other way around.

To validate this hypothesis, this thesis in the Chapters 2 through 6 explores and extends the theory on such supply chain management aspects as: *Inventory*, *Handling*, *Network structure*, *Order fulfillment* and *Sharing the benefits*.

Chapter 2 on *Inventory* extends the well-known single echelon single period news vendor equation¹ to a formula suitable for a multi-echelon and multi-period divergent distribution network. We derive the formula for the optimally tuned distribution network via marginal analysis². From this formula it can be read that downstream nodes must be tuned to higher service levels than upstream ones. This means that the client at the most downstream node, the retail store, experiences the customer-service level that is being set by the most upstream node.

From the formula one can also derive the optimal inventory positioning. If both lead-times and added value are equal between the nodes of the retail supply chain, most of the inventory should be positioned downstream. If a node is replenished with a relatively high lead-time, extra safety stock is needed at that node. If a node adds more value than the other nodes, part of the inventory remains upstream of that node. If the most upstream node adds most of the value, all inventory should be positioned at the most downstream nodes. In the retail supply chain normally the most upstream node, the manufacturer, adds most of the value. *If we consider the retail supply chain to include the supplier, all inventory should be at the shop.* Simulations support these findings.

The costs of *Handling* are mainly determined by the order sizes. Chapter 3, extends the single-echelon EOQ-model (Economic Order Quantity) to a multi-echelon divergent supply chain model. The chapter concludes that compared to a non integrated supply chain, where every supply chain partner minimizes his own costs, in a synchronized supply chain, the number of transactions goes down, overall system inventory goes down and overall system costs go down even more.

Chapter 4 is on *Network structure*. It explores the use of stock-less consolidation points and direct shipments that skip a network echelon. Application of the theory in a case example shows that quite frequently (in the case example almost in one-third of the situations) it is worthwhile passing by the manufacturer's warehouse and driving straight from production to one or more retail distribution centers. The chapter also explores the use of retail consolidation centers, where manufacturers can deliver all of their goods for a retailer, where-after the retailer moves these goods on to the other distribution centers. Using the logistics cost model in Appendix B indicative costs per pallet are calculated. An interesting retail network structure is one where the consolidation points and any central slow mover distribution center are distributed and collocated with the RDC's and a carousel of trucks move the goods on between these locations. In the current situation the overall costs per pallet will be around 30 Euro; this figure drops to around 13 Euro with the carousel in operation. Chapter 4 finally compares the network structure where goods are cross docked at the manufacturer and stored at the retailer with the distribution structure at Wal-Mart where goods are stored at the manufacturers and cross docked at the retailer.

Chapter 5 on *Order fulfillment* speculates on ways to improve the Shop Order fulfillment process. To give some examples: An integral logistics calculation soon might show that more goods should be positioned at the store. It might be worthwhile to pack small items into assortment boxes with a mixed content. For slow movers with ample shelf space, one

¹How many newspapers should the news vendor buy, when he pays h and earns p when sold.

²In the equilibrium, one extra newspaper most probably costs as much as its expected yield.

might concentrate ordering on given days of the week, thus enhancing the warehouse order pick operation.

The paradox of a synchronized supply chain is that downstream supply chain partners need to invest in order to save costs at upstream partners. It is obvious that Supply Chain Synchronization will only be implemented between supply chain partners if there exist adequate contractual arrangements to *Share the benefits*. This is the subject of Chapter 6. It is concluded that the regular commercial negotiations between retailer and supplier should be kept separate from the logistics negotiations, as these are completely cost justifiable. Furthermore the logistic negotiations on Inventory, Handling and Network-structure should each be treated and compensated differently.

Throughout the thesis observations and design choices are being made. Using these, Chapter 7 *Puts the pieces together* and gives a final comprehensive description of all aspects of Supply Chain Synchronization.

A synchronized retail supply chain is a supply chain, where distribution is synchronized to production and where store replenishment is synchronized to warehouse operation. That supply chain indeed has the overall lowest cost. From a supply chain perspective inventory

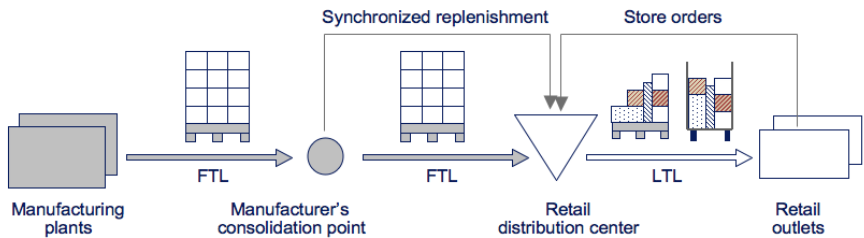


Figure 2: Synchronized retail supply chain

should be at the retailer, close to the client. It should move to the retailer at the lowest costs, that is on full pallets in full truckloads. This then should happen prior to urgent replenishment needs, as soon as goods become available from production. "Ship as soon as you can and don't wait till you have to!" In other words distribution should be synchronized to the production schedule. The manufacturer's warehouse then becomes a stock-less cross docking point, where goods from the various plants can be consolidated into the same truck to a retail distribution center. That supply chain structure is shown in Figure 2.

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Chapter 1

Grocery retailing

1.1 Introduction

This thesis actually is a design. A blueprint of a better retail supply chain. A supply chain where downstream processes are synchronized to upstream processes. In other words: a supply chain, where distribution is synchronized to production and where store replenishment is synchronized to warehouse operation. Our hypothesis is that such a synchronized supply chain, not only is the supply chain with the overall lowest costs, but also is a supply chain that offers a better customer service. This is at least true in grocery retail, but undoubtedly also in quite some other fields. Synchronizing the supply chain avoids handling, reduces inventory, removes time pressure, allows for consolidation of transport, facilitates network redesign and at the same time improves customer service. This way of managing the retail supply chain is almost the opposite of the current practice in retail supply chain management. Retail supply chain management has evolved over time. We broadly follow here the four stages recognized in (Fernie et al., 2000):

1. supplier control (pre-1980)
2. centralization (1981-1989)
3. just-in-time (1990-1995)
4. relationship (1996-to date)

In the first stage suppliers made direct to store deliveries (DSD's) on a weekly or longer basis. Store managers negotiated with suppliers and kept surplus stock that did not fit on the shelves in a 'backroom'. In the second stage, the retailers concentrated into retail chains and in areas with a high enough concentration of stores constructed purpose-built regional distribution centers (RDCs), to take over and to centralize the role of the 'backroom' and to consolidate products from suppliers for frequent onward delivery to stores. In stage 3, the just-in-time phase, major efficiency improvements were achieved. It has become common practice in food retail to frequently reorder and deliver (daily or even more often) in order to squeeze inventory out of the downstream supply chain. Triggered by the scanning of goods at the point-of-sale, the retail outlet stores are replenished within hours. Subsequently, the

manufacturer is equally required to replenish the retail distribution centers within short lead times. This forces the manufacturer to deliver from stock, as he is unable to produce his complete product portfolio that frequently. As a result retailers, after stage 3, are operating a costly demand driven (pull) supply chain, with frequent deliveries, in small quantities and with stringent timing requirements. Or to quote (Fernie et al., 2003): "Retailers now begin to appreciate that there are no 'quick wins' such as that of centralization in the 1980's. If another step change in managing retail logistics is to occur, it can only be realized through supply chain cooperation."

Today's retail supply chain has a multi-echelon structure, with a series of interconnected stock points. Multi-echelon supply chains are difficult to manage, already when they are within the realm of one single company, let alone the situation where several companies manage them jointly, as is the case in retail distribution. In addition there is considerable complexity: assortments of over 30,000 items within a supermarket are not at all exceptional.

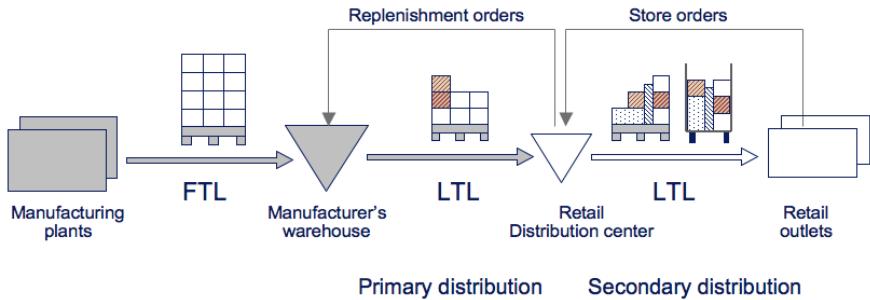


Figure 1.1: The retail supply chain

A supply chain structure that is not uncommon amongst grocery retailers is the one that is shown in Figure 1.1. From left to right in this figure: The various plants of a certain manufacturer replenish his regional warehouses. This is an efficient operation with full truckloads (FTL) and with full pallets. It is (forecast) driven by the planning and production processes in the manufacturing plants. The mostly regional manufacturer's warehouses subsequently supply the distribution centers of various retail companies (primary distribution), within their service area. This is a less efficient operation, often with less than full truckload (LTL) and with client specific mixed pallets. It is (demand) driven by the retailer's replenishment orders. The retailers then take control over the replenishment of their own retail outlets (secondary distribution). But even this operation not always is efficient. It is (demand) driven by the retail shop orders. It might run less than full truckload with pallets and/or rolling cages not always being full and assembled on demand. The inventory in the supplier's warehouse is the main client order decoupling point, separating the forecast driven part of the supply chain from the demand driven part (Hoekstra and Romme, 1992).

Actually the demand-driven distribution concept with daily replenishments is adequate only for items that are manufactured daily or where shelf space limitations constrain inventory to cover more than a day's demand. For the majority of items in the assortment it is a cumbersome and costly control method, with much handling and high time pressure.

1.2 Literature

Retail supply chain management has been, and still is, an interesting field of study for Operations Research. This has resulted in important mathematical tools and methodologies to optimize retail supply chain inventory levels, even for divergent retail distribution networks, see e.g. (Diks and De Kok, 1998). For a good overview of the state of the art of operations research in supply chains, we refer to (De Kok and Graves, 2003). In scientific operations research literature, like in retail practice, there is a strong focus on inventory management and on inventory reduction, subject to service constraints. In that perspective supply chain management is almost synonymous with safety stock positioning.

Retail management literature, outside the field of Operations Research, for a long time did not seem to recognize the importance of the supply chain. As stated by Fernie et al.: "Although numerous texts (on retail management) have been published, they continued to focus on Retail Marketing. Most books on this subject ignore the supply chain. This is surprising in that the key to success in retailing is the ability to buy well to meet customers' needs and coordinate the logistics to get these products to the shelf as efficiently as possible." (Fernie et al., 2000) Or to quote (Kotzab and Bjerre, 2005): "Logistics has been a topic for industrial companies rather than for retailing companies. This however changed with the presentation of the Wal-Mart distribution system in a Harvard Business Review article (Stalk et al., 1992)]. Logistics and supply chain management is now being re-recognized as a core competence of retailing. Many retailers operate with a loss, as costs are above sales and, compared with industrial companies, retail logistics costs take a higher share on total costs (between 10 to 30% of total costs). However, successful retailing companies are able to operate logistics below 10% of total costs, whilst increasing logistics service, as Wal-Mart has demonstrated. Focusing on logistics can help retailing companies to operate profitably and avoid harmful price battles."

In this thesis we will show that a focus on inventory management is not enough to get a good supply chain. A logistics cost breakdown rapidly reveals that in the retail supply chain -and certainly so in grocery retail- the costs of inventory are considerably lower than the costs of handling and the costs of transportation. The challenge is to attack all elements of the retail logistics costs structure in such a way that the overall supply chain costs are minimal, whilst maintaining or improving customer service. To achieve that, it is necessary to coordinate, or rather synchronize, the processes along the supply chain, in *quantity*, in *time* and possibly in *price*.

Coordination in *quantity* can be achieved by granting quantity discounts. The article by Monahan on quantity discounts to increase vendor profits (Monahan, 1984), albeit criticized for not really maximizing profit and limited to lot-for-lot situations, can be seen as a starting point for quite some other publications on vendor-buyer or supply chain coordination. Lee and Rosenblatt in (Lee and Rosenblatt, 1986) generalize Monahan's lot-for-lot model to the situation where the supplier's order size is an integer multiple k of the buyer's order size. But, because they do not explicitly model the supplier's client-order processing costs, the model is limited to 1-lot for k -lots. Subsequently Goyal simplifies their algorithm and Banerjee develops a joint economic lot size model (Goyal, 1987), (Banerjee, 1986). Just to name a few others: (Goyal and Gupta, 1989), (Banerjee and Banerjee, 1994), (Banerjee and Burton, 1994) and (Goyal, 1995). The majority of these models is single product, two-echelon one buyer - one supplier and use EOQ-type calculations, with linear inventory holding costs and fixed order processing costs. Tsay suggests using quantity flexibility

contracts between retailer and supplier to achieve quantity coordination (Tsay, 1999). A recent paper by Sarmah et al. gives a good overview of the various vendor-buyer quantity co-ordination models (Sarmah et al., 2006).

Co-ordination in *time* and joint replenishment is the subject of another line of research. Viswanathan and Piplani introduce the common replenishment epoch (CRE). Buyers get a discount when they shift their order moments to a common cycle. The supplier can give the discount because he saves on transaction costs due to the combined handling of the orders. Chan and Kingsman relax the necessity of a common cycle. They show that it is good enough when supplier and retailers synchronize their processes in timing to fixed multiples of an underlying schedule. Chen and Chen describe the savings when products within a product family are replenished jointly; they also mention the savings in production. But none of the literature goes as far as we will do in this thesis: make the common cycle to coincide with the production schedule and eradicate a whole layer of cycle stock for every echelon that is synchronized. See (Viswanathan and Piplani, 2001), (Chan and Kingsman, 2005) and (Chen and Chen, 2006).

Quite some literature on supply chain coordination includes *price* in their models and moves away from cost minimization to profit maximization. A recent overview of literature in that field can be found in the introductory paragraph of (Chen and Chen, 2006). In our research however, we will not follow that road and we will restrict ourselves to cost justifiable supply chain savings.

A recent paper, that gives an overview of supply chain coordination on all of the aspects mentioned above is (Li and Wang, 2007).

This paragraph lists only literature that is relevant to our supply chain management concept in general. Literature that is addressing specific aspects of supply chain management, will be treated in the respective chapters.

1.3 Problem statement

The basis of this research, the problem statement, is:

Design the (grocery) retail supply chain with the overall lowest costs, whilst increasing customer service, by synchronizing downstream client processes to upstream supplying processes.

This different way of working, called Supply Chain Synchronization (Van der Vlist, 2004) is the subject of this thesis. We consider the supply chain to include the suppliers, i.e. we search for the supply chain with of the overall lowest cost all the way from the production plant to the retail store. Current retail supply chain practice is focused on optimizing the retail part of the supply chain and tries to force the manufacturing industry to adapt its batch oriented production processes to the frequently ordering retail supply chain. Supply Chain Synchronization goes further than that, in that it recognizes that there are limits to the flexibility of the production processes and given these limits, it organizes the distribution in the most efficient way. It does so by synchronizing distribution to production. Similarly Supply Chain Synchronization recognizes that there are also limits to the flexibility of the distribution center operation, such that not everything can be delivered within short notice

in a cost-effective way and a more efficient store replenishment process might be found when certain predefined ordering schedules are being followed.

In this research Supply Chain Synchronization will not be limited to inventory management, but is described as a comprehensive supply chain management methodology, comprising concepts that deal with all elements of the retailer's logistics operation. The research however is limited to cost justifiable fact based supply chain improvements and does not look at marketing driven coordination mechanisms like revenue-sharing. The research approach is shown in Figure 1.2

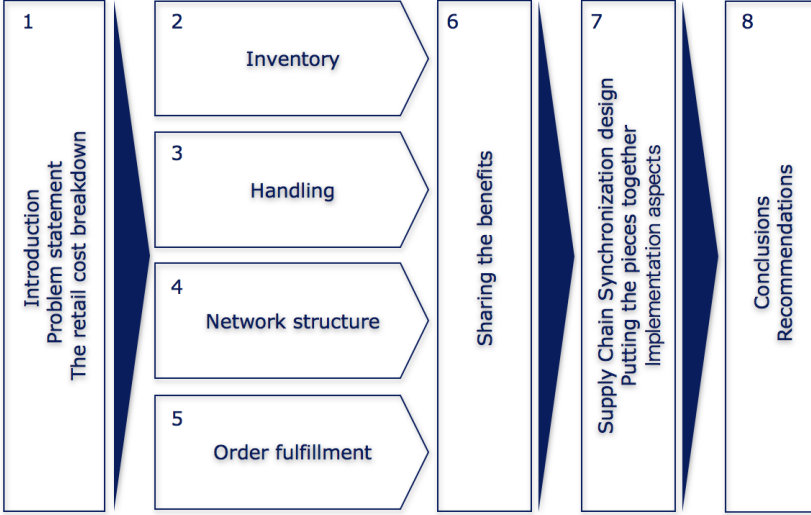


Figure 1.2: Research approach

At the heart of this research lies the retail logistics cost breakdown, as shown in the next section. From this cost breakdown it can be seen, that the main cost components can only be attacked in cooperation with down-stream supply chain partners. The cost breakdown also guides us to identify which supply chain management aspects the design of a synchronized supply chain should address particularly.

We start our research by studying the following four fundamental supply chain management aspects: Inventory, Handling, Network structure and Order fulfillment. We will study the state of the art in scientific research on each of these aspects and extend it where needed. Throughout our research we will make observations that are relevant to our research subject. We will translate these observations into design choices that together form the basis of our supply chain design and validate the supply chain synchronization concept. Subsequently we will discuss how to share the benefits of supply chain improvements. And finally, putting all the pieces together, we will give a comprehensive description of Supply Chain Synchronization and compare it with other supply chain management Improvement concepts.

The structure of this thesis closely follows the research approach. The next section concludes this first chapter by showing the logistics cost breakdown that we developed of both retailer and supplier. The following four chapters each deal with one of four supply chain

management aspects. The first supply chain management aspect is Inventory in Chapter 2. The chapter starts with a discussion of centralized versus de-centralized planning and vendor managed inventory, using and extending various models from literature. Still on inventory, the chapter gives an overview of the current theory on inventory management, both from a service and from a cost minimization perspective. It concludes that safety stock should be placed more forward, downstream the supply chain. Chapter 3 deals with Handling. As handling is related to order sizes, the analysis uses and extends the EOQ-model. Differently from many other supply chain management concepts, this chapter also explicitly deals with cycle stock. By moving inventory forward as soon as it becomes available, upstream cycle stock disappears and all cycle stock is there downstream to serve customers and to reduce the needs for safety stock. Chapter 4 analyzes the retail distribution network structure. An important element in this analysis is consolidation. The chapter ends with a challenging network structure called the ‘Carrousel’. The next chapter, Chapter 5, is on order fulfillment. It argues that the voluminous cheap and fast moving goods should be moved on full pallets, preferably even to the stores. The chapter also explores another way to reduce the costs of order fulfillment: working with predefined mixes, such as assortment boxes. The chapter finally shows that managing shop order behavior can simplify order picking at the retail distribution centers. This requires a different shelf management methodology. To get the various elements of Supply Chain Synchronization implemented, there needs to be a willingness to share the benefits. This is the subject of Chapter 6. Chapter 7 gathers the design elements from all of the preceding ‘topical’ chapters and puts the pieces together into a coherent design. The various observations and design choices together should also prove the validity of the concept and identify the field of application and the limits of Supply Chain Synchronization. The final Chapter concludes and recommends further work. Case studies can be found in several chapters and in appendix A.

1.4 The logistics cost structure in food retail

Figure 1.3 shows a logistics cost breakdown (in percentages) at a typical classical food retailer for the secondary distribution part of the supply chain, running from the retail distribution centers down to, but not including the retail stores. This retailer’s logistics cost breakdown plays an important role in the development of Supply Chain Synchronization. The figure actually is a weighted average of several case studies in the Netherlands, that were performed during this research. The cost breakdowns from the different retailers appeared to be surprisingly consistent. With some knowledge of a specific retailer’s operation and using simple cost figures such as the ones given in the cost model in Appendix B, one can fairly easy get a reasonably good estimate of the logistics cost structure.

Both in supply chain theory and in supply chain practice, a lot of attention has been given to the costs of inventories, especially at the retailer. The retailer’s cost breakdown in Figure 1.3 reveals that, at least in the dry grocery cases that have been studied to develop this cost breakdown, not the costs of inventory, but the other elements dictate the logistics costs. In this example cost breakdown, the retailer owns the warehouses. So the costs of warehousing are represented as fixed cost. The variable inventory holding costs in the retail distribution centers then is only a tiny 2% of the total logistics costs at the retailer. So, saving 10% on inventory saves only 0.2% on the logistics costs, that in itself are only a percentage of the purchase price. Actually the retailer can influence only 9% of the logistics costs, but over 60% of the logistics costs depend on the shop ordering behavior. In other

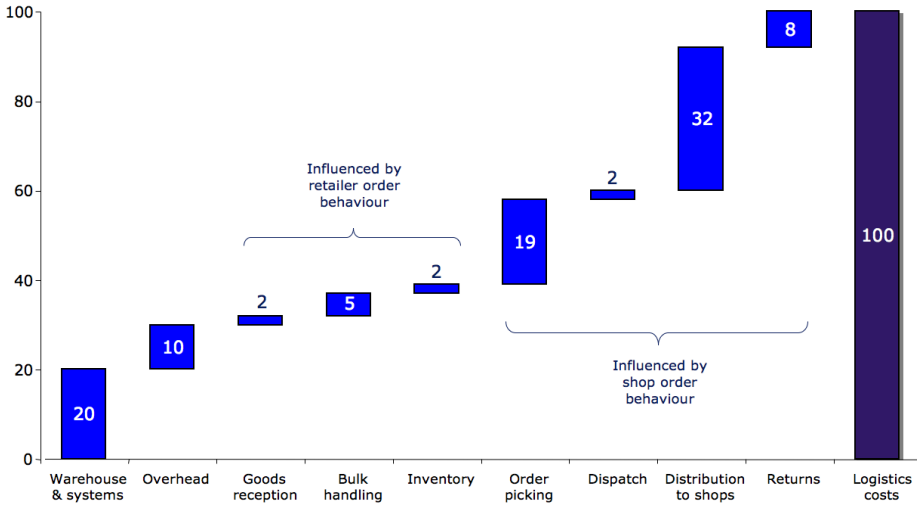


Figure 1.3: Retailer's logistics cost breakdown (dry grocery)

words realizing savings in logistics costs at the central retail organization is in the hands of the retail outlets, the next party downstream the supply chain.

In the case that the retailer does not own the warehouses but has outsourced the warehousing, to a large extent the costs of warehousing would become variable as well. But even then they would not be the most important cost component.

Similar conclusions can be drawn from Figure 1.4 , which shows a joint cost breakdown of both the primary and the secondary distribution at a typical dry grocery supplier and a retailer. The supplier of course also has other retail clients and in the same way the retailer has other suppliers. In the case studies performed during this research, on average 40% of the logistics costs were generated at the suppliers and 60% at the retailers. The figure has been constructed by scaling an average supplier's cost breakdown to the 40% and an average retailer's cost breakdown to the remaining 60%.

In this picture the same phenomenon can be seen, that not so much the supplier, but much more the retailer can influence the logistics costs structure at the supplier. In the normalized cost breakdown in Figure 1.4 over two third of the logistics costs at the supplier depend upon the retailer's ordering behavior. The supplier can change these cost elements only in co-operation with his retail clients. If however the replenishment control mechanism between supplier and retailer is changed from decentralized ordering by the retailers to centralized inventory management by the suppliers, these cost elements now rest in the hands of the supplier himself allowing him to seek a cost optimal situation.

To produce at low cost, the manufacturing industry produces an item at intervals in batches. For the purpose of this research this is taken for granted and discussions on flexible manufacturing and set-up-time reduction on filling and packaging lines are considered to be outside scope of this research. With the current product proliferation, manufacturers might

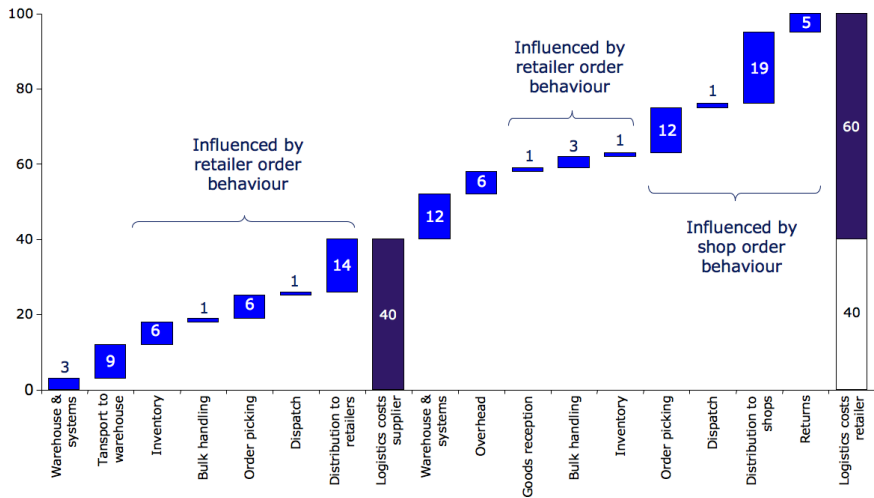


Figure 1.4: Joint supplier-retailer logistics cost breakdown (dry grocery)

produce virtually hundreds of different articles, despite the efforts to reduce the number of stock keeping units. It is a fact of life, that the mostly batch oriented production processes cannot be adapted such that they can produce all these different articles synchronously to the demand driven retail chain. This, together with the short order lead times imposed upon the suppliers, forces the suppliers to deliver from stock.

1.5 Analysis

Based on the contents of this chapter the following observations can be made:

Observation 1

Handling and distribution dominate logistics costs

Not the costs of inventory, but the costs of order picking, shipping and transportation are the most important elements in the retail logistics cost breakdown.

Observation 2

Co-operation can reduce logistics costs

The relatively high costs of handling and distribution are a consequence of the ordering behavior of the downstream supply chain partner. Changing that ordering behavior can reduce these costs.

Observation 3

Efficient production requires production in batches

To produce at low cost, the manufacturing industry produces an item at intervals in batches.

Observation 4

Short lead-times force suppliers to deliver from stock

With the current product proliferation, manufacturers might produce virtually hundreds of different articles, despite the efforts of power retailers to reduce the number of stock keeping units. It is a fact of life, that the mostly batch oriented production processes cannot be adapted such that they can produce all these different articles synchronously to the demand driven retail chain. This, together with the short order lead times imposed upon the suppliers, forces the suppliers to deliver from stock.

Observation 5**Production and distribution frequencies do not match**

An apparent mismatch exists between the supplier's low production frequency and the retailer's high ordering frequency. As a result high volumes of cycle stock are sitting at the supplier's warehouse.

These observations lead to the following design choices:

Design choice 1**Design the supply chain with an integration focus**

A cost effective retail supply chain concept should have a supply chain integration focus because the main retail logistics' cost components can only be influenced in cooperation with downstream supply chain partners.

(Based on observations 1 and 2)

Design choice 2**Synchronize distribution to production**

The main idea behind Supply Chain Synchronization, is to not try to synchronize upstream processes to downstream processes, but to synchronize downstream replenishment to upstream processes, both in timing and in quantity. This means synchronizing retail distribution to production and synchronizing retail shop replenishment to retail distribution center operations.

(Based on observations 3, 4 and 5)

Chapter 2

Inventory management

2.1 Introduction

The stock points in a retail distribution network are keeping two types of inventory: cycle stock and safety stock. Cycle stock is the result of producing or ordering goods in certain batches. If processes have not been synchronized, the cycle stock on average will be half the batch size or order size. Safety stock is stock that might be needed if demand is higher than forecast or if replenishment processes are uncertain. One could argue that cycle stock is the price we pay for the inflexibility of our processes and that safety stock is the price we pay for our lack of information. That lack of information makes demand difficult to forecast.

This chapter is on safety stock and the next one, Chapter 3, discusses cycle stock. This chapter discusses calculating and positioning safety stock, for two quite different situations:

1. The first situation is one where supply chain partners buy from upstream and sell downstream. The price difference then can be seen as added value or holding costs. Goods traversing the supply chain accumulate value or costs and the closer they are to the final customer, the more expensive they become. This is in line with generally accepted commercial standards.
2. The second situation looks at the supply chain from an integrated perspective, holding costs then are considered to be systemwide and moving goods from one place in the supply chain to another does hardly affect the holding costs, provided storage costs are more or less equal between locations

There is a vast body of literature on inventory management. Most of that literature, like we do in this chapter, follows an operations research approach aiming at the development of concise mathematical formulas to calculate safety stock levels. Safety stock is there to guard against the unknown, the unpredictable. And the basis for calculating safety stock thus should always be the forecast error; the better the forecast, the lower the safety stock can be.

Ever since Magee described base stock control and Clark and Scarf showed that in a multi-stage serial distribution network controlling the inventory per echelon is the better policy,

(Magee, 1958) (Clark and Scarf, 1960) many articles have been published that one way or another, extend their work, both in serial and divergent networks. See Axsäter and Rosling for a more elaborate comparison of echelon versus installation stock policies (Axsäter and Rosling, 1993).

As said, controlling the inventory per echelon (i.e. to base reordering throughout the supply chain on total downstream inventory and on end-customer demand) generally is better than managing inventory per installation (i.e. to base reordering on local inventory and local demand), as is so often done in practice. Managing inventory per echelon requires downstream visibility of all stock levels within an echelon. More than ever before, modern information and communication technology can facilitate that downstream visibility. But it requires supply chain partners, who provide that visibility and it requires IT-systems, which offer that functionality. In practice both the willingness and the system's capabilities frequently are lacking.

In the next section we will first have a closer look at centralized and de-centralized planning concepts and vendor managed inventory. Then Section 2.4 deals with the service level approach. Section 2.5 deals with the cost minimization perspective, using a multi-echelon version of the newsvendor formula. Solutions will be different in a supply chain where the goods are bought and sold between supply chain partners and consequently increase in price and accumulate holding costs as they travel downstream towards the consumer or in an integrated supply chain where holding costs are systemwide and supply chain partners separately have arranged a financial settlement. Section 2.6 discusses the first situation, the one with cumulative holding costs and Section 2.7 deals with the second situation, the one with systemwide or absolute holding costs. Section 2.8 integrates the service level and cost minimization approach and suggests to use both in such a way, that given the target service level as specified by management, maximum profit is being assured. The chapter ends with an Analysis with an overview of observations and design choices.

In retail practice replenishment most often is on a periodic basis, e.g. daily; we therefore limit ourselves to periodic review methodologies only. Furthermore, for the time being, in this chapter on inventory theory we neglect lot sizes. But we come back at the subject of lot-sizing at the end of this chapter.

2.2 Centralized versus De-centralized planning

Within the context of retail distribution systems we define a system with de-centralized control to be a system, where the receiving party orders from the next higher echelon based on its local viewpoint (sometimes called a 'Pull'-system) and a system with centralized control to be a system, where decisions upon deliveries are taken based on some system-wide viewpoint (sometimes called a 'Push'-system). A similar definition of push and pull is given by e.g. (Silver and Peterson, 1985). Others, like (Zipkin, 2000), reserve the word 'Pull' for pure Kanban systems in the context of the just-in-time approach. In view of the confusion around the meaning of the words push and pull, we will avoid using them and use the terms centralized and de-centralized control instead. Some, like (Dellaert et al., 2000) and (De Kok, 2001), consider push systems to be forecast driven and pull systems not. In our view however both centralized and de-centralized systems can be forecast driven; a system without an explicit forecast apparently predicts constant demand, which still is a forecast.

At times there seems to be a general feeling that de-centralized control systems (Pull') are demand driven and good and that centralized control systems ('Push') are imperious and bad. We will argue that in most cases the opposite is true. From a supply chain perspective decentralized systems never can be better than a correctly implemented centralized system; see e.g. (De Kok, 2001).

It is not always directly clear whether an inventory management system is a push or a pull system. Some systems are a mixture of both push and pull. A good example of such a combination of push and pull might be a retail organization where the retail distribution center pulls inventory from the suppliers and allocates and pushes the incoming goods downstream toward the retail outlets. One could argue that pure pull systems do not exist, because a pull system assumes that enough inventory or production capacity is available to fulfill the pull-orders. Whenever that inventory or capacity does not exist, the supplying party one way or another will take some form of allocation decision and chooses how much to deliver to whom. That allocation decision can be seen as a push order. Although in retail practice one most often encounters pull systems, a great deal of literature on multi-echelon inventory distribution systems deals with push systems, because most of that literature supposes centralized ordering and allocation by a single decision maker. See e.g. (Axsäter, 2003).

The pull order that a receiving party places upon the supplying higher echelon, will be based on some elements of the locally available information. These information elements are e.g. the order pipeline, the own stock position and (provided downstream visibility) the downstream stock position plus a forecast of future demand. The push order generated by the higher echelon is based on similar information elements that (again provided downstream visibility) include the information available at the lower echelon. Due to this broader view across all downstream clients, the push order from a system perspective can be a better order. Without proper downstream visibility a push system cannot operate.

2.3 Vendor Managed Inventory

2.3.1 Introduction

The implementation of centralized planning, where an outside supplier manages the inventory at a retail distribution center for the products that this supplier delivers, is called Vendor Managed Inventory or VMI for short. Under such a VMI regime, the supplier might own the stock (consignment stock or Vendor Owned Inventory VOI), or might not own the stock in the retail distribution centers. VMI dates back to the mid-nineties and has been promoted extensively by the international ECR-organization. To implement VMI, the vendor needs visibility on downstream stock levels at his clientele. It is important to note, that many of the effects attributed to VMI stem from the better information exchange and could have been achieved without VMI.

There is quite some literature on VMI. This literature comes in two flavors. Part of it is proper VMI literature and deals with topics like implementation, flexibility gain and savings; the other part uses the label VMI as synonymous to centralized or push inventory management. If it comes to modeling, the VMI literature generally still uses fairly simple one buyer - one supplier models. Hardly any article studies the situation of a supplier with more than one buyer. Consequently the outcomes should be treated with care.

2.3.2 Proper VMI

Cachon and Fisher studied VMI in a continuous replenishment project at Campbell soup. Retailer inventories were reduced on average by 66% whilst maintaining or even increasing average fill rates. This improvement reduced the retailer's cost of goods sold by 1.2%, which is significant in the low profit margin grocery industry. Interestingly they found that these savings could also have been achieved without VMI, if the retailer would have used the same order calculation formulas and would have ordered full pallets and full truckloads only (Cachon and Fisher, 1997). This at least suggests that the main savings were on handling and not so much on inventory; which is in line with the logistics' cost breakdown from Chapter 1.

Holmström describes a case example of a VMI - implementation and stresses the importance of keeping the implementation simple. Preferably the VMI functionality should be a standard component in ERP systems. (Holmström, 1998)

Achabal et al. describe the implementation of VMI between an apparel supplier and 30 retail stores, using a decision-support system, that forecasts demand both at aggregate and store level. (Achabal et al., 2000)

Çetinkaya and Lee studied how the lead-time flexibility created by VMI facilitates the consolidation of shipments. They use a heuristic to solve the problem. In a note, reacting on this article, Axsäter presents an efficient algorithm for exact optimization of this problem and describes an alternative heuristic. (Çetinkaya and Lee, 2000), (Axsäter, 2001).

Also Disney et al. describe the impact of vendor managed inventory on transport operations. They are interested in the effect that different delivery patterns, e.g. shipping in full truckload, has on the ordering pattern to the supplier. They conclude that vendor managed inventory performs better than order batching. (Disney et al., 2003)

Similarly Cheung and Lee describe the possibilities under VMI to change delivery routes from many stops and small drops to fewer stops and larger drops. (Cheung and Lee, 2002)

We will have a closer look at several of these articles in Chapter 4.5 on transport consolidation.

Kaipia et al., using a one-supplier one-buyer supply chain model (see Figure 2.1), stress the fact that with VMI the supplier gains in reaction time (Kaipia et al., 2002). Prior to VMI, the supplier delivers from stock. To maintain that stock the supplier uses a reorder point, say ROP1. With VMI, the supplier needs another reorder point (say ROP2) to maintain the stock at his client. Because (1) the variation of the end consumer demand σ_2 is lower than the variation of the retailer's orders σ_1 that the supplier previously received and (2) the supplier might review the stock levels more frequently than his client previously did and (3) assuming the supplier's production lead-time time to be equal to the one used to replenish his own stock, the value of this reorder point ROP2 can be set lower than the value of reorder point ROP1. In doing so, the advantages of VMI are translated into lower supply chain inventory.

But Kaipia et al. in their article do something different. They examine the situation where the supplier with VMI maintains stock levels at the client location, that are identical to the ones he maintained himself in his own warehouse prior to the implementation of VMI and at that are reviewed as frequently as he did with his own inventory. This means that the supplier sets the value of ROP2 equal to the 'old' value of ROP1, that he used previously

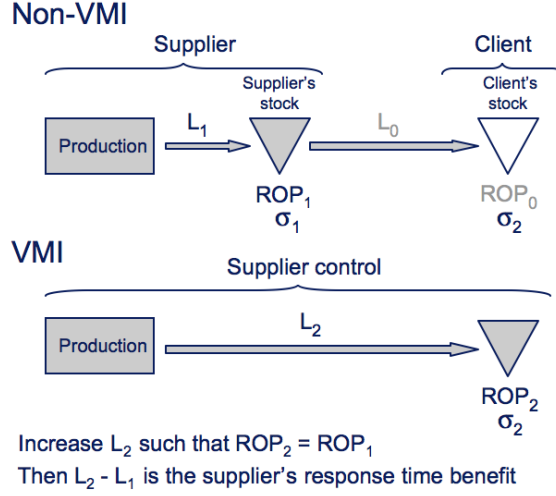


Figure 2.1: Gain in lead-time flexibility with VMI

for managing his own stock. Kaipia et al. then calculate how much longer the delivery lead time (in the article called response time RT) needs to be to indeed make ROP_2 equal to ROP_1 . In doing so, they do not translate the advantages of VMI into lower inventory, but in lead-time (response time) flexibility (or response time benefit, as it has been called in their article) equal to $RT_2 - RT_1$.

Because the response time benefit is very susceptible to production lead-time RT_1 , the outcomes of the model should be treated with care. But the model might be very useful indeed, to convince management of the advantages of VMI.

2.3.3 Centralized inventory management under the heading of VMI

Yao et al. study the effects of VMI on order sizes by applying the EOQ formula on a one buyer - one supplier VMI-model. They do so inaccurately, since they neglect the supplier's handling and distribution costs when fulfilling the buyer's order. This is being dealt with in Chapter 3, when discussing the EOQ formula. (Yao et al., 2007)

Also Dong and Xu studied VMI with consignment stock, using a one-supplier - one-buyer supply chain model. They do better than Yao et al. and explicitly model the supplier's order fulfillment costs. With consignment stock, the buyer has no inventory related costs and benefits most. Total system inventory will drop and under certain conditions, may become even lower than the current inventory at the supplier. This means, that buyer and supplier under certain conditions both can benefit, even with consignment stock.

Interestingly Dong and Xu discriminate between the effects of VMI in the short term and in the longer term, because due to the savings realized through VMI, the buyer is able

to lower his sales price, resulting in higher sales volumes. It might be worthwhile refining their model in order to get more precise answers. For instance in their current model, they treat both the transaction costs and the inventory holding costs at supplier and buyer as a constant. However with VMI the replenishment quantities tend to become larger, because the supplier when calculating these quantities takes into account the overall system transaction costs. In many retail supply chains enlarging the replenishment quantities has a great effect on the transaction costs, because not the costs of inventory, but the costs of handling are the dominant cost component. Actually Dong and Xu mention this extension to their model when suggesting further research. By the way, the same results would have been achieved with a good service based pricing scheme, without VMI. (Dong and Xu, 2002)

Also Lee and Chu study VMI with a one-supplier one-buyer supply chain model. They restrict their research to one period in order to be able to apply the news vendor formula. Their conclusion is that under VMI the supplier will position more inventory at the retailer, than the retailer would have done. (Lee and Chu, 2005)

2.3.4 The reality of VMI

It is often seen in retail practice, that VMI projects do not have the success that VMI theoretically should have. Possible reasons might be:

- The retailer is forcing the supplier to maintain inventory levels at the retail distribution centers between the same limits the retailer used prior to VMI. In such cases the push orders that are being generated by the supplier are identical to the pull orders that the retailer would have generated. The only difference is that the burden of generating the orders has shifted from retailer to supplier.
- The retailer is forcing the supplier to keep the inventory at the retail distribution center in consignment (or vendor owned inventory, VOI), without giving the supplier the freedom to change inventory levels and delivery moments to recoup his extra costs.
- The retailer does not want to loose the possibility of forward buying (i.e. buying more than strictly needed) on supplier promotions and frustrates the VMI implementation by parallel buying on promotions.
- Competition in retail is fierce and negotiations with suppliers are tough. VMI requires investment in a lasting partnership. Quite some retailer feels that VMI creates dependencies and might weaken his negotiation position. This means that a VMI implementation should be simple and easy to implement, using standard IT-system components.

Or to quote Blatherwick in (Blatherwick, 1998):

“Manufacturers are unlikely to understand the supply chain strategy of the retailers. Retailers are unwilling to share all their marketing plans and strategies with the manufacturer. This is particularly true if retailers have strong own label presence and thus compete with the major brands. With imperfect information it is debatable who is in the best position to manage the forecasting and supply chain strategy for any particular item.”

It might therefore be wise to base our design for a synchronized supply chain not only on centralized planning, but to allow for *decentralized* planning as well.

Companies are part of many supply chains. Centralized control of the whole web of supply chains with full visibility is highly unrealistic. Fransoo et al. study the effects of limited information exchange in such a multi-echelon multi-company inventory planning situation. They conclude that managing the interfaces between independent supply chains, by communicating required service levels and selectively limiting the amount of information that flows across, already leads to reasonable results. In terms of VMI it could mean aiming at achieving a certain product availability in the retailer's distribution centers. (Fransoo et al., 2001)

2.4 The service level perspective

As shown in Figure 2.2 Inventory can be managed from two perspectives:

- from a customer service level perspective
- from a cost minimization perspective

This section deals with the service level perspective; the following Section 2.5 deals with the cost minimization perspective.

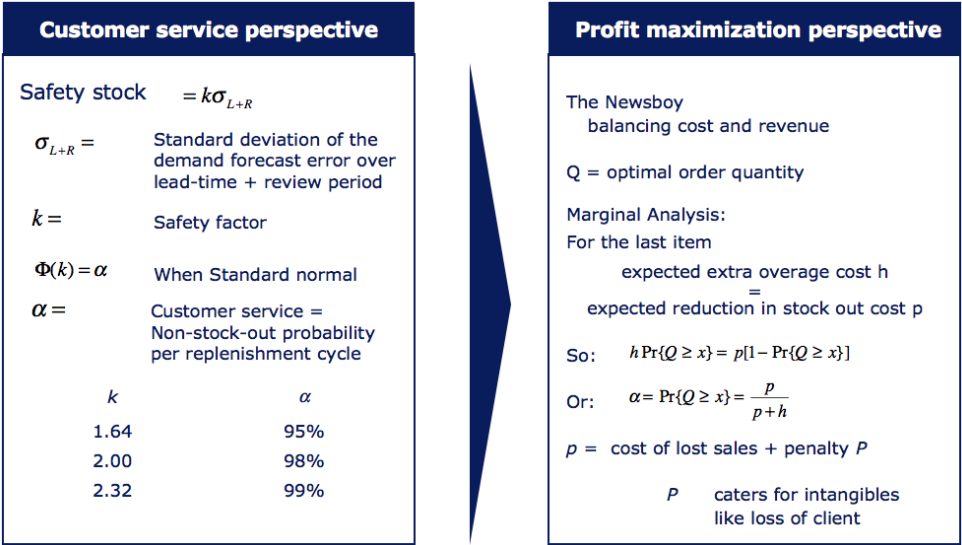


Figure 2.2: Inventory can be managed from a customer-service perspective or from a cost minimization perspective

Managing inventory and calculating safety stock levels based on customer service considerations is widely used in retail practice. In that case the target customer service level per stage is not the result of some integral supply chain consideration, but the target customer service level at each of the stages is set by local management based on their specific business objectives. This target customer-service level acts as a constraint in the design of the supply

chain and its inventory control mechanism and it is a key performance indicator during the operation. The supply chain literature defines several service measures. See e.g. (Silver and Peterson, 1985), (Meyr et al., 2000) and (Diks et al., 1996).

The most frequently used service measures are:

α No stockout probability

The probability of no stockout per replenishment cycle.

β Fill rate The fraction of customer demand that can be satisfied from stock on hand

The fill rate measure β quite naturally is fit for measuring the order performance in business-to-business delivery. When fulfilling consumer demand from the shelves in a retail outlet, measuring the stock-out probability $(1 - \alpha)$ by counting the article types that could not be delivered, is equally suitable.

2.4.1 Calculating safety stock levels

For a single stage system, the non-stock-out probability α , the customer service level, directly translates into the required safety stock level by taking the inverse of the demand distribution function.

$$\text{Safety stock} = k\sigma_{L+R} \quad (2.1)$$

with σ_{L+R} the standard deviation of the demand, or better the standard deviation of the forecast error, over the lead-time L plus the review period R and with k a safety factor selected such that

$$\Phi(k) = \alpha \quad (2.2)$$

with $\Phi(\cdot)$ the probability distribution function. See e.g. (Silver and Peterson, 1985) and (Van Donselaar, 1990).

In case of the Standard Normal Distribution, the values of k have been widely tabulated and every logistics manager knows the following key figures by heart.

k	Customer service level α
1.64	95%
2.00	98%
2.32	99%

2.4.2 Safety stocks in a multi stage network

For an overview of the theory on safety stocks in a multi-echelon divergent networks, we use a classification similar to the one used by Inderfurth in (Inderfurth, 1994). In classifying the various control methodologies for a two-stage distribution system, we first distinguish between decentralized and push strategies, resulting in the following classification:

1. decentralized control strategies
 - installation stock control

- echelon stock control (= base stock control)
2. centralized control strategies
- stockless depot (= cross docking)
 - two-shipment-policy

2.4.3 Decentralized planning, installation stock control

At the most downstream echelon, at the level of the retail outlets, installation stock control and echelon stock control are identical. One level upstream, at the level of the retail distribution centers, they no longer are identical. Even though echelon stock control is proven to be the better strategy, in retail practice most often replenishment orders from retail distribution centers to suppliers are based on installation stock, i.e. the local stock in the retail distribution centers. And equally the production schedules at the suppliers are based on the local inventory levels in the supplier's warehouses. Once the retail outlet at the most downstream echelon has set its target service level, in theory the supplying higher echelons should offer a 100% customer service level, to guarantee the service level at the lowest echelon. In practice they will set their customer service levels at 98 to 99%, as they cannot achieve 100%. Each echelon then uses Equation (2.1), to calculate its own safety stock levels to satisfy service levels that become higher when going upstream the supply chain. This practice results in high upstream inventory levels in the distribution network. But clearly the only service level that counts, is the one offered by the most downstream stage to the final consumer.

2.4.4 Decentralized planning, echelon stock control

If (in a 2-echelon network) the central depot reorders from suppliers, using an echelon stock policy and the retailers are facing independent normally distributed demands, then the total system safety stock should be:

$$\text{System safety stock} = k \sqrt{L \sum_{i=1}^N \sigma_i^2 + \left\{ \sum_{i=1}^N \sqrt{l_i + 1} \sigma_i \right\}^2} \quad (2.3)$$

With L the lead-time from the supplier to the central depot and l the lead-time from the central depot to each of the retailers, with σ_i the standard deviation of the demand at the i -th retailer and N the number of retailers. See e.g. (Van Donselaar, 1990), (Inderfurth, 1994) and (Eppen and Schrage, 1981).

If the retailers are facing independent and normally distributed identical demand and are all on equal distance from the central depot, the formula reduces to:

$$\text{System safety stock} = k \sigma \sqrt{N} \sqrt{L + N(l + 1)} \quad (2.4)$$

Van Donselaar suggests to use the following approximation to calculate the safety factor k for the system as a whole:

$$\Phi(k) = \frac{1}{3} + \frac{2}{3} \alpha \quad (2.5)$$

The safety stock in the central depot is the total system safety stock resulting from (2.3) minus the local safety stock at each of the retailers. But the heuristic does not result in a real network-wide optimal solution, as will be shown in Section 2.5.

2.4.5 Centralized planning, stockless depot

Operating a stockless retail depot and cross docking goods at the retail distribution center, has been introduced in the retail practice by Wal-Mart (see e.g. (Stalk et al., 1992)). The basic approach for the situation with a stockless depot is described by (Eppen and Schrage, 1981) The depot orders from the suppliers, using a base stock policy, and allocates the incoming material to the retailers on equal stock-out probability. The equation for calculating the total system safety stock is the same as for the stock keeping central depot (2.3). But using the regular k -value from Equation 2.2, instead of the inflated k from Equation 2.5.

It is interesting to use Equation 2.4 to compare the amount of safety stock needed when replenishing via a stockless depot versus the amount of safety stock needed when delivering directly, for both the extremes $L \gg N(l + 1)$ and $L \ll N(l + 1)$ respectively (see Figure 2.4.5).

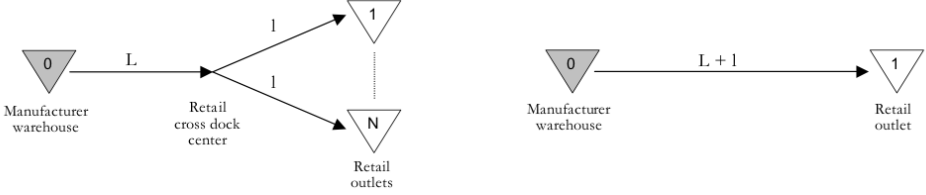


Figure 2.3: Delivery via a stockless depot (a) or direct delivery (b)

For $L \gg N(l + 1)$ it follows from (2.4) that, provided demand is uncorrelated, with delivery via a stockless depot the total system safety stock is a factor \sqrt{N} lower than with direct delivery to each of the N retail outlets.

$$\text{Stockless depot } SS_{system} \approx k\sigma\sqrt{N}\sqrt{L}$$

$$\text{Direct delivery } SS_{system} \approx N.k\sigma\sqrt{L}$$

Assuming the lead time from the depot to the shops to be 1 day, $L \gg N(l + 1)$ means that the distance to the supplier must be much larger than twice the sum of the distances from the depot to all of the outlets served by that depot. The value of N , the number of outlets per depot in food retail might be considerable (e.g. 50 - 150); which means that this condition is not easily satisfied.

For $L \ll N(l + 1)$ delivery via a stockless depot reduces to direct delivery and the total system safety stock is equal for both situations.

$$\text{Stockless depot } SS_{system} \approx k\sigma N\sqrt{l + 1}$$

$$\text{Direct delivery } SS_{system} \approx N.k\sigma\sqrt{l + 1}$$

This condition might be easier to satisfy in food retail, because the number of outlets per depot N can be significant.

2.4.6 Centralized planning, the two-shipment-strategy

It might well be that the shipment frequencies in a distribution network are different, e.g. the central depot is being replenished weekly, whilst the retailers receive a daily replenishment. If the central depot is keeping stock, a centralized strategy allows for multiple allocation decisions during the weekly replenishment cycle. This situation has been described by Van der Heijden. His main conclusions are (Van der Heijden, 1999):

- Most of the stock should be positioned at the local retailers.
- Already a two-shipment policy, which means that the central depot replenishes the local retailers only twice per replenishment cycle, is near optimal.
- Under a two-shipment policy, the 1st shipment at the beginning of the cycle may consist of as much as 90% of the volume and the 2nd shipment should be already halfway (= at 50%) of the replenishment cycle to re-distribute the remaining 10%. This is called a 50/10 strategy.

The same two-shipment allocation policy has earlier been addressed by McGavin et al.. They advised a pragmatic 50/25 policy, which means shipping 75% immediately and the remaining 25% halfway the interval. The 50/25 policy realizes almost 90% of the lost sales reduction achievable under the "best"-policy, but has the considerable advantage of its simplicity. Güllü and Erkip studied the effect of fixed shipment costs on the two-interval policy; they conclude that higher shipment costs very soon make shipping everything in the first shipment the best policy. (McGavin et al., 1993) and (Güllü and Erkip, 1996)

2.5 The cost minimization perspective

Managing inventory from a cost minimization perspective means balancing cost and revenue. That is exactly what the so-called newsvendor formula is all about. In its basic form, the newsvendor formula is a single period and single stage model. The newsvendor formula can be derived rather easily via marginal analysis. Because the newsvendor formula essentially is nothing else but balancing cost and revenue, it is not surprising that analytical research on inventory management in multi period and multi stage distribution networks (at least when aiming at cost minimization) often results in newsvendor formula type of results. A good example is (Van Houtum et al., 1996), later extended by (Diks and De Kok, 1998). Van Houtum et al. and Diks and De Kok in their respective papers have derived the multi-period and multi-stage newsvendor formula via cost minimization. In this section we will derive the same result via marginal analysis. In order to facilitate the matching, we will stick as close as possible to the notation of Diks and De Kok. This remainder of this section is structured as follows. In the next paragraph we will describe the classical single stage - single period newsvendor model. Then we will extend the newsvendor model to multi-period and multi-stage divergent distribution networks and derive the equation for the optimal solution. Subsequently we will look at some characteristics of cost-optimally tuned distribution networks. When deriving the optimal solution we will discriminate between

the situation where holding costs are cumulative and represent added value in Section 2.6 and the situation where holding costs are systemwide and absolute in Section 2.7. The final paragraph notes some concluding remarks and suggests further research.

2.5.1 The classical Newsvendor Problem

The newsvendor problem is to determine today's best quantity of newspapers to buy, such that profit is maximized. There is a stock-out cost p related to demand that cannot be met and a cost h associated with non-sold items. With X being the stochastic demand, the newsvendor would like to choose the optimal order quantity Q^* such, that adding one more newspaper does not add any profit, because for that extra newspaper the expected extra (overage) cost h are just equal to the expected reduction in stock-out (underage) costs p . Or:

$$h \Pr\{Q^* \geq X\} = p[1 - \Pr\{Q^* \geq X\}] \quad (2.6)$$

This can be written as the well-known newsvendor formula, which formula states that the non-stock-out probability $\Pr\{Q^* \geq X\}$ i.e. the target service level α should be:

$$\alpha = \Pr\{Q^* \geq X\} = \frac{p}{p + h} \quad (2.7)$$

In general the stock-out cost p has two components. In any case there will be a variable component related to the product value, which expresses the costs of the lost sales. Furthermore there might be a fixed penalty cost component P , not directly related to the product value, to compensate for such aspects as client dissatisfaction and the risk of losing a client. A higher penalty value in the newsvendor formula results in a higher target service level to be set. Because the (underage) costs p are measured per item, the fixed penalty should also be incurred per unit short.

The newsvendor formula specifies the non-stock-out probability or the service-level, with the highest profit. The outcome of the newsvendor formula depends solely on the overage costs h and the underage costs p and is independent of demand variability. Higher demand unpredictability and thus a higher forecast error, means a higher value of Q^* , but the service level that maximizes profit remains the same.

2.5.2 Extending the newsvendor model

The basic single-stage single-period newsvendor formula, as treated in the former paragraph, is a classic in inventory management. Thanks to its simplicity it provides good insight and many textbooks on inventory management start the discussion on stochastic inventory models with this newsvendor or newsboy problem. See e.g. (Bramel and Simchi-Levi, 1997), (Silver and Peterson, 1985), or (Zipkin, 2000).

Only in more recent years it is being recognized that the basic newsvendor formula in an adapted form can play an important role in setting the control parameters in complex multi-echelon and multi-period inventory systems. Already in 1996 Van Houtum et al. indicate that the optimal order-up-to levels in a multi-echelon inventory network can be

calculated with a newsvendor type formula that specifies the non out of stock probabilities, or target service levels in serial inventory systems. (Van Houtum et al., 1996). Diks and De Kok extended this work and proved that the same formula has a broader applicability. The formula is valid both in serial and in divergent networks (Diks and De Kok, 1998). As will be shown, the formula not just resembles, but when interpreted in an appropriate way, is nothing else but the newsvendor formula applied to each echelon of the network.

Consider a single item discrete time multi-echelon inventory system, with fixed lead times, with linear holding costs and controlled by a periodic review policy. We assume further that inventory is controlled by managing at each of the nodes the echelon stock levels, as introduced in (Clark and Scarf, 1960). Since review and ordering is periodic, we deal with a so-called (R, S)-environment with R indicating the review period and S the echelon order-up-to levels. Without loss of generality we set R to 1 unit of time. Demand occurs only at the lowest echelon; in case of a stock-out at the lowest echelon a fixed penalty is incurred per item and per period. Stock-outs at this lowest echelon will be backordered. Ordering costs are neglected. Items traversing the network incur holding costs on their path, i.e. they accumulate value.

At the beginning of every period each node places an order at the next upstream node, i.e. at the next higher echelon, so as to raise its echelon inventory position to a defined order-up-to-level. The echelon inventory position encompasses all inventory at or on its way to downstream nodes, plus all outstanding orders. The most upstream node, the root node at the highest echelon orders from an external supplier, with ample stock. When goods arrive at the root node of an echelon, they are sent off immediately to the downstream successor nodes, according to the orders these nodes have placed. Goods arrive at downstream nodes after the specified lead-times. In case of shortage at any echelon, the available goods will be allocated to the downstream nodes via some sensible allocation algorithm. Non-allocated goods will be kept in stock at the root node of the respective echelon for delivery the next period.

2.5.3 Marginal analysis

We assume inventory in the distribution network to be managed per echelon. Each node in such a (divergent) distribution network is root node of his echelon. For each node as a root node of his echelon, inventory norms need to be set, to control the inventory within each echelon in the network. In a multi-echelon inventory system, the order-up-to-level of the most upstream node (the root node) completely determines the amount of inventory in the system. The order-up-to-levels of the other nodes only regulate the distribution of the stock, because they each determine the amount of inventory within their echelon. We apply the newsvendor formula to each of the echelons, in such a way, that the system as a whole operates at minimum cost. We only consider the long run steady state. The convergence to such a steady state has been shown extensively in literature on Markov-decision processes.

The application of the newsvendor formula then leads to set target service levels (i.e. non-stock-out probabilities) for every echelon in the system, such that the echelons together operate at an integral cost optimum. Managing inventory per echelon, automatically implies the application of the newsvendor formula at each of the echelons. Every echelon, or in fact the root-node i of each echelon, should set its echelon order-up-to-level S_i at target level \hat{S}_i , such that its echelon as a whole, assuming ample supply from the next higher ech-

elon, delivers to the clients at the most downstream nodes within that echelon the customer service specified by the newsvendor formula.

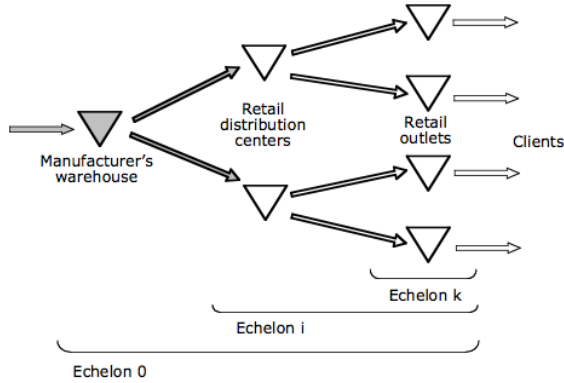


Figure 2.4: Retail distribution network

A good example of such a multi-echelon distribution network is a 3-echelon retail network, with retail stores at the lowest echelon k , that are facing consumer demand. The stores are being replenished from retail distribution centers at the root of the intermediate echelons i . Subsequently the retail distribution centers reorder from a manufacturer's warehouse at the root of echelon 0, the highest echelon in the network considered. Such a network is shown in Figure 2.4. Mark that we count from upstream to downstream, from left to right.

The manager of a retail store to a certain extent faces the same problem as the newsvendor does. Today's consumer demand can only be met by what is available in the store. Provided that we have adapted the elements of the newsvendor formula to the multi-echelon and multi-period environment, the store manager, like the newsvendor, can perform the same marginal analysis with underage and overage costs. See (De Kok, 2006). If he raises his order-up-to-level, he will be confronted with overage costs h . If he lowers his order-up-to-level, he will be confronted with underage costs p . His order-up-to-level is properly tuned, if raising his order-up-to-level by 1 item will not increase his profit, because it would lead to 1 more item added to his inventory with expected overage costs just equal to the expected reduction in underage costs. The same holds for all higher echelons. Each of the nodes should set its echelon order-up-to-level such that (if downstream nodes have been properly tuned) raising the echelon order-up-to-level by such an amount that 1 more item is being added to the inventory at each of the end nodes k within its echelon, would not add any profit, because the expected overage costs of that 1 extra item at each of the end nodes are just equal to the expected reduction in underage costs.

To tune the network and to derive the mathematical formula that specifies the network optimum, we need to work recursively from downstream to upstream nodes, from right to left through Figure 2.4. The marginal analysis, leading to the optimal solution can be performed either by marginally raising the order-up-to-levels, or with the same result, by marginally lowering them, as described in more detail in the subsequent paragraphs. First

the order-up-to-levels of all upstream nodes should be set high, so as to assure ample supply of items to be downstream nodes. Then the order-up-to-levels S_k of the end nodes k should be lowered to the total network lowest cost optimum. That is the point where raising the order-up-to-level S_k by 1 does not add any profit to the network as a whole, because the expected overage cost of that 1 extra item equals the expected reduction in underage costs. Thereafter, whilst keeping the order-up-to-levels at the end nodes k tuned, the order-up-to-levels S_k^i of the nodes in the next higher echelon, the root nodes of the echelon i , should also be lowered to the network optimum. The optimum is the point where raising the order-up-to-level of a root node by as many, as there are end nodes k in an echelon does result in 1 extra item at each of the end nodes, but does not add any profit, because the expected overage cost of these extra items equals the expected reduction in underage costs. And so on, till the root node of the whole network has been reached and tuned.

The direct relationship between the order-up-to-level upstream at the root node of an echelon and the overage/underage situation at each of the end-nodes downstream within that echelon is only true, if a so-called sample-path condition holds, i.e. one might think in path through the network.

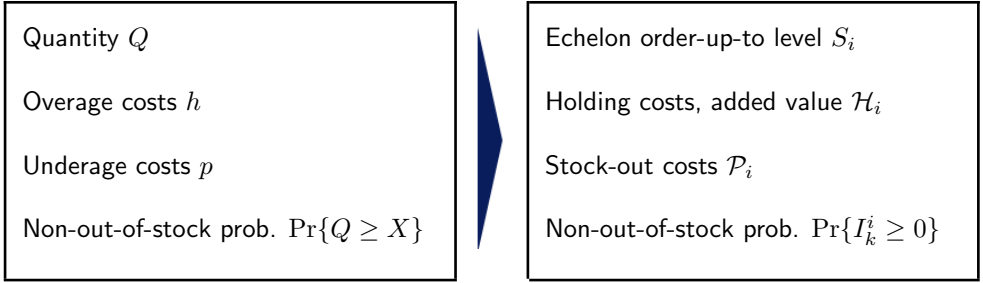


Figure 2.5: Extending the newsboy to a multi-period & multi-stage distribution network

2.6 Holding costs represent added value

This section deals with the situation where the different stages in the distribution network represent commercial entities that purchase upstream and sell downstream. Holding costs per stage then represent the value added at that stage, the difference between the purchase price and the sales price.

Applying the newsvendor model to a multi-echelon, multi-period environment leads to adaptations in the model. First of all the variables change, as illustrated in Figure 2.5 and described in this paragraph.

Q

Where the newsvendor had to buy a quantity Q to fulfill the consumer demand of that day, the retail store manager already might have leftover inventory from the former day. He replenishes by filling up what is missing, e.g. by ordering up to a certain order-up-to level S_k . Similarly every other node in the network reorders up to its echelon order-up-to-level

S_i . Instead of looking at the probability that demand X is below Q , we now express the target customer-service level as the probability that the net stock I_k^i in end-node k in the echelon with the root node i is positive at the end of a replenishment cycle, or $\Pr\{I_k^i \geq 0\}$.

h

To the newsvendor h meant the cost of leftover goods, that is the price he paid. In many a multi-period environment, whenever an item is not sold to a client or ordered by a lower echelon, such non sold or non delivered inventory can be carried on to the next period. Assume now that each stage in the network purchases the goods from the next upstream stage and sells them to the next downstream stages. Generally accepted accounting standards consider the difference between the purchase price paid upstream and the sales price realized downstream as the value added at that stage. That price difference should cover all costs made at that stage. These costs are e.g. the interest paid on the value of the inventory, the costs associated with the shelf space the items are taking, the costs of handling and delivering the goods and any commercial margin. We adhere to that practice and consider the added value at each stage to be the holding costs at that stage. We therefore use the terms ‘holding cost’ and ‘added value’ interchangeably. When treating holding costs this way, it looks as if items that traverse the distribution network accumulate value. Mark that in the EOQ-formula the inventory holding cost H does not include handling and delivery. See Chapter 3.

p

To the newsvendor the out-of-stock (underage) cost p meant the costs of a lost sale plus a mostly fictitious fixed penalty to compensate other factors such as the loss of a client. In our multi-echelon and multi-period environment where stock-outs at the end nodes k are backordered, there are no lost sales costs, other than extra inventory holding cost. And similar to the newsvendor one might consider an extra fixed penalty P per item per period back-ordered to compensate other aspects, like the loss of a client in case of a stock-out.

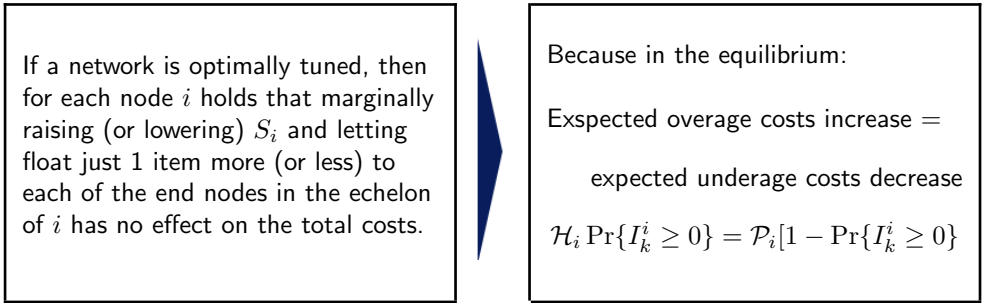


Figure 2.6: Marginal analysis

2.6.1 Tuning the network by raising the order-up-to-levels

Assume the order-up-to-level of each node in a distribution network to be set such that the network as a whole is optimally tuned, even though we do not yet know what the optimal

order-up-to-levels are. Assume now the echelon order-up-to-level at the root node of echelon i and the order-up-to-levels of all downstream nodes to be raised marginally such that there will be just one extra item leftover downstream at each of the end nodes k within echelon i . If that direct relation between raising the order-up-to-level at the root node of an echelon and extra leftover items downstream at the end nodes within that echelon exists, we say that the sample path condition holds.

Raising S_i	
<p>The 1 item left over at k, that otherwise would have remained at node $i - 1$ now incurs extra holding costs along the path from i to k</p> $\mathcal{H}_i = \sum_{n=i}^k h_n$	<p>But at the same time saves the penalty P and the holding costs of staying 1 more period at node $i - 1$ equal to the holding costs incurred along the path from 0 to $i - 1$</p> $-\mathcal{P}_i = -P - \sum_{n=0}^{i-1} h_n$

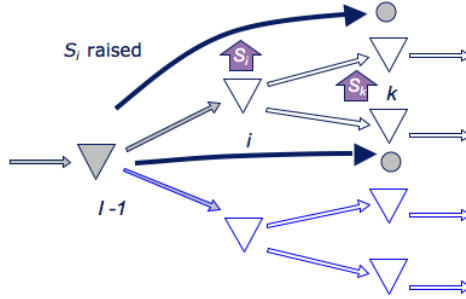


Figure 2.7: Raising S_i

If the echelon is properly tuned, 1 item extra inventory at each of the end nodes k within echelon i leads to expected extra overage costs \mathcal{H}_i that are equal to the expected reduction in penalty costs \mathcal{P}_i . See Figure 2.6.

The extra overage cost \mathcal{H}_i to be considered at each of the end nodes k is the summation $\sum_{n=i}^k h_n$ of the extra holding costs over each of the downstream paths traversed by an item from the i th echelon root node i down to each of the respective end-nodes k , for each period that the items are left over. Only the extra holding costs downstream from node i need to be considered, because, had the i th echelon order-up-to-level been just lower and correctly set, the items would have remained upstream at node $i - 1$.

At the same time at each of the end nodes k there might be expected a reduction of the penalty \mathcal{P}_i . This reduction will be anyhow the fixed penalty P , plus a reduction in holding

costs at node $i - 1$, because the items that due to raising S_i flowed to each of the end nodes k within echelon i , no longer are stored at node $i - 1$. The avoided holding costs are the holding costs $\sum_{n=0}^{i-1} h_n$ per item, that is the added value which these items had already accumulated upstream from node i . This same result can also be achieved by marginally lowering the order-up-to-levels, as will be shown in the next paragraph.

2.6.2 Tuning the network by lowering the order-up-to-levels

Assume the order-up-to-level of each node in a distribution network to be set such that the network as a whole is optimally tuned, even though we do not yet know what the optimal order-up-to-levels are.

Lowering S_i	
<p>The 1 item not delivered to the client costs the penalty \mathcal{P}_i. The item is back ordered and remains 1 period extra at node $i - 1$ with extra holding costs incurred along the path from 0 to $i - 1$:</p> $\mathcal{P}_i = P + \sum_{n=0}^{i-1} h_n$	<p>But at the same time saves the holding costs otherwise incurred along the path from i to k:</p> $-\mathcal{H}_i = - \sum_{n=i}^k h_n$

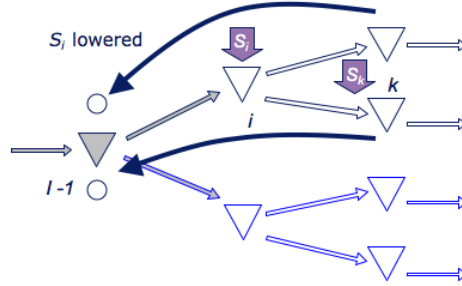


Figure 2.8: Lowering S_i

Assume now the echelon order-up-to-level at the root node of echelon i and the order-up-to-levels of all downstream nodes to be lowered such, that there will be just one extra item short and backordered downstream at each of the end nodes k within echelon i . If that direct relation between lowering the order-up-to-level at the root node of an echelon and items short downstream at the end nodes within that echelon exists, we say that the sample path condition holds. If the echelon is properly tuned, 1 item less inventory at each of the end nodes k within echelon i leads to expected extra penalty costs p_i that are equal to the

expected reduction in holding costs h_i . The extra penalty cost p_i to be considered at each of the end nodes k will be anyhow the fixed penalty P , plus extra holding costs at node $i - 1$, because the items that otherwise would have been delivered, due to lowering S_i now remain one period extra at node $i - 1$. The extra holding costs are the holding costs $\sum_{n=0}^{i-1} h_n$, that is the added value which these items had already accumulated upstream from node i .

At the same time at each of the end nodes k there might be expected a reduction of the holding costs h_i . The avoided holding costs are the holding costs $\sum_{n=i}^k h_n$ that otherwise would have been accumulated over each of the downstream paths traversed from the i_{th} echelon root node i down to the end-nodes k .

2.6.3 Finding the optimum

Assuming the order-up-to-level of every node to be properly tuned, so as to contribute to the minimal cost optimum for the network as a whole, then for every echelon i the following equation should be satisfied:

$$\mathcal{H}_i \Pr\{I_k^i \geq 0\} = \mathcal{P}_i [1 - \Pr\{I_k^i \geq 0\}] \quad (2.8)$$

or

$$\Pr\{I_k^i \geq 0\} = \frac{\mathcal{P}_i}{\mathcal{P}_i + \mathcal{H}_i} = \frac{P + \sum_{n=0}^{i-1} h_n}{P + \sum_{n=0}^{i-1} h_n + \sum_{n=i}^k h_n} \quad (2.9)$$

The resulting equation (2.9) is identical to formula (8) in (Diks and De Kok, 1998). The formula says that every node i , as root node of echelon i , should raise its order-up-to-level such that the non stock-out probability $\Pr\{I_k^i \geq 0\}$ is being realized at each of the downstream end-stock-points k within that echelon. Note, that there still would be an optimal solution, even if the fixed penalty $P = 0$.

If we define $H_i = \sum_{n=0}^i h_n$ and $H = H_k$ equation (2.9) can be rewritten more clearly as:

$$\Pr\{I_k^i \geq 0\} = \frac{(P + H_{i-1})}{(P + H_{i-1}) + (H - H_{i-1})} \quad (2.10)$$

Equation 2.10 immediately shows that the fixed penalty cost P at the most downstream end node k , if caused by echelon i should be increased with the cost of holding the downstream missing item, just upstream of echelon i . And similarly that the holding cost H at the most downstream end node k should be decreased with the cost of not holding upstream of echelon i the surplus items that are already downstream at the end nodes k .

The formula can be simplified yet another step as follows:

$$\Pr\{I_k^i \geq 0\} = \frac{P + H_{i-1}}{P + H} \quad (2.11)$$

This is the form presented in (Van Houtum et al., 1996). This result is valid for all nodes in the network, assuming that the sample path condition holds. The reasoning calculates

along traversable paths and the result holds for every traversable path in both serial and divergent networks. The formula calculates the target service level that clients experience at the end nodes k . That is the service level where the total cost of the multi-echelon system is minimal, or conversely where the total profit is maximal. The outcome apparently is independent of the demand characteristics.

The lead time demand does not appear in formulas equations (2.9), (2.10) or (2.11). There will be a constant amount of pipeline inventory in-transit downstream the various stages of the network, equal to the average lead-time demand. If the lead-times are longer, the in-transit inventory and the safety stock levels will be higher, but this does not affect at all the service level specified in equations (2.9), (2.10) or (2.11).

The applicability of the outcome to divergent networks seems contra-intuitive, as the formula does not appear to take into consideration the possibilities for risk pooling of safety stocks that exist in divergent networks. But one should realize that the newsvendor formula only calculates the target customer service levels. These target service levels still have to be translated into appropriate safety stock levels and order-up-to-levels, taking into account the demand distribution and delivery times. And these levels surely are different in serial or divergent environments.

Translating the outcomes of the newsvendor type equations (2.9), (2.10) or (2.11) into order-up-to-levels is only straightforward for the most downstream network node, by taking the inverse of the demand distribution function. Doing the same for more upstream network nodes, would result in order-up-to-levels that are too low, because one does not take into consideration that the more downstream nodes offer a less than 100% service level, which lower service needs to be compensated by higher order-up-to-levels upstream.

The too low order-up-to-levels, resulting from such a straightforward calculation can be considered as a lower bound, as e.g. done by Shang and Song in (Shang and Song, 2003). They calculate an upper bound for the order-up-to-levels, through step-by-step truncating the network. Every step the order-up-to-level is calculated for the now becoming most downstream node of the truncated network. They suggest a heuristic for determining the order-up-to-levels by taking the average of the lower and the upper bound.

Diks and De Kok formulate an accurate algorithm to compute near optimal policies for divergent networks, using formula (2.9). (Diks and De Kok, 1999)

2.6.4 The cost-optimal solution with cumulative holding costs

We will now further analyze the cost optimal solution with cumulative holding costs or added value creation along the supply chain. The analysis is supported with simulation.

From the equations (2.9), (2.10) or (2.11), that describe the cost-optimal parameter setting in a multi-echelon distribution network, it can be seen that the optimal out of stock rate or target service level for downstream nodes is higher than for upstream nodes. Take for example the 3-echelon retail distribution network shown in Figure 2.4. If the holding costs at each of the nodes are equal to 1 and the out of stock penalty incurred at the end nodes is equal to 10, then the target service levels to be realized at the end nodes k will be respectively for node 0 (= the supplier) $10/13 = 77\%$, for node i (= the retail distribution center) $11/13 = 85\%$ and for node k (= the shop) $12/13 = 92\%$. The service level that

clients will experience at the shops at the lowest echelon k , in this example, will not be 92%, which is cost optimal for the end-nodes k , but considerably lower, viz. 77%, which is cost optimal for the 3-echelon network as a whole. A service level of 92% would have been optimal for the network as a whole (with holding costs at each echelon still being 1), had the penalty value been 35, because $35/38 = 92\%$.

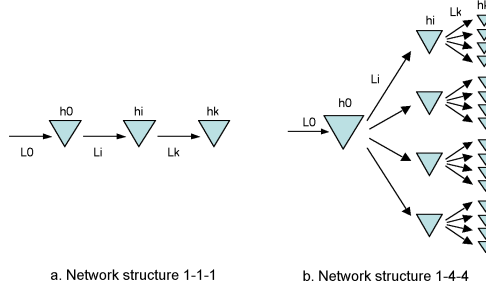


Figure 2.9: Serial and divergent 3 echelon network structures

The series of tables that follow, contain simulation results to analyze the various aspects of the cost optimal solution in a 3-echelon network. Demand is gamma distributed. The average demand in the tables is either 50 or 100. In both cases, the standard deviation of the demand is 60. The tables study the effect of varying the holding costs, the lead-times, the network structure and the penalty costs. In each table one of these variables is changed while the others are kept constant. The values of the variables that are kept constant are shown in the header of the tables.

Most variables in the tables always are shown in 3 columns, representing the value in the most upstream root node 0, in the intermediate node i and in the end-node k respectively.

The effect of the holding costs

Table 2.1 shows the effect of different holding costs on the optimal inventory positioning along a 3 echelon serial network (1-1-1) and Table 2.3 for a divergent network (1-4-4). The holding costs (left 3 columns) in these examples are either 1 or 5. All lead-times are 1 and the out-of-stock penalty is 10.

In the cost optimal situation, the upstream order-up-to-levels are set to lower service levels than the ones at downstream nodes (at least when of course corrected with the average lead-time demand μ). As a result at upstream nodes there will be a constant shortage and available supply needs to be allocated. Consequently, if the holding costs at the various nodes are equal (top and bottom line of the left 3 columns), most of the inventory (the next 3 columns) will be pulled downstream to the end nodes (the 3rd of these 3 columns), as is shown in the first line in Table 2.1 and Table 2.3. This forward positioning of inventory is in line with the findings of Whybark and Yang (Whybark and Yang, 1996). If however the holding costs of the various stages in the network differ from one another, it is cost effective to keep part of the inventory just prior to a node with higher holding costs. Remind that the holding costs represent the added value that items traversing the distribution

network accumulate. So, if in a table the holding costs at the various nodes are equal, like $h_0 = h_i = h_k = 1$, the accumulated value is 1, 2 and 3 respectively. This means that even though the value of the goods increases on their way downstream the network it still is worthwhile positioning most of the inventory downstream. The stock levels shown in the 3 columns are the average local stock after delivery to downstream nodes, just prior to receiving replenishment. This means that these stock levels effectively are the safety stock levels at each of the nodes. The next 3 columns show the non-out-of-stock rate, or service level α_k at the end-nodes k , as realized in the simulation. These should be compared with the service level values in table 2.2, calculated with formula 2.9, as given by (Diks and De Kok, 1998).

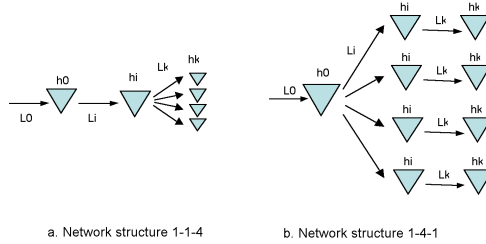


Figure 2.10: Various other network structures

It is interesting to note that the amount of inventory at the end nodes at the lowest echelon is almost identical in a serial (Table 2.1) and a divergent network (Table 2.3) and is independent of the lead-time demand. The inventory at the end nodes is the average stock, that is needed to guarantee the customer-service α_k specified by the equations (2.9), (2.10) or (2.11).

For the higher echelons the inventory figures for the divergent network are lower then for the serial one, due to the better opportunity for risk pooling . Apparently service level and average stock are strongly related.

Maybe the most important result important result is that if the holding costs at an upstream echelon are high (e.g. 5 in the column most left, both in Table 2.1 and Table 2.3), then all inventory is positioned at the downstream nodes and none of the intermediate nodes in the divergent network and almost none in the serial network structure is keeping stock at all. We consider in this research the retail supply chain to comprises the suppliers manufacturing facilities. In most retail supply chains the production process adds most of the value. Consequently in such supply chains inventories should be positioned all the way downstream, preferably in the store.

The effect of the network structure

Table 2.4 shows the effect of various network structures on the optimal positioning of inventory along the network. The network structures that have been used in the tables in this chapter are either 1-1-1 and 1-4-4 as shown in Figure 2.9, or 1-1-4 and 1-4-1 as shown in Figure 2.10.

The effect of the network structure on the inventory at the end nodes is small, because in

Table 2.1: Cost-optimal inventory positioning in a serial network

Gamma distribution			Penalty = 10			Network 1-1-1			$L_0 = L_i = L_k = 1$		
$\mu = 50 \ \sigma = 60$			Holding costs = Added value								
Holding cost			Local stock			Non-out-of-stock rate			Up to levels		
h_0	h_i	h_k	I_0	I_i	I_k	α_k^0	α_k^i	α_k^k	\hat{y}_0	\hat{y}_i	\hat{y}_k
1	1	1	5	4	88	0.766	0.847	0.915	273	251	223
5	1	1	0	0	50	0.606	0.876	0.915	205	285	223
1	5	1	43	0	43	0.597	0.647	0.915	243	163	223
1	1	5	24	31	39	0.611	0.658	0.720	256	201	126
5	5	1	0	0	27	0.454	0.711	0.952	161	185	268
5	1	5	0	1	30	0.487	0.731	0.780	171	229	146
1	5	5	54	0	29	0.506	0.546	0.780	230	136	146
5	5	5	0	0	22	0.412	0.617	0.804	150	155	156

$\mu = 100 \ \sigma = 60$											
Holding cost			Local stock			Non-out-of-stock rate			Up to levels		
h_0	h_i	h_k	I_0	I_i	I_k	α_k^0	α_k^i	α_k^k	\hat{y}_0	\hat{y}_i	\hat{y}_k
1	1	1	12	7	90	0.769	0.849	0.923	491	411	331
5	1	1	0	0	53	0.579	0.873	0.939	411	425	345
1	5	1	35	0	52	0.606	0.664	0.939	451	332	345
1	1	5	14	27	41	0.580	0.648	0.709	446	362	235
5	5	1	0	0	36	0.469	0.712	0.960	379	348	367
5	1	5	0	6	36	0.494	0.723	0.783	390	380	258
1	5	5	52	1	35	0.503	0.541	0.783	441	299	258
5	5	5	0	0	24	0.374	0.629	0.796	351	327	263

Table 2.2: Service levels to be realized at end-node k as calculated with formula 2.9,

Penalty = 10			Holding costs = Added value		
h_0	h_i	h_k	α_k^0	α_k^i	α_k^k
1	1	1	0.769	0.846	0.923
5	1	1	0.588	0.882	0.941
1	5	1	0.588	0.647	0.941
1	1	5	0.588	0.647	0.706
5	5	1	0.476	0.714	0.952
5	1	5	0.476	0.714	0.762
1	5	5	0.476	0.524	0.762
5	5	5	0.400	0.600	0.800

Table 2.3: Cost-optimal inventory positioning in a divergent network

Gamma distribution			Penalty = 10			Network 1-4-4			$L_0 = L_i = L_k = 1$		
$\mu = 50 \quad \sigma = 60$						Holding costs = Added value					
Holding cost			Local stock			Up to levels					
h_0	h_i	h_k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k			
1	1	1	0	0	91	4415	1004	237			
5	1	1	0	0	54	3522	1108	252			
1	5	1	38	0	54	3591	729	252			
1	1	5	4	46	40	3537	765	124			
5	5	1	0	0	39	3073	796	270			
5	1	5	0	1	31	3002	809	143			
1	5	5	78	0	30	3074	575	143			
5	5	5	0	0	22	2693	635	157			

$\mu = 100 \quad \sigma = 60$											
Holding cost			Local stock			Up to levels					
h_0	h_i	h_k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k			
1	1	1	1	0	85	7564	1599	331			
5	1	1	0	0	50	6729	1672	349			
1	5	1	25	0	48	6715	1326	349			
1	1	5	19	21	43	6736	1340	238			
5	5	1	0	0	33	6285	1414	367			
5	1	5	0	0	35	6302	1422	258			
1	5	5	63	0	33	6375	1210	258			
5	5	5	0	0	25	6021	1260	263			

Table 2.4: The effect of the network structure on cost-optimal inventory positioning

Gamma distribution $\mu = 50 \quad \sigma = 60$				Penalty = 10 $h_0 = h_i = h_k = 1$			$L_0 = L_i = L_k = 1$ Holding costs = Added value		
Network				Local stock			Up to levels		
	0	i	k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k
a	1	1	1	11	3	95	289	255	232
b	1	1	4	4	0	91	1102	1015	232
c	1	4	1	9	2	96	1132	254	232
d	1	4	4	0	0	89	4355	1001	232

$\mu = 100 \quad \sigma = 60$									
Network				Local stock			Up to levels		
	0	i	k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k
e	1	1	1	12	7	90	491	411	331
f	1	1	4	7	1	85	1890	1605	331
g	1	4	1	8	4	89	1918	406	331
h	1	4	4	1	0	85	7564	1599	331

the optimal situation almost the whole inventory is positioned at the end nodes and hardly any at the more upstream nodes. The more divergent the network structure, the greater the possibilities for risk pooling, resulting in lower safety stock levels at the higher echelons. If all end nodes were facing identical and independent standard normal distributed demand the safety stock levels would drop with the square root of the number of network branches joining at a higher echelon. Although demand is Gamma distributed, the effect is clearly visible in the simulation results in Table 2.4. Compare for example the local (safety) stock levels I_0 , I_i and I_k in lower part of the table. Network structure 1-1-4 at line f can be realized by joining four times network structure 1-1-1 at line e. The safety stock level at root node 0 between the two structures then should drop with a factor $\sqrt{4} = 2$ and so it does.

But more important are the order-up-to-levels shown in Table 2.4, both in the top half and in the lower half of the table, because they clearly show that equation (2.9) is also valid in divergent networks as well, reasoning along paths from the root node 0 to the end node k . Take for example the network structure 1-1-1 in line e in the lower half of the table, which is a serial system, but could also be seen as one such a path from the root node 0 to each of the end nodes k . The network structure 1-1-4 at line f contains four of these paths each facing i.i.d demand with average demand $\mu = 100$ and standard deviation $\sigma = 60$ at the end nodes k . The order-up-to-levels 1605 at branch node i just prior to the four paths diverging is almost exactly four times the order-up-to-level 406 required by a single path, as shown by network structure 1-1-1. The same holds for the order-up-to-level 1599 again at node i in network structure 1-4-4 at line h. The figures are exactly one another's multiple, when corrected with the changes in local safety stock. Reasoning this way it can be intuitively understood that the equation (2.9) holds in a symmetric balanced divergent network with all nodes facing i.i.d. demand.

Intuitively it is harder to grasp that the same is true for divergent networks facing unbalanced non identical demand. This is shown in Table 2.5. The table shows three linear networks a, b and c facing different demand at their end nodes k . Network a is facing demand with $\mu = 100$ and $\sigma = 60$, network b is facing demand with $\mu = 100$ and $\sigma = 60$ and network c is facing demand with $\mu = 83$ and $\sigma = 100$. All demand is Gamma-distributed.

We now consider network a and network b to be two paths in a divergent network ab with network structure 1-2-1. The order-up-to-level 766 at the root node 0 where the two network branches are splitting up, should be compared with the sum of the order-up-to-levels 495 and 285 (= 780) of the individual paths a and b. After splitting up the order-up-to-levels The order-up-to-levels at the intermediate nodes i and at the end nodes k remain identical to those of the individual paths a and b.

Similarly when we combine three paths a, b and c into a divergent network abc with network structure 1-3-1, we need to compare the order up to level 1246 of the root node of the divergent network abc with the sum of the order up to levels of the root nodes of the individual paths a, b and c that count up to 1240. The order-up-to-levels at the intermediate nodes i and at the end nodes k remain identical to those of the individual paths a, b and c.

The effect of the lead-time

Still using simulation we will now analyze the effect of lead-times on the positioning of inventory in the retail supply chain. Table 2.6 gives some simulation results that show

Table 2.5: The order up to levels in an unbalanced divergent network

Gamma distribution	Penalty = 10			$h_0 = h_i = h_k = 1$		$L_0 = L_i = L_k = 1$			Holding costs = Added value		
	Network			Demand		Local stock			Up to levels		
	0	i	k	μ	σ	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k
a	1	1	1	100	60	12	7	90	491	411	331
b	1	1	1	50	60	12	1	94	285	249	235
c	1	1	1	83	100	14	6	131	460	406	350
ab	1	2	1						766		
abc	1	3	1						1246		

Table 2.6: The effect of lead-times in a linear system

Gamma distribution			Penalty = 10			Network 1-1-1			$h_0 = h_i = h_k = 1$		
$\mu = 50 \ \sigma = 60$									Holding costs = Added value		
Lead-times			Local stock			Up to levels					
L_0	L_i	L_k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k			
1	1	1	10	1	92	280	248	234			
5	1	1	108	2	96	578	248	234			
1	5	1	0	61	107	538	542	235			
1	1	5	0	0	144	510	506	528			
5	5	1	58	70	106	799	542	235			
5	1	5	63	0	158	784	518	526			
1	5	5	0	37	180	1802	1327	526			
5	5	5	38	37	169	999	779	525			
$\mu = 100 \ \sigma = 60$											
Lead-timest			Local stock			Up to levels					
L_0	L_i	L_k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k			
1	1	1	12	7	90	491	411	331			
5	1	1	104	6	91	980	401	331			
1	5	1	0	63	100	940	909	330			
1	1	5	7	0	141	922	855	821			
5	5	1	52	72	101	1399	901	331			
5	1	5	69	0	143	1382	854	820			
1	5	5	0	27	154	1349	1327	820			
5	5	5	35	35	154	1802	1327	819			

that the effect is considerable. Comparing this table with Table 2.1 one can see that even more safety stock needs to be positioned downstream and that on top of that extra safety stock is needed directly after a section with a long lead-time because safety stock levels are proportional to the square root of the lead-time. This resembles the discussion on system safety stock and the effects of lead-time in Section 2.4.5

We conclude this overview of simulation results with an analysis of the combined effect of longer upstream lead times and higher upstream holding costs (= added value). In the retail supply chain normally downstream lead-times are short. But upstream the lead-times can be longer e.g. with distant suppliers or as a result of production scheduling. Table 2.7 shows the combination of such a higher upstream lead-time with varying holding costs at the root node of the network. We consider the retail supply chain to comprise the supplier's manufacturing facilities. This means that the added value upstream (= holding cost) will be higher than the value added at the downstream nodes. The table shows that the higher upstream holding costs reduce or even eliminate the need for extra safety stock upstream caused by the longer upstream lead-time.

In Table 2.8 the same aspect is shown, but this time for a much higher penalty value.

Table 2.7: Upstream lead-times and holding costs

Gamma distribution			Penalty = 10			Network 1-1-1			Holding costs = Added value		
$\mu = 100$ $\sigma = 60$											
Lead-times			Holding costs			Local stock			Up to levels		
L_0	L_i	L_k	h_0	h_i	h_k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k
1	1	1	1	1	1	12	7	90	491	411	331
1	1	1	5	1	1	0	0	53	411	425	345
5	1	1	1	1	1	98	9	94	981	410	330
5	1	1	5	1	1	11	4	63	821	435	345
5	1	1	10	1	1	2	1	51	776	461	375
10	1	1	5	1	1	36	6	68	1342	434	344
10	1	1	10	1	1	15	3	56	1279	453	363

Gamma distribution			Penalty = 10			Network 1-4-4			Holding costs = Added value		
$\mu = 100$ $\sigma = 60$											
Lead-times			Holding costs			Local stock			Up to levels		
L_0	L_i	L_k	h_0	h_i	h_k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k
1	1	1	1	1	1	1	0	85	7564	1599	331
1	1	1	5	1	1	0	0	50	6729	1672	349
5	1	1	1	1	1	93	1	85	14045	1583	331
5	1	1	5	1	1	0	0	52	13143	1659	346
5	1	1	10	1	1	0	0	36	12635	1717	376
10	1	1	5	1	1	6	0	53	21163	1637	348
10	1	1	10	1	1	0	0	38	20682	1689	364

Table 2.8: Upstream lead-times and holding costs with high penalty

Gamma distribution			Penalty = 100			Network 1-1-1			Holding costs = Added value		
$\mu = 100$ $\sigma = 60$											
Lead-times			Holding costs			Local stock			Up to levels		
L_0	L_i	L_k	h_0	h_i	h_k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k
1	1	1	1	1	1	29	21	220	669	559	451
1	1	1	5	1	1	1	9	192	599	559	451
5	1	1	1	1	1	148	34	225	1205	571	447
5	1	1	5	1	1	61	25	204	1085	571	447
5	1	1	10	1	1	33	15	180	1018	561	447
10	1	1	5	1	1	122	28	203	1645	568	444
10	1	1	10	1	1	81	23	187	1578	568	444

Gamma distribution			Penalty = 100			Network 1-4-4			Holding costs = Added value		
$\mu = 100$ $\sigma = 60$											
Lead-times			Holding costs			Local stock			Up to levels		
L_0	L_i	L_k	h_0	h_i	h_k	I_0	I_i	I_k	\hat{y}_0	\hat{y}_i	\hat{y}_k
1	1	1	1	1	1	8	5	211	9806	2128	451
1	1	1	5	1	1	0	0	169	9062	2128	451
5	1	1	1	1	1	204	9	211	16435	2111	447
5	1	1	5	1	1	7	0	174	15579	2119	454
5	1	1	10	1	1	0	0	145	15061	2119	454
10	1	1	5	1	1	69	1	151	23782	2112	456
10	1	1	10	1	1	13	0	151	23247	2112	456

2.7 Holding costs are network wide

The former Section 2.6 considered holding costs to be cumulative and represent the added value that items traversing the distribution network accumulate on their paths. That point of view is well in line with commercial practice of buying upstream and selling downstream, but does not lead to the logistics optimum.

From a supply chain perspective one might look at costs completely different. To find the true cost minimum, one needs to separate the logistics aspects of the supply chain from the commercial ones. It is appropriate to think in layers or levels: a logistics and a commercial layer, as shown in Figure 2.11. Strategic agreements and purchasing contracts should provide stable commercial relationships, within which boundaries one can try to find at the logistics level the logistics solution with the overall minimum costs and at the commercial level decide how to distribute costs and revenues amongst supply chain partners. For a more detailed description see (Kornelius et al., 1992).

This line of thinking has consequences for the holding costs. Why would goods accumulate value and become dearer the more downstream they are positioned? From a logistics or supply chain point of view goods need to be produced, handled, moved, stored, insured, etc. and to cover these costs goods need to have a value and a final sales price, high enough to compensate for all these costs made by the supply chain parties, plus the required commercial margins. But this value should not increase when goods are moved along the supply chain. Assuming storage costs at a supplier's warehouse to be fairly equal to those of a retail distribution center, it should not make any difference on the overall supply chain costs whether goods are stored at the one or at the other location. This means that goods get one ball park absolute holding costs figure H that comprises all the holding costs represented by the separate holding costs figures h_n in the former section. And like the penalty costs it will be incurred at the most downstream echelon k . In other words $\sum_{n=0}^{k-1} h_n = 0$ and $h_k = H$.

Inserting this in equation 2.9 results in:

$$\Pr\{I_k^i \geq 0\} = \frac{P + \sum_{n=0}^{i-1} h_n}{P + \sum_{n=0}^{i-1} h_n + \sum_{n=i}^k h_n} = \frac{P}{P + H} \quad (2.12)$$

Which is nothing but the newsvendor equation. Which means that the inventory within the whole distribution network, which is the echelon inventory of the most upstream root node 0, should be such high that the customer-service level or non out of stock probability realized at the most downstream nodes k equals the outcome of the newsvendor equation.

In a distribution system under echelon control the amount of inventory is completely determined by the order-up-to-level of the most upstream root node. This means that -at least in a serial system- the order-up-to-level of this most upstream root node 0 can be calculated from the service level determined by the newsvendor formula, by taking the inverse of the distribution function. In a serial system the order-up-to-levels of the more downstream nodes i and k only have a minimum level, below which they cause out of stocks to happen at the most downstream node k , which increases the overall costs. Raising the order-up-to-levels above their minimum value allows more items to flow downstream, but because the items do not accumulate holding costs, this has no effect on the overall system costs. In a divergent system the order-up-to-levels echelons determine the possibilities for

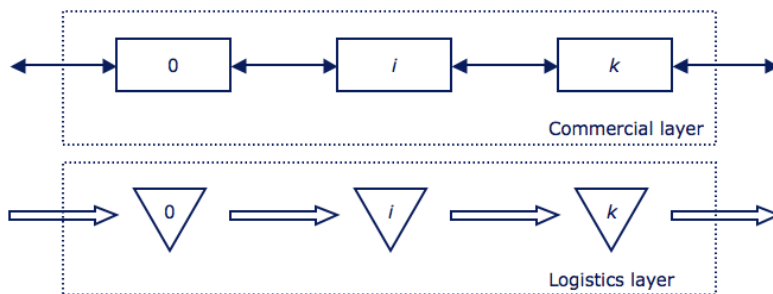


Figure 2.11: Think in layers

risk pooling, which means that they have an optimal value and the order-up-to-level at the root node might be slightly lower due to the risk pooling effect. But simulations show that the amount of inventory held back for risk pooling purposes is very limited. This means that in a distribution network with systemwide holding costs H all inventory will be positioned downstream.

With all inventory downstream, one might compare the highest echelon with a stockless depot, as already discussed in Section 2.4.4 and for the two-echelon case described by Eppen and Schrage in (Eppen and Schrage, 1981). Total systems safety stock can be calculated from Equation 2.3.

2.8 An overall inventory management strategy

It is interesting to compare supply chain inventory management from a service level perspective, described in Section 2.4 with inventory management from a cost minimization or cost optimal perspective as described in Section 2.6 and Section 2.7.

Service level perspective. If in retail practice inventory is being managed from a service level perspective, more upstream nodes are forced to offer a high service level; these service levels cannot be calculated and the result is certainly not optimal. As a result in the retail supply chain most of the inventory clogs upstream, generally at the manufacturer, unable to serve immediate consumer needs. In that case the highest customer-service in the supply chain is being offered by the manufacturer, the supply chain partner that is the farthest away from the consumer. Ironically the lowest customer service in the supply chain is offered by the most downstream stage, the only one that is facing consumer demand.

Cost minimization perspective. If on the contrary the inventory is managed from a cost minimization or costs optimal perspective, the highest target service level is at the lowest echelon. The more upstream, the lower the target service level. As a result lower echelons pull the inventory downstream. If the handling costs/added value at the various echelons are comparable, almost all inventory will be pulled downstream. If also the added value of the production process, which normally is higher than the added value at the various distribution nodes, is taken into consideration, all

inventory is pulled down to the lowest echelon; so all inventory is there, where it can serve customers.

Furthermore, as shown in the analyses earlier in this chapter, to offer the consumer the same service level, the total supply chain inventory with cost optimal control, will be lower than with the target service level approach.

The target customer service level that will be offered to the clientele at the retail outlets, in practice will always be determined by management. The upstream supply chain should be designed such, that this target service level is being met.

Designing the upstream supply chain using the customer service approach, will result in even higher target service levels at the more upstream nodes in the supply chain, with inventory clogging upstream.

Designing the upstream supply chain using the cost optimization approach requires a figure for the mostly fictitious part of the penalty costs that caters for such intangibles as the loss of the client.

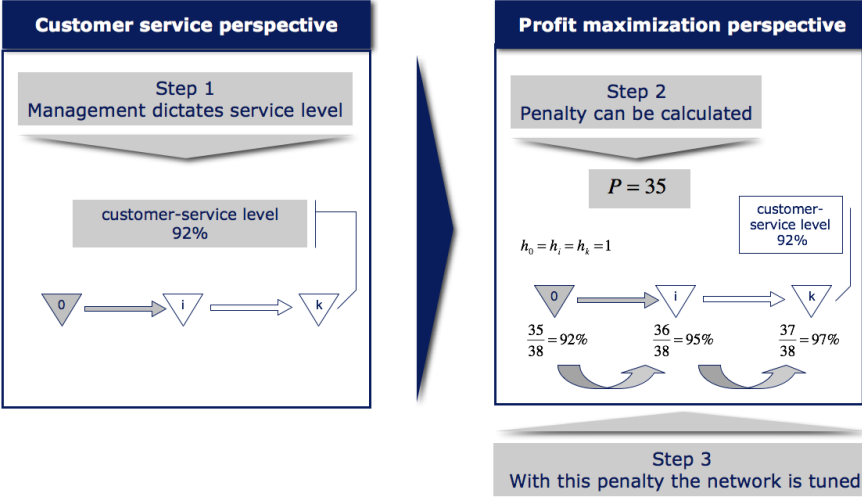


Figure 2.12: The best strategy is a combination of both

A useful integral inventory management strategy, based on a combination of the two inventory control methodologies, might be the following:

1. management determines the target customer service level to be offered (by the supply chain as a whole) at the retail outlets towards the clientele
2. this target service level is applied at the most upstream network-node using equations (2.9), (2.10) or (2.11) to get a value for P , the fictitious part of the penalty cost,
3. based on this penalty cost, the network as a whole is designed using the cost optimal methodology.

Table 2.9 shows some figures for the penalty versus the service level in a three echelon network with holding cost 1 at each echelon. The service levels in the table are the ones realized at the lowest, most downstream node k . The table should be read as follows: If management sets the overall target customer service level (non-out of stock) for this three echelon network at 96.8%, the network should be designed with a penalty value of 90. The subject is illustrated with some simulation results in Table 2.10.

2.9 The effect of order quantities

2.9.1 The non-effect of order quantities in a serial system under echelon control

In a multi-echelon inventory system that is controlling inventory with installation stock, the orders from downstream stages not only are the triggers to delivery, but at the same time are the sole means of exchanging information. That however is different in a system that is controlling inventory with echelon stock. Upstream stages now have visibility of downstream stock levels and the orders from downstream stages just trigger delivery.

This is illustrated in Figure 2.13. The figure depicts a serial distribution network with three nodes: 0, i and k . The most downstream node k happens to operate with a fixed reorder quantity of size Q ; the other nodes in the network operate with lot size one. The upper half of the figure shows the state of the network at time t and the lower half of the figure one period later at time $t + 1$. At time t the most downstream node k is facing orders from outside clients of size q_t . Based on these orders and the locally available inventory, these clients get delivered a quantity d_t .

Assume now, that at time t node k still keeps so much inventory, that it is not necessary yet to reorder a quantity Q . As a result of shipping the quantity d_t to the outside customers, node i experiences a reduction in echelon inventory of size d_t , even though it does not receive a replenishment order from node k . In order to keep the echelon inventory at the specified level, it reorders a quantity of size d_t at the next higher network root node 0. And similarly the network root node 0 reorders the same quantity d_t from the outside supplier. The replenishment order placed by root node 0 is not a reaction on the incoming replenishment order from node i , but is a reaction on the drop in echelon stock due to the delivery of quantity d_t to the outside clients. Every node places replenishment orders to keep the inventory within his downstream echelon at the required level. Because node k does not place a replenishment order, but node i does, there will be a buildup of inventory at node i , until node k reorders.

Assume now that at time $t + 1$ the inventory at node k has dropped to such a level, that it is necessary to place a replenishment order of size Q . In reaction to that order, node i ships a quantity D_{t+1} . As a result of this, the inventory built up at node i now shifts to node k . Neither the placement of the replenishment order Q_{t+1} , nor the delivery D_{t+1} do have any effect on the reordering behavior or on the echelon stock levels at the upstream nodes i and 0.

In a distribution network with echelon inventory control, the use of lot sizing at downstream nodes has no effect at higher echelon nodes.

Table 2.9: Penalty versus customer service in a 3-echelon network

Penalty	Service level		
	0	i	k
10	76.9%	84.6%	92.3%
20	87.0%	91.3%	95.7%
30	90.9%	93.9%	97.0%
40	93.0%	95.3%	97.7%
50	94.3%	96.2%	98.1%
60	95.2%	96.8%	98.4%
70	95.9%	97.3%	98.6%
80	96.4%	97.6%	98.8%
90	96.8%	97.8%	98.9%
100	97.1%	98.1%	99.0%

Table 2.10: Penalty and service level in serial and divergent networks

Gamma distribution $\mu = 100 \quad \sigma = 60$		$h_0 = h_i = h_k = 1$	Network	1 - 1 - 1	$L_0 = L_i = L_k = 1$	Holding costs = Added value		
Penalty	Service level	Costs excl. penalty	Local stock			Up to levels		
10	77.5%	311	12	7	90	491	411	331
20	87.0%	448	23	12	128	556	455	365
30	90.6%	528	23	16	151	586	485	386
40	93.2%	604	33	17	169	617	501	402
50	94.3%	656	32	19	181	631	516	413
60	94.8%	661	30	19	190	638	527	423
70	96.0%	730	35	23	202	660	541	431
80	96.4%	735	32	23	208	663	549	438
90	96.9%	827	32	27	217	677	562	444
100	97.0%	837	34	24	221	680	562	450

Gamma distribution $\mu = 100 \quad \sigma = 60$		$h_0 = h_i = h_k = 1$	Network	1 - 4 - 4	$L_0 = L_i = L_k = 1$	Holding costs = Added value		
Penalty	Service level	Costs excl. penalty	Local stock			Up to levels		
10	78.0%	5772	1	0	85	7564	1599	331
20	88.8%	7669	5	2	122	8279	1754	363
30	91.9%	8753	4	1	143	8646	1851	390
40	94.0%	9540	6	4	160	8957	1918	398
50	95.1%	10162	6	5	172	9162	1969	410
60	95.8%	10676	8	5	182	9332	2006	420
70	96.3%	11033	2	4	190	9455	2063	431
80	97.0%	11559	9	5	202	9664	2087	441
90	97.2%	11897	9	5	207	9749	2109	445
100	97.4%	12149	2	4	211	9803	2150	452

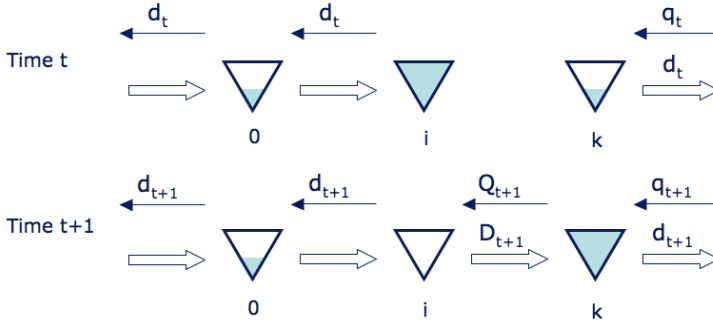


Figure 2.13: Lot sizing in a multi-echelon network

2.9.2 The disturbing effect of order quantities in a divergent system under echelon control

Order quantities may have no effect in a serial system, they do however have an effect (and a disturbing one) in divergent systems. In the earlier sections of this chapter it was shown that an optimally tuned divergent network experiences shortage at downstream nodes. This means that one needs to allocate, to divide the shortage in a decent way.

The use of (minimal) order quantities limits the possibility and the effectiveness of allocation. It makes no difference whether these order quantities happen to be calculated economic order sizes or just case packing sizes. A decentralized system that utilizes (minimal) order quantities that cover the needs for more than one review period, will not order every review moment and not all receiving parties (e.g. retailers) will run out of stock at the same review moment. So in a decentralized system with e.g. daily review, one party might order today, two others will order tomorrow and yet another the day after tomorrow. If the supplying party (e.g. the retail distribution center) has no downstream visibility and only sees the incoming orders, the system degenerates to a first come first serve (FCFS) system. The one party that orders today, might take away inventory that, if properly allocated, could have covered the urgent needs of several other parties that will order tomorrow.

If the supplying party however indeed has downstream visibility of inventory levels and preferably also visibility of forecast demand, it will at least have some possibility to allocate across several review moments. The allocation clearly will be more effective if the receiving parties run out of inventory simultaneously and if the ordering moments are synchronized. In a centralized system if the supplying party does not manage the inventory levels of the receiving parties on equal run out time, in order to get the ordering and delivery moments synchronized, it will hardly be possible to allocate; the centralized system then degenerates to a decentralized system.

With Supply Chain Synchronization the situation is quite different, the replenishment moments of all retailers now are synchronized to the production schedule which enables a fair allocation strategy. The retailers either get delivered once or in case of the two-interval-strategy (see 2.4.6) twice per production period; in both cases the replenishment moments

are synchronized.

2.10 Analysis

Based on the contents of this chapter the following observations can be made:

Observation 6

Centralized control offers distribution flexibility

Centralized control (Push, VMI) offers the flexibility to shift delivery moments. Consequently one can (a) consolidate shipments and transport to reduce the costs of transport and (b) ship upon availability to reduce overall inventory. Furthermore Centralized control allows (c) to deliver in larger quantities to reduce the costs of handling.

Observation 7

Not all relations allow centralized control

Not all supplier-retailer relations are such, that centralized control by the supplier will be feasible, as the retailer might fear to lose control.

Observation 8

Two-shipment-strategy is good enough

If downstream storage capacity is limited or in a divergent network considerable imbalance exists in downstream demands, a two-shipment strategy might be a good one. It reduces downstream storage requirements and offers a new allocation moment. This however goes at the expense of the extra handling costs associated with putting part of the goods into storage and retrieving them again at the second shipment moment.

Observation 9

Inventory management has a service or cost target

Inventory can be managed either from a service level perspective or from a cost minimization perspective. In retail practice most often the service level perspective is used.

Observation 10

The service level theory cannot optimize a network

The service level perspective is unable to specify how safety stock should be distributed across a multi-echelon supply chain. As a result service level requirements imposed upon upstream supply chain partners tend to be exaggerated.

Observation 11

Cost minimization needs a penalty value

The cost minimization perspective is able to derive formulas that specify the distribution of safety stock in a multi-echelon supply chain, provided one can specify the stock-out penalty value.

Observation 12

Distribution: most safety stock downstream

The cost minimization perspective shows, that in the cost optimal situation already with cumulative holding costs almost all safety stock is kept at the downstream end nodes, the retail outlets. Hardly any safety stock is kept upstream; certainly so in divergent networks, that need less safety stock upstream due to the risk pooling possibilities. In systems with

absolute holding costs inventory will well-positioned downstream even more. In general the differences between the safety stock levels in serial and divergent networks are small. Only prior to a node with higher holding costs, some safety stock is being kept. If a node is facing a replenishment lead-time even more safety stock should be positioned downstream and on top of that extra safety stock is needed at that node. If the most upstream node has higher holding costs, all safety stock is positioned downstream. This means that in a production-distribution supply chain all safety stock should be positioned downstream.

Observation 13

Production-distribution: all safety stock downstream

In the retail production-distribution supply chain the most upstream node is the manufacturing plant. That node is adding more value than the downstream nodes. Consequently in the retail supply chain, different to many people's thinking, all safety stock should be positioned downstream, at the retail outlet. That is where consumers show up and that is where out of stock really means loss of sales. There should be as much inventory as possible on the shelves, with the remainder that doesn't fit located in the retail distribution centers ready to fill the shelves. As little inventory as possible should be held at the manufacturer's warehouses. This is a conclusion that Whybark and Yang reported already in 1996 based on retail simulations (Whybark and Yang, 1996).

These observations lead to the following design elements:

Design choice 3

Make centralized *and* decentralized control possible

Theoretically supplier managed centralized control might be better than retailer managed decentralized control. In practice the retailer might wish to retain flexibility.

Based on observations 6 and 7

Design choice 4

Ship all at once, or ship twice

In case of downstream storage limitations or demand imbalance: ship twice.

Design choice 5

Realize target service level at minimal costs

The service level and the cost minimization perspective can be combined as follows: management dictates the required service levels and subsequently these service levels are being realized at minimal cost.

Based on observations 9, 10 and 11

Design choice 6

Position safety stock downstream

The supply chain reorder levels should be set such, that all safety stock is positioned at the most downstream nodes of the network.

Based on observations 12 and 13

Chapter 3

Handling

3.1 Introduction

Chapter 2 mainly looked at safety stock and neglected lot sizes. In retail practice however, production sizes and even more so replenishment quantities play an important role, because they determine the amount of cycle stock, that without synchronization at each of the locations in the supply chain on average will be equal to half the production batch or the order size. But the order size not only determines the amount of cycle stock, it also may have a strong impact on one of the most dominant supply chain cost components: the costs of handling. Literature on lot sizing generally only considers the inventory aspects, like e.g. (Chen et al., 2001). But the handling aspects of order sizes might often be much more important: the costs of handling and transportation may far exceed the inventory holding costs. The logistics cost breakdown in Figure 1.3 on page 7 shows that the costs of handling in retail might be more than 10 times as high as the costs of inventory.

The next section 3.2 deals with the change of unit sizes along the supply chain. And section 3.3 tries to view the logistics' costs from an integrated supply chain perspective. The next two sections 3.4 and 3.4.2 describe synchronization and the effects on cycle stock. Section 3.4.3 mentions the applicability of the two-shipments-strategy and ship only twice per period. Section 3.4.4 deals with the management aspects of a synchronized supply chain. Section 3.5.2 gives an overview of the EOQ theory for a single buyer. The sections thereafter extend the EOQ theory first to a two echelon supply chain, with a single supplier and a single buyer and then to a multi echelon supply chain as a basis to model supply chain synchronization in Section 3.5.4.

3.2 Break bulk

The order quantities and thus the units that are handled along the supply chain from the manufacturing plants all the way down to the retail outlets vary. Over and over again larger units are broken down into smaller units, with each conversion requiring the necessary handling.

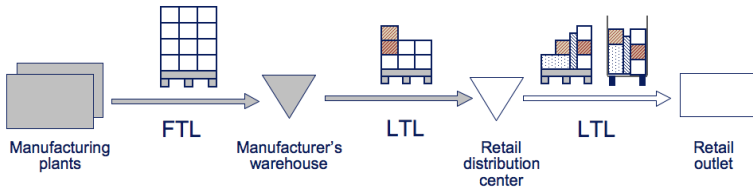


Figure 3.1: An example of the break bulk of handling units along the supply chain

An example might be the situation depicted in Figure 3.1.

- The manufacturing plants in this example produce full pallets with carton boxes or sealed trays, all with the same product. These full pallets are being shipped in full truckloads (FTL) to the manufacturer's warehouse.
- Upon receipt of retail orders the manufacturer assembles and ships full- or mixed-pallets in trucks not always full (LTL, less than truckload) to the retail distribution centers. After which the truck moves on, to one or more distribution centers of other retailers, to drop off the rest of the truckload.
- Upon receipt of shop orders, the retail distribution centers pick boxes and even individual items, assemble them on pallets and roll cages and ship them in trucks not always full (LTL) to the retail outlets. The pallets or roll cages in general will contain the carton boxes or sealed trays as produced by the manufacturer. But wherever a full box of the same product does not fit in the space reserved on the shelf for that particular product, the mixed pallet or roll cage toward the retail outlet might also contain crates or boxes with loose products, individually picked on order.

This means that the original homogeneous pallets with boxes that are all containing the same product, on their way to the consumer are broken down and reassembled with other boxes or individual products into units that fit the demand of the next party in the supply chain.

In general, the handling costs (per item) are lower when the units that are being handled are larger. For a manufacturer it is e.g. cheaper to retrieve and to dispatch a full pallet than to operate an order pick line suitable for picking individual cases and assembling mixed pallets. The pricing system (or quantity discount scheme) of the manufacturer should reflect that, such that when the retailer calculates the optimal replenishment quantity, these quantities equal large and full units. With a good pricing system, that properly reflects the manufacturer's handling and transportation costs, the retailer in the example in Figure 3.1 might find out that for many products ordering full pallets is cheaper. He might even find out that for some products with high demand ordering a full truckload is advantageous.

As described above, on their way from production to consumer, goods live in units that along the supply chain decrease in size. Over and over again larger units are broken down into smaller units. This process of breaking down larger units and reassemble them into other units, the spread over the various locations, the storage at every stage, plus the fact that it is an order driven process that is constrained in time, is the dominant cost element in retail distribution.

To achieve structural savings, the challenge would be to

- try to move the larger units one step further down the supply chain than current practice
- eliminate or structurally simplify one or more stages in the process
- break the time constraint by preparing the larger part of the work outside the order cycle

3.3 An integral cost approach

From an integrated supply chain point of view however, the ‘order size’ can be looked at differently:

The moment that goods have been produced, the inventory is there and the inventory carrying costs have to be borne. Assume now that the storage costs do not differ too much between the various warehouses along the supply chain. In that case moving goods from one warehouse to the other, e.g. from the manufacturer to the retailer, hardly affects the overall storage costs. If there is a need for an optimal replenishment quantity calculation at all, not the actual inventory carrying costs should be part of the equation, but the difference between holding inventory in one point of the supply chain versus holding that inventory in another point of the supply chain.

Also the transaction costs can be looked at differently. The transaction costs include the cost of transportation, handling, management and administration.

- The costs of handling are substantial. They are determined by the units shipped. So preferably goods move with full pallets in full trucks.
- The costs of management and administration are primarily related to the number of order lines; to keep these cost elements low, the number of order lines and thus the number of shipments should be as low as possible.
- As to the cost of transportation, eventually the goods have to move down the supply chain anyhow. Assuming full truck loads, the only thing that counts is whether to ship now or later. In other words, only the interest on the earlier investment in transport goes into the equation.

This illustrates that from an integrated supply chain perspective moving goods from one point in the supply chain to the next point in the supply chain should be done in as few shipments as possible and in full truckloads with full pallets.

When goods are being moved in larger quantities, downstream inventory (cycle stock) increases. The hindsight of this is that if there is no or insufficient information exchange on downstream demand and inventory levels, which means that supply chain partners generate their orders based on local installation stock only, both high downstream inventory levels and bulky shipments do have a negative effect on information transmission to upstream supply chain partners: the variability will be increased and the information will be delayed. See (Småros, 2005) and (Fransoo et al., 2001).

Current administrative practice, to send an invoice the moment goods are being moved from one party in the supply chain to the next and on top of that against transfer prices that

become higher the more goods move downstream the supply chain, definitely obstructs that.¹ An optimal supply chain configuration at the lowest integrated cost can only be achieved when financial settlement and logistics are treated separately. From a logistics point of view the supply chain configuration with the overall lowest costs should be selected. Subsequently such commercial arrangements should be negotiated as to facilitate that optimal supply chain configuration. This subject will be further addressed in Chapter 6

An interesting observation can be made here on the positioning of inventory: Due to the predominance of the costs of handling, moving goods in large quantities considerably decreases the distribution costs. It was shown in Chapter 2 on inventory management, that the lower the distribution costs are, relative to the costs of production, the more forward the safety stock should be positioned. So moving goods in large quantities goes hand-in-hand with positioning them more downstream the supply chain.

3.4 Synchronization

3.4.1 Introduction

Traditionally downstream stock points reorder (call off, pull) from an upstream stock point whenever stock levels drop below a certain set reorder level. In terms of retail distribution: a shop reorders from a retail distribution center, a retail distribution center reorders from a manufacturer's warehouse and the inventory level in the manufacturer's warehouse triggers production scheduling at the factory.

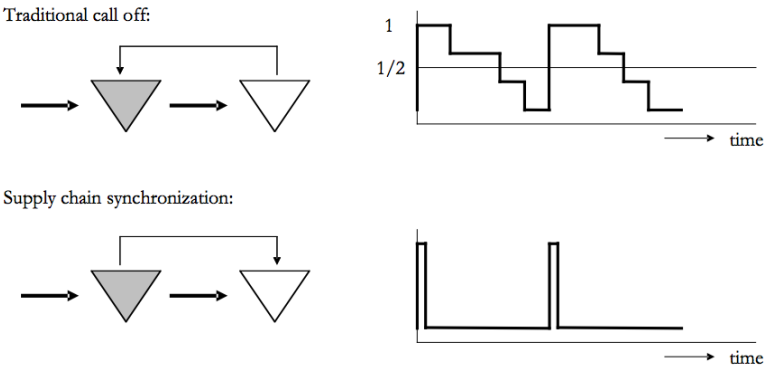


Figure 3.2: Supply Chain Synchronization and cycle stock

Figure 3.2 shows the situation where an upstream manufacturer's warehouse supplies to a downstream retail distribution center. The upper part of the figure shows the traditional situation where the downstream stock point calls off from the upstream stock point; the lower part of the figure shows the situation under supply chain synchronization. The right

¹Even if companies agree not to send an invoice when goods are being shipped, VAT tax laws might require an invoice in case of international shipments.

hand side of the figure shows the development over time of the stock level in the upstream stock point. The figure does not show all of the stock, but only that part of the stock that theoretically can be regarded as destined for the downstream stock point under consideration.

In the traditional call off situation depicted in the upper half of this figure, the downstream stock point on average appears to call off three times per production interval. The quantity ordered each time is the optimal replenishment quantity (see equation 3.2), as determined by the downstream stock point, without any knowledge of the production cycle at the manufacturer. Directly after production the full forecasted demand of the downstream stock point for the whole production period is available in the manufacturer's warehouse, waiting there to be called off. Because there is no synchronization between the production moment and the moments of call off, the average cycle stock in the manufacturer's warehouse will be half the forecasted demand during the production interval; regardless how frequently the downstream stock point reorders.

Let us for instance assume that the manufacturer produces the article under consideration once a week on Friday. In a given week the retailer might call off on Monday, Wednesday and Thursday; the next week he might call off on Tuesday, Wednesday and Thursday. In either case on average the manufacturer's warehouse will keep half a week of stock.

As is shown in the lower part of the figure, with Supply Chain Synchronization, that is different. Immediately when goods become available, the (larger part of the) forecasted demand of the downstream stock point is being shipped. There is no cycle stock waiting in the manufacturer's warehouse anymore. There will be more inventory at the downstream stock point now, but less than one would intuitively expect, as will be shown in the following.

3.4.2 The effects on cycle stock and handling

In order to study the effects of Supply Chain Synchronization on transaction costs and inventory costs, we will consider two extreme situations. First the situation where a retail distribution center during a production interval currently reorders a given article only once. The other extreme is the situation, where a retail distribution center reorders a given article very frequently, for instance daily.

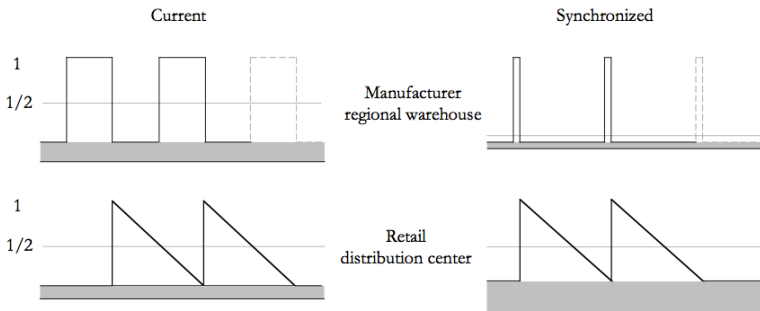


Figure 3.3: One delivery per production interval

In Figure 3.3 the situation is shown, where per production interval of a given product a

retail distribution center is being delivered only once. The upper half the figure shows the inventory levels in the manufacturer's distribution center; the figure shows the inventory that theoretically is destined for one of the distribution centers of this retailer. The lower half of the figure shows the inventory levels of the same article in one of the retailer's distribution centers. The left half of the figure shows the inventory levels under the current way of working and the right half of the figure shows the inventory levels when working synchronized. In each of these figures, the non filled area under the graph represents the cycle stock to fulfill forecasted demand and the shaded area represents the safety stock, that in case of deterministic demand is not being touched upon.

When a retailer currently calls off only once during the production cycle of a certain article, then on average the call off moment will be half way between the two production moments. We assume that the product under consideration is being produced once a week; then the manufacturer's distribution center on average will hold half a week of stock of the product, as is shown in the upper left part of the figure. Assuming that the retailer delivers daily to his retail outlets, then the inventory level in the retailer's distribution center will be as shown in the lower part of the figure; also the retailer is keeping half a week of stock in each of his distribution centers.

Had the deliveries to the retailer been synchronized to the production moments, then the inventory levels would have been as shown in the right half of the figure. Apart from some safety stock, there is no further cycle stock left at the manufacturer. The cycle stock levels in the retail distribution center however remained equal, only the delivery moments have been shifted. This means that the overall cycle stock level in this part of the supply chain is reduced by 50%.

In the extreme situation of currently one delivery per production interval, synchronizing the supply chain will reduce the overall cycle stock in the supply chain by 50%, whilst the number of transactions remains the same.

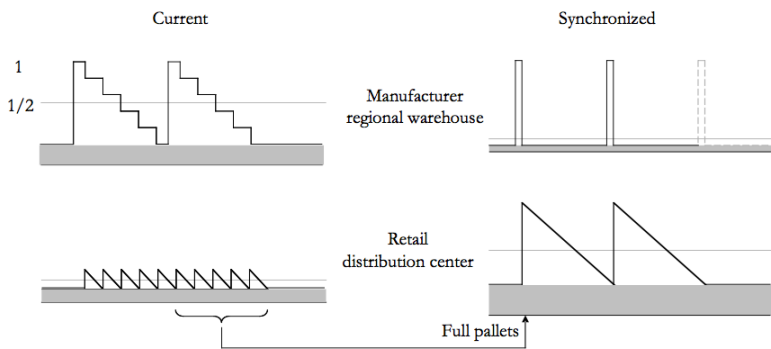


Figure 3.4: Many deliveries per production interval.

Figure 3.4 shows the situation that is current practice with most retailers. Per production interval of a given product the retail distribution centers call off frequently, to keep their inventory low. Again the upper half of the figure shows the inventory levels in the manufacturer's warehouse, the lower half of the figure shows the inventory levels in the retailer's

distribution center. And again the left half of the figure shows the inventory levels under the current way of working, whereas the right half of the figure shows the inventory levels when working synchronized.

Let us assume that the manufacturer produces the product under consideration once a week and that currently the retailer calls off daily and delivers all of his outlets also every day. The inventory levels in the manufacturer's warehouse are then as shown in the upper left part of the picture and the inventory levels in the retailer's distribution center are as shown in the lower left part of the figure. Again the manufacturer holds half a week of stock, but the retailer holds only half a day of inventory (apart from safety stock).

Had the number of deliveries be limited to once per production period and synchronized to the production moments, then the inventory levels would have been as shown in the right half of the figure. Apart from some safety stock, there is no further cycle stock left at the manufacturer. The retailer however now holds half a week of stock. This means that the overall cycle stock level in the supply chain remained the same, but has been moved from manufacturer to retailer.

Actually this is a typical VMI situation. It shows that VMI with consignment stock does not raise the inventory costs for the supplier. The capital tied up in the consignment stock, was previously tied up in the inventory in his own warehouse.

In the extreme situation of currently many deliveries per production interval, synchronizing the supply chain will leave the overall cycle stock in the supply chain intact, but will shift it from manufacturer to retailer. But more importantly, the number of transactions drops dramatically. As is also shown in Figure 3.4, due to the fact, that the number of transactions drops, goods can be more easily consolidated into full pallets and into full truckloads.

The above situations were extreme. Most products will be somewhere in between of these two extremes. Supply Chain Synchronization that way saves both on inventory (and inventory carrying cost) and on transactions (and transaction costs). With some article types one saves more on inventory costs, with others more on transaction costs. Normally in grocery retail, from a supply chain point to view, savings on transaction costs are much greater than savings on inventory carrying costs, because the transaction costs comprise the dominant cost components order picking and transportation.

3.4.3 Shipping frequencies

It is important to note, that it is not necessary to ship all goods immediately as they become available. Although the previous Figures 3.3 and 3.4 might seem to suggest such. Only so much needs to be shipped synchronously to it becoming available, as is needed to assure efficient handling and transport and to assure sufficient coverage of the immediate client's needs. This has been illustrated in Figure 3.5

When everything is shipped immediately downstream to the retail distribution centers, the manufacturer's warehouse effectively becomes a stock-less depot as treated in section 2.4.5 and described by (Eppen and Schrage, 1981). But, as argued above, instead of shipping all at once, one might choose to ship several times per production period, as long as handling and transport efficiency is assured. The downside of not shipping everything once is the extra cost of taking the goods in stock in the supplier's warehouse and the extra cost of retrieving

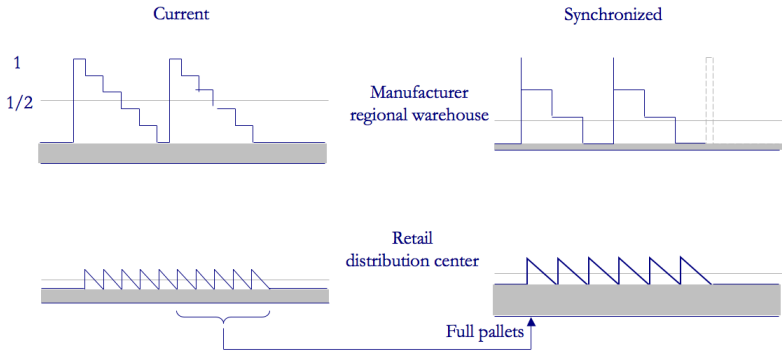


Figure 3.5: Not everything needs to be shipped at once.

and dispatching them at some later moment. The good thing is that less storage space is needed at the retailer’s distribution centers. From an inventory management point of view, shipping twice is near optimal, as discussed in section 2.4.6 and described by (Van der Heijden, 1999).

3.4.4 Managing Supply Chain Synchronization

Supply Chain Synchronization can be achieved both by centralized planning and by decentralized planning.

Centralized planning is not easy to implement. It requires the willingness to cooperate and to invest in the relation (or the power to exert cooperation). The supplier needs to have visibility of the various retailers’ downstream inventories, which requires setting up a data link for the daily exchange of the inventory status of all the products of this supplier between the IT-systems of a supplier and his retail clients. The supplier’s system should facilitate managing the inventory levels at each of the distribution centers of each of his retail clients, with flexible rule setting for the generation of shipment orders. The inventory levels and replenishment rules will be different for each of the retail clients.

Decentralized planning is easier to implement and gives more flexibility to the retailer. It requires far less data exchange. The supplier daily publishes his production schedule for the next period, on a restricted site on the Web or via e-mail. The inventory planners at the retailers check the published production schedule and order for each product a quantity enough to cover the needs till the next production run. The workload for the inventory planners at the retailer is less than currently: instead of checking the inventory status of all products every day, they now only check those products scheduled for production. The supplier can entice the retailers to order against his production schedule by offering a discount on timely ordered goods. When this discount is in the form of a decent service based pricing scheme, it will guide the retailer to the correct ordering behavior. If the production system has enough volume flexibility on the yet published production schedule, the supplier virtually can produce to order.

Many retailers perform so-called ‘*Forward Buying*’, by ordering more than they need on special price offers. Those retailers experience centralized planning by the supplier as a means to block their possibility for forward buying. With decentralized planning however they still can perform forward buying. They even can perform forward buying on products without special offers, by ordering a quantity larger than the needs till the next production run, whenever this generates a large enough discount; for instance when ordering 3 pallets extra might mean running a full truckload.

3.5 EOQ-analysis

3.5.1 Introduction

In this and subsequent sections, optimal reorder sizes will be calculated, with help of the EOQ-formula; first we will do so for a single buyer, as can be found in any textbook on logistics see e.g. (Silver and Peterson, 1985). We will then extend it to a multi-echelon serial supply chain. Finally we will give a modeling framework for a divergent supply chain.

We will use the following notation:

i	index, indicating the network node subscript 0 indicates the root node, subscript i indicates an intermediate node and subscript k indicates an end node In a three echelon system this would be: 0 supplier's warehouse; 1 = retailer's distribution center, 2 = retail store
D	demand per period
A_i	costs per purchase order
a_i	costs per unit purchased
C_i	client order fulfillment costs per order includes a.o. order set-up costs and transportation
c_i	client order fulfillment costs per item includes a.o. order picking and loading/unloading
C_{-1}	production plant set up, production run and warehouse delivery costs are included in A_0
T_i	transaction costs per shipment = $\begin{cases} A_0 & \text{for } i = 0 \\ A_i + C_{i-1} & \text{for } i = 1, \dots, k \end{cases}$
t_i	transaction costs per unit = $\begin{cases} a_0 & \text{for } i = 0 \\ a_i + c_{i-1} & \text{for } i = 1, \dots, k \end{cases}$
H_i	holding costs = $v_i * r_i$
v_i	unit value
r_i	capital opportunity cost rate
Q_i	purchase order quantity
R_i	replenishment interval
P	penalty per unit short per unit time
I, II, III	index indicating the situation that is being modeled
TC_i	total costs node i
TSC	total system costs
TRC	total relevant costs
K	enlargement/reduction factor K^P production batch, K^Q order size, K^I inventory, K^C costs

3.5.2 The EOQ for a single buyer

In the case of a single buyer, the optimal replenishment quantity Q is a trade-off between two relevant cost elements. These are on the one hand the transaction costs AD/Q and on the other hand the inventory carrying costs $HQ/2$, with A the fixed order cost or set-up cost per order, D the demand per period and h the inventory holding cost, i.e. the item

price P times the inventory carrying charge r . Minimizing the total relevant costs results in the optimal replenishment quantity Q^* , also known as the economic order quantity (EOQ). This section 3.5.2 gives an overview of the EOQ theory for a single buyer. Section 3.5.3 thereafter extends the EOQ theory to a two echelon supply chain, with a single supplier and a single buyer.

For a single buyer the total relevant costs, i.e. the transaction costs plus the inventory carrying costs, are:

$$\text{Total relevant costs TRC} = \frac{AD}{Q} + \frac{HQ}{2} \quad (3.1)$$

Relevant here means influenced by the order size. Minimizing (3.1) results in the well-known formula (see e.g. (Silver and Peterson, 1985)) for the optimal replenishment quantity Q^* or the economic order quantity EOQ, as given in (3.2):

$$\text{Optimal replenishment quantity } Q^* = \sqrt{\frac{2AD}{H}} \quad (3.2)$$

This replenishment quantity is optimal from the perspective of the ordering party, because it minimizes the total costs for the ordering party. The same formula is often used to determine batch sizes with stochastic demand; in which case D represents the average demand. Applying the formula for the optimal replenishment quantity (3.2) to the total relevant costs function (3.1) results in (3.3), the formula for the minimum relevant costs:

$$\text{Minimum relevant costs } TRC^* = \sqrt{2ADH} \quad (3.3)$$

Dividing the optimal replenishment quantity by the average demand per time period, results in the optimal replenishment interval (3.4). For a given product this could be e.g. a week; in that case the optimal replenishment quantity covers a weeks demand.

$$\text{Optimal replenishment interval } R^* = \frac{Q^*}{D} = \sqrt{\frac{2A}{DH}} \quad (3.4)$$

In an almost identical manner the manufacturing industry decides upon the optimal production quantity. Division by the average demand per time period in that case results in the optimal production interval. For a given product this could be e.g. a month; in which case the optimal production quantity covers a months demand. In many supply chains the phenomenon can be seen, that the production- or ordering- frequency (see (3.4) varies along the supply chain and increases downstream the supply chain towards the client, or conversely the replenishment-quantities and the replenishment intervals decrease.

$$\text{Optimal replenishment frequency } f^* = \frac{1}{R^*} = \sqrt{\frac{DH}{2A}} \quad (3.5)$$

With $H = vr$ the formula (3.5) for the optimal replenishment frequency can be rewritten as follows:

$$\text{Optimal replenishment frequency } f^* = \sqrt{Dv} \sqrt{\frac{r}{2A}} \quad (3.6)$$

If we assume the inventory carrying charge r and the order cost A to be fairly constant within a product group, we can replace the second term in formula (3.6) by a constant. The optimal replenishment frequency now can be written as:

$$\text{Optimal replenishment frequency } f^* = l\sqrt{Dv} \quad (3.7)$$

This shows that the optimal replenishment frequency is proportional to the square root of the demand times the product value. Frequently within a product group, the demand for products with a low value is large and for products with a high value is low. This reminds of Pareto and renders Dv and consequently the optimal replenishment frequency fairly constant within that product group.

The calculation of the optimal replenishment quantity (3-1) supposed that shortages were not permitted. If shortages are permitted, the optimal replenishment quantity becomes:

$$\text{Optimal replenishment quantity } Q^* = \sqrt{\frac{2AD}{H}} \sqrt{\frac{P+H}{P}} \quad (3.8)$$

with p the penalty per unit short per unit time.

And the fraction of time (in the deterministic case) that no shortage exists reminds the Newsboy formula from Chapter 2:

$$\text{Fraction of time that no shortage exists } \frac{S}{Q} = \frac{P}{P+H} \quad (3.9)$$

with S the inventory level just after receiving a batch Q^* . See e.g. (Hillier and Lieberman, 1995) and (Zipkin, 2000)

3.5.3 Extending the EOQ-model

The literature overview in Section 1.2 showed that the EOQ-model has often been used as a model for supply chain analyses. Most of these models concern a single item two-echelon supply chain, with a single buyer and a single supplier. The reference always is the current situation where buyer and seller apply the EOQ model uncoordinated and independently to determine their own optimal order quantity, based on their own order costs A and their own inventory holding costs H . This reference situation then is compared with a situation with some more elaborate form of buyer-vendor coordination.

Suppliers in the grocery retail most often are confronted with considerable setup costs A_s when changing a production line from one packaging type or product to the next. On the other hand their product value v_s and thus the holding costs H_s is relatively low. Calculating the optimal replenishment quantity Q_s^* with high set up costs and low holding costs, results in large production batches, covering a certain period of demand R_s^* ; this could e.g. be a month. See equations (3.2) and (3.4).

The manufacturing industry delivers goods to the retail industry not against a price that just covers the production costs, but against a sales price that one way or another also covers the costs of distribution C_s and a commercial margin. Due to this higher sales price the inventory carrying costs H_r at the retailer are higher than those at the manufacturing industry.

The retailer, when calculating the optimal replenishment quantity Q_r^* considers as relevant transaction costs only his own purchase order costs, represented by A_r in the modeling

framework in Figure 3.6. These order costs are considerably lower than the set-up costs at the supplier. In order to recoup his order fulfillment and distribution costs C_s , the supplier includes these in the product price, resulting in higher inventory holding costs at the retailer. High inventory holding costs combined with low transaction costs indicates that the retailer will order in small quantities, which quantities in general cover a much shorter demand period than is being covered by the production quantities at the supplier; this could e.g. be a week.

The example with a monthly producing manufacturer and a weekly re-ordering retailer, actually is a quite frequently occurring scenario. The consequence of this scenario is that the weekly reordering retailer during the month every time gets delivered goods, that have been sitting at the manufacturer's warehouse, ever since their production. Instead of weekly ordering e.g. 10 boxes, the retailer could have ordered a full pallet, thus saving the manufacturer the costly handling of individual boxes.

From an integrated supply chain perspective, not only the purchase order transaction costs A_r of the retailer, but also the fulfillment costs C_s of the manufacturer should have been part of the numerator in (3.2) when calculating the optimal replenishment size between supplier and buyer. This would have resulted in larger replenishment quantities. But in a non-integrated supply chain, towards the retailer the transaction costs of the supplier are a fixed part of the product price and thus part of the denominator in (3.2) resulting in even smaller replenishment quantities. As a result the number of transactions and the transaction costs will be higher than would have been necessary from an integrated supply chain perspective.

Independent



Integrated

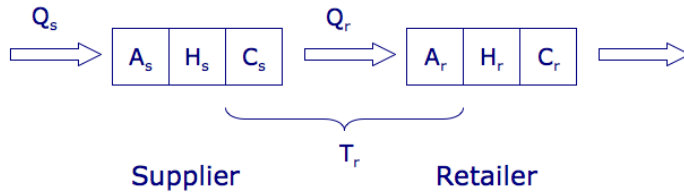


Figure 3.6: Two-echelon EOQ-model

We therefore suggest to extend the EOQ-model as shown in Figure 3.6. This model shows that supply chain partners do not have two, but do have three main cost elements:

- the costs of placing an order (or the order set-up costs)
 A per order and a per unit

- the inventory carrying costs (or the holding costs)
 $H = vr$
- the order fulfillment costs (or the delivery costs)
 C per order and c per unit

The EOQ-model does not minimize the total costs, but the sum of only two of these three main cost elements: the order cost or set-up cost A and the inventory holding cost H . In the EOQ-model the delivery costs C are considered not to be relevant. From the perspective of a single party this is correct, because the ordering decisions have no impact on the costs of delivery to the customer of that single party. Likewise in a multi-echelon supply chain the costs of delivery to the client of the most downstream buyer C_{i+1} cannot be impacted by upstream ordering patterns and therefore in the model can be ignored. The costs C_s of the outgoing shipments at the supplier however cannot be disregarded, as they depend upon the buyer's ordering decisions. These costs, comprising of order picking, shipping and transportation can be considerable. They can run to over 50% of the supplier's logistics costs as shown in the cost breakdown in Chapter 1.1. In our further analyses in this thesis we extend the EOQ-model with the delivery costs C per order as part of the transaction costs T , the sum of the ordering costs A_r of the retailer and the delivery costs C_s of the supplier. So: $T_r = A_r + C_s$ and similarly with the costs per unit $t_r = a_r + c_s$.

One possibility for the manufacturer to assure that the retailing clients when calculating their order sizes take into account at least some of the manufacturer's delivery costs C_s , is granting the retail clients quantity discounts. A classic example in supply chain literature is Monahan who uses the EOQ-theory to calculate what quantity discount should be offered to clients to increase their order sizes, such that vendor profit is optimized. Monahan's model has several restrictions, one of which is that the model assumes a lot-for-lot or order-for-order operation. Lee and Rosenblatt generalized the model to a one lot- for- several-lots ($Q_s = kQ_r$). The lot-for-lot restriction exists because both Monahan and Lee and Rosenblatt do not separately model the delivery cost C_s , but consider these to be comprised in the order set-up cost A_s , either once or k -times. (Monahan, 1984) (Lee and Rosenblatt, 1986)

The EOQ-model presupposes the order costs A to be fixed and independent of the order quantity Q and the inventory holding costs $HQ/2$ to be proportional to the order quantity Q . In retail practice this might indeed be true within certain boundaries. It however definitely is not true for the delivery costs C . The logistics costs model in Appendix B shows that there are vast cost differences between picking and shipping an individual item, a full box of items, a full pallet with boxes or even a full truckload. A proper quantity discount scheme should reflect at least some of these differences in the transaction cost structure at the supplier².

Some manufacturers have gone further along that route and offer full service-based pricing, consisting of a base price v_s^b , sometimes called factory gate price, that covers production costs and commercial margin and on top of that base price give an additional charge that reflects their actual distribution and transportation costs. Figure 3.7 shows the effect of a good discount scheme or service based pricing scheme on the calculation of the optimal replenishment quantity.

²It is unclear why Zipkin states: it is not easy to construct a plausible scenario where a quantity discount makes sense. ((Zipkin, 2000)p 57)

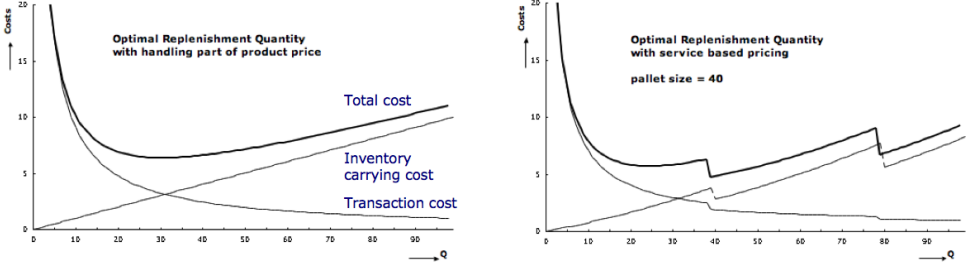


Figure 3.7: Optimal replenishment quantity calculation with a discount scheme.

3.5.4 Modeling Supply Chain Synchronization

In this section we use the EOQ theory to study cycle stock and handling consequences in a serial (= non-divergent) multi echelon supply chain. In a three-echelon system, these nodes could represent a single supplier, a single retailer and a single retail store. In the next section we will broaden the theory to divergent systems. For the time being all lead-times = 0. The supply chain root node (the supplier's stock-point) is replenished by a manufacturing plant, that has no finished goods inventory. The notation is given in Table 3.5.1. Figure 3.8 presents the modeling framework.

We model three situations:

- I Non-integrated Supply Chain** where each supply chain partner decides upon his own order size, so as to minimize his own costs.
- II Integrated Supply Chain** where each supply chain partner optimizes his order size so as to minimize the joint transaction costs with the supply node upstream
- III Synchronized Supply Chain** where the production batch size is calculated so as to minimize overall supply chain costs and where goods are being positioned downstream the supply chain directly after production

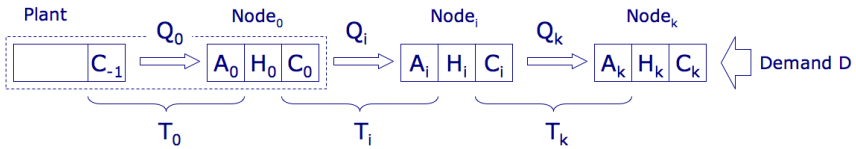


Figure 3.8: EOQ-modeling Framework

As indicated in the modeling framework, the indices count downstream from the rootnode with index 0, via intermediate nodes with some index i till the end node with index k .

We will refine the EOQ formula with both fixed and variable cost elements as follows.

1. fixed purchase costs A_i per order,
2. variable handling costs a_i per unit purchased,
3. holding costs $H_i = v_i r$ i.e. the unit value times a carrying charge
4. fixed delivery costs C_i per shipment and
5. variable costs c_i per unit shipped.

Furthermore T_i represents the fixed transaction costs, consisting of the sum of both the fixed purchase order costs A_i of the buying party and the fixed order fulfillment cost component C_{i-1} of the selling party. Similarly t_i represents the variable transaction costs, consisting of the sum of both the variable order costs a_i of the buying party and the variable order fulfillment costs c_{i-1} of the selling party. Thus:

$$T_i = A_i + C_{i-1} \text{ and } t_i = a_i + c_{i-1} \quad (3.10)$$

The dashed line in the modeling framework indicates that the supplying production plant and the root node, the supplier's warehouse, are modeled as integrated, because they belong to the same organization. This has been realized by considering the purchase order costs A_0 to include the production costs C_{-1} .

Situation I Non-integrated Supply Chain

In the non-integrated situation, each of the supply chain partners makes his own trade off and calculates independently his own optimal order size. This situation occurs when the upstream supplying party sells at a fixed, all inclusive price.

The total relevant costs that a buying party will take into consideration when calculating the optimal order size are the ordering and holding costs:

$$TRC_i^I = v_i D + \frac{v_i r Q_i^I}{2} \quad (3.11)$$

With index I referring to *Situation I*.

From this equation we cannot directly calculate the optimal order size, because the value v_i is a function of the order size Q_i . We assume the unit value v_i to be based on a fixed commercial purchase price v_{i-1}^p , that is not a direct function of the order size, plus the own purchase costs per unit, such that

$$v_i = v_{i-1}^p + a_i + \frac{A_i}{Q_i^I} = v_i^{If} + \frac{A_i}{Q_i^I} \quad (3.12)$$

with v_i^{If} representing the total fixed costs per unit purchased. The total inventory related costs of the buyer can now be calculated to be:

$$TC_i^I = v_i^{If} D + \frac{A_i D}{Q_i^I} + \frac{v_i^{If} r Q_i^I}{2} + \frac{A_i r}{2} \quad (3.13)$$

With the first two terms representing the purchasing and transaction costs and the second two terms the costs of financing. From this equation 3.13 we can now derive the optimal order quantities to be:

$$Q_i^{*I} = \sqrt{\frac{2A_i D}{v_i^{If} r}} \quad \text{with} \quad Q_0^{*I} = \sqrt{\frac{2A_0 D}{v_0 r}} \text{ the production batch size} \quad (3.14)$$

Limiting our scope to the transaction and inventory holding costs, ignoring $v_i^{If} D$ and $A_n r/2$ and inserting the value of Q_i^{*I} in equation (3.11) the total system costs within our scope can be calculated from:

$$TSC^I = \sum_{n=0}^k \left(\frac{A_n D}{Q_n^I} + \frac{v_n^{If} r Q_n^I}{2} + \frac{C_{n-1} D}{Q_n^I} \right) \quad (3.15)$$

or:

$$TSC^I = \sum_{n=0}^k \frac{1}{2} \left(\frac{T_n}{A_n} + 1 \right) \sqrt{2 A_n D v_n^{If} r} \quad (3.16)$$

The total average system inventory (cycle stock) will be:

$$I^I = \sum_{n=0}^k \frac{Q_n^I}{2} = \sum_{n=0}^k \sqrt{\frac{A_n D}{2 v_n^{If} r}} \quad (3.17)$$

In situation I the supplier's delivery costs C_{i-1} per shipment and c_{i-1} per unit are in an indirect way incorporated in the fixed purchase price v_i^p and thus in the product value v_i , based on some standard order size " $Q^?$ ".

Situation II Integrated Supply Chain

In the integrated situation each supply chain partner again calculates the optimal order size from the total relevant costs, which are all costs components influenced by Q_i^{II} . These are again the total purchasing and transaction costs with the upstream supplying party $i-1$ plus the inventory holding cost. But this time the buyer when determining Q^{*II} also takes into consideration the delivery costs of the supplier. This situation occurs e.g. when the supplying party sells at a base price (factory gate price) and on top of that charges the buying party for the logistics costs (= order fulfillment and delivery) C_{i-1} per shipment and c_{i-1} per unit. This situation also represents a VMI arrangement in which case not the buyer but the supplier will perform the order calculations.

The total relevant costs to a buying party to determine the order size from, for the integrated situation are again:

$$TRC_i^{II} = v_i D + \frac{v_i r Q_i^{II}}{2} \quad (3.18)$$

But this time the goods value v_i is different. In situation I the delivery costs of the supplier one way or another were included in some indirect way in the fixed unit purchase price v_{i-1}^p . In situation II all supply chain cost elements that are impacted by the order size Q_i^{II} are explicitly taken into consideration when calculating the order size.

In situation I client party i could not but base his order size calculation on the fixed sales price v_{i-1}^p that one way or another covers all costs of the supplying party i , including the variable transaction costs c_{i-1} and the amortization of any fixed transaction costs C_{i-1} over an unknown fixed " $Q^?$ ".

The base purchase price (factory gate price) is equal to the value at the preceding stage:

$$v_{i-1}^b = v_{i-1} \quad (3.19)$$

Under a service based pricing arrangement supplier $i - 1$ will charge client i this fixed base cost price v_{i-1}^b plus on top of that the actual variable logistics costs (= order fulfillment and delivery) C_i per shipment and c_{i-1} per unit . The purchase price then becomes

$$v_{i-1}^p = v_{i-1}^b + c_{i-1} + \frac{C_{i-1}}{Q_i^{II}} \quad (3.20)$$

The value of the goods v_i remains the basis for calculating the holding costs figure $v_i r$. The value of the goods v_i is:

$$v_i = v_{i-1} + c_{i-1} + a_i + \frac{C_{i-1}}{Q_i^{II}} + \frac{A_i}{Q_i^{II}} = v_{i-1}^b + t_i + \frac{T_i}{Q_i^{II}} = v_i^b \quad (3.21)$$

Buying party i considers the base price offered by the supplying party $i - 1$ as fixed, because this price is not influenced by his ordering decision Q_i . When we split the value v_i as given in equation 3.21 in a fixed part $v_i^{II^f}$ that is independent of the order size and a part that is dependent on the order size, we get:

$$v_i = v_i^{II^f} + \frac{T_i}{Q_i^{II}} \quad (3.22)$$

Feeding this into the relevant cost equation 3.18 tells the total inventory related costs of the buyer to be:

$$TC_i^{II} = v_i^{II^f} D + \frac{T_i D}{Q_i^{II}} + \frac{v_i^{II^f} r Q_i^{II}}{2} + \frac{T_i r}{2} \quad (3.23)$$

With the first two terms representing the purchasing and transaction costs and the second two terms the financing. From this equation 3.23 we can now derive the optimal order quantities to be:

$$Q_i^{*II} = \sqrt{\frac{2T_i D}{v_i^{II^f} r}} \quad \text{with} \quad Q_0^{*II} = \sqrt{\frac{2A_0 D}{v_0 r}} \quad \text{the production batch size} \quad (3.24)$$

These values for Q^{*II} have been derived using the fixed cost component $v_i^{II^f}$. The holding costs however remain $v_i r$.

Limiting our scope now to the transaction and inventory holding costs and ignoring $v_i^{II^f} D$ and $T_i r/2$ and inserting Q_i^{*II} yields as total system cost

$$TSC^{II} = \sum_{n=0}^k \sqrt{2T_n D v_n^{II^f} r} \quad (3.25)$$

The total system inventory for the integrated situation (cycle stock) then becomes:

$$I^{II} = \sum_{n=0}^k \frac{Q_n^{II}}{2} = \sum_{n=0}^k \sqrt{\frac{T_n D}{2v_n^{II^f} r}} \quad (3.26)$$

Like we did in Section 2.6 we might call $t_i + \frac{T_i}{Q_i}$ the added value h_i . Then:

$$v_i = v_{i-1} + h_i = \sum_{n=0}^i h_n \quad (3.27)$$

Situation III Synchronized Supply Chain

In the synchronized situation goods are being distributed downstream, as soon as they become available. The end node k is the only node keeping inventory. The manufacturing plant will calculate the optimal production batch size Q_s^* so as to minimize the overall system costs.

The total system costs of a synchronized supply chain are:

$$TSC^{III} = \sum_{n=0}^k \frac{T_n D}{Q_s^{III}} + \frac{v_k r Q_s^{III}}{2} \quad (3.28)$$

from which the optimal production batch size Q_s can be calculated, to be:

$$Q_s^{*III} = \sqrt{\frac{2(\sum_{n=0}^k T_n)D}{v_k r}} \quad (3.29)$$

Inserting Q_s in equation (3.28) results in the formula for the total system cost:

$$TSC^{III} = \sqrt{2(\sum_{n=0}^k T_n)D v_k r} \quad (3.30)$$

And finally average total system inventory (cycle stock) will be:

$$I^{III} = \frac{Q_s^{III}}{2} = \sqrt{\frac{(\sum_{n=0}^k T_n)D}{2v_k r}} \quad (3.31)$$

In a supply chain with network wide holding costs that do not differ very much from one stage to the other, the production batch size in equation 3.29 is larger than the production batch or any of the transfer batches Q_i in either the non-integrated or the integrated situation. If for instance we assume both the transaction costs and the holding costs to be equal between the stages or $T_i \approx T$ and $v_i \approx v$, then equation 3.29 becomes:

$$Q_s^{*III} = \sqrt{\frac{2kTD}{vr}} \quad (3.32)$$

However, in a supply chain where holding costs represent added value, again assuming the transaction costs and holding costs to be fairly equal between the various stages, Equation (3.29) now becomes

$$Q_s^{*III} = \sqrt{\frac{2kTD}{kH}} = \sqrt{\frac{2TD}{vr}} \quad (3.33)$$

Which is equal to the order size in the integrated supply chain

Table 3.1: Overview of results

<i>Situation</i>	<i>Production batch</i>	<i>Order size</i>	<i>System inventory</i>	<i>System costs</i>
<i>I Non</i>	$\sqrt{\frac{2A_0D}{v_0r}}$	$\sqrt{\frac{2A_iD}{v_i^{If}r}}$	$\sum_{n=0}^k \sqrt{\frac{A_nD}{2v_n^{If}r}}$	$\sum_{n=0}^k \frac{1}{2} \left(\frac{T_n}{A_n} + 1 \right) \sqrt{2A_nDv_n^{If}r}$
<i>II Int</i>	$\sqrt{\frac{2A_0D}{v_0r}}$	$\sqrt{\frac{2T_iD}{v_i^{II}r}}$	$\sum_{n=0}^k \sqrt{\frac{T_nD}{2v_n^{II}r}}$	$\sum_{n=0}^k \sqrt{2T_nDv_n^{II}r}$
<i>III Sync</i>	$\sqrt{\frac{2(\sum_{n=0}^k T_n)D}{v_kr}}$	$\sqrt{\frac{2(\sum_{n=0}^k T_n)D}{v_kr}}$	$\sqrt{\frac{(\sum_{n=0}^k T_n)D}{2v_kr}}$	$\sqrt{2(\sum_{n=0}^k T_n)Dv_kr}$

Comparison

We will now compare the three situations. For ease of comparison, the results are summarized in Table 3.1.

To be able to compare the various outcomes we need a reference point to relate v_i^{If} to v_i^{II} . As reference point we take the goods value v_{i-1} used for valuing the inventory at the supplier. From this reference value the supplier either calculates a fixed sales price v_{i-1}^p or he takes this reference value as base price v_{i-1}^b .

$$v_{i-1}^I = v_{i-1}^{II} = v_{i-1} \quad (3.34)$$

We now assume that the supplier in situation I calculates the fixed purchase price using a fixed order quantity $Q^?$. We then get:

$$v_i^{If} = v_{i-1}^p + a_i \quad (3.35)$$

Which results in:

$$v_i^{If} = v_{i-1} + c_{i-1} + \frac{C_i - 1}{Q^?} + a_i \quad \text{and} \quad v_i^{II} = v_{i-1} + c_{i-1} + a_i \quad (3.36)$$

It then follows that

$$v_i^{If} = v_i^{II} + \frac{C_{i-1}}{Q^?} \quad \text{and} \quad v_i^{If} \geq v_i^{II} \quad (3.37)$$

Production batch

The production batch sizes in the non-integrated situation and in the integrated situation are identical. The calculations both are based on the production transaction costs internal to the supplier's production plant and his warehouse.

The production batch Q_0 in the synchronized situation is calculated against the total system transaction costs and the inventory holding costs $v_k r$ at the most downstream node k . If holding costs are considered to be systemwide and the holding costs $v_0 r$ in the supplier's warehouse is comparable with the holding costs $v_k r$ at the most downstream node, the production batch size will be larger than in the non-integrated and in the integrated situation, or:

$$Q_0^{III} > Q_0^{II} = Q_0^I \quad \text{s.t. } v_i r \approx v_k r \text{ and } T_i > 0 \quad \forall i \quad (3.38)$$

Dividing the production batch size in the synchronized situation by the one in the other situations gives the factor $K_0^{P^{III-I}}$ by which the production batch size is larger:

$$\text{Production batch enlargement factor } K_0^{P^{III-I}} = \sqrt{\left(1 + \frac{\sum_{n=1}^k T_n}{T_0}\right) \frac{v_0}{v_k}} \quad (3.39)$$

If the production transaction costs are much higher than the total supply chain transaction costs, or: $T_0 \gg \sum_{n=1}^k T_n$, then the production batch size remains more or less the same.

Order size

With both $T_i \geq A_i$ and $v_n^{If} \geq v_n^{IIIf}$ the numerator in the EOQ formula going up and the denominator going down, it follows that surely $Q_i^{*II} \geq Q_i^{*I}$

Dividing Q_i^{*II} by Q_i^{*I} results in the factor $K_i^{O^{II-I}}$, by which the order sizes in the integrated situation are larger than in the non-integrated situation. The result is:

$$K_i^{O^{II-I}} = \frac{Q_i^{*II}}{Q_i^{*I}} = \sqrt{\frac{T_i}{A_i}} \sqrt{\frac{v_i^{If}}{v_i^{IIIf}}} = \sqrt{\frac{Ci-1}{A_i}} + 1 \sqrt{\frac{v_i^{If}}{v_i^{IIIf}}} \quad (3.40)$$

For $v_n^{If} = v_n^{IIIf}$ this result is in line with the findings by Monahan, who further derives that the buyer will be willing to increase his order size by this factor K_i if he gets a discount d_{K_i} of at least:

$$d_{K_i} \geq \sqrt{2A_i D v_i r} \frac{(K_i^{O^{II-I}} - 1)^2}{2K_i^{O^{II-I}}} \quad (3.41)$$

See (Monahan, 1984).

So it can be concluded that integration will increase the shipment sizes by a factor K , as specified in equation 3.40.

The order size, or better the transfer batch size, in the synchronized supply chain is equal to the production batch size. Dividing this production batch size by the production batch size in the integrated situation, results in the following order size enlargement factor:

$$K_i^{O^{III-II}} = \sqrt{\frac{\sum_{n=0}^k T_n}{T_n} \cdot \frac{v_n}{v_k}} \quad (3.42)$$

Thus:

$$Q_i^{III} > Q_i^{II} > Q_i^I \quad \text{s.t. } v_i \approx v_k \text{ and } T_i > 0 \quad \forall i \quad (3.43)$$

System inventory (cycle stock)

Integration not only for every node increases the optimal order size, but as a direct consequence also the average inventory (cycle stock), that in each node on average will be equal to half the order size. Consequently the inventory enlargement factor K_i^{III-II} is the same as the ordered size enlargement factor $K_i^{O^{II-I}}$ specified in equation (3.40).

The average inventory in a synchronized supply chain is different. Only the end node k is keeping inventory and the amount equals half the production batch size. Dividing the inventory level in a synchronized supply chain by the inventory in an integrated supply chain and assuming that the holding costs in all nodes are fairly equal, yields a factor $K_s^{III-II} < 1$. This means that the total cycle stock in a synchronized supply chain is smaller than the inventory in an integrated supply chain.

$$K_i^{III-II} = \frac{\sqrt{\sum_{n=0}^k T_n}}{\sum_{n=0}^k \sqrt{T_n}} < 1 \quad \text{s.t. } v_n \approx v_k \text{ and } T_n > 0 \quad \forall i \quad (3.44)$$

In other words:

$$I^{III} < I^{II} \quad \text{but} \quad I^{II} > I^I \quad (3.45)$$

If again we assume the production transaction costs to be much higher than the total transaction costs at the lower echelons, or: $T_0 \gg \sum_{i=1}^k T_i$, then the production batch size remains more or less the same. The manufacturer then sticks to the original production batch size. In that case

$$K_i^{III-II} = \frac{\sqrt{T_0}}{\sqrt{T_0} + \sum_{n=1}^k A_n} < 1 \quad \text{s.t. } v_i r \approx v_k r \text{ and } T_0 \gg \sum_{n=1}^k T_n \quad (3.46)$$

Or:

$$I^{III} < I^I \quad \text{and together: } I^{III} < I^I < I^{II} \text{ (cycle stock)} \quad (3.47)$$

As part of this research we simulated the stock levels in the current and in the synchronized supply chain with the data from 8 manufacturers and 2 retailers. These stock levels were total stock levels, cycle stock plus safety stock. We found that in all situations the total stock levels in the synchronized supply chain were lower than before. And in many cases the total supply chain stock even dropped below stock levels currently kept at the manufacturer alone. See also Appendix A.

System costs

The last analysis is the overall cost analysis. One can read, from Table 3.1, that in the non-integrated situation the overall costs in every node differ from the integrated situation, by a factor

$$K_i^{C^{I-II}} = \sum_{n=0}^k \frac{1}{2} \left(\frac{T_n}{A_n} + 1 \right) \sqrt{\frac{A_n}{T_n}} \sqrt{\frac{v^{If}}{v^{II^f}}} = \sum_{n=0}^k \frac{1}{2} \left(\sqrt{\frac{T_n}{A_n}} + \sqrt{\frac{A_n}{T_n}} \right) \sqrt{\frac{v^{If}}{v^{II^f}}} \quad (3.48)$$

Since:

$$\left(\sqrt{\frac{T_n}{A_n}} + \sqrt{\frac{A_n}{T_n}} \right) \geq 2 \quad \text{and} \quad v^{If} \geq v^{II} \quad (3.49)$$

it follows that

$$K_i^{C^I-II} \geq 1 \quad \text{or} \quad C^I \geq C^{II} \quad (3.50)$$

So, the costs in the non integrated situation I are higher than those in the integrate situation II

Assuming again the holding costs $v_i r$ to be fairly constant across the supply chain, the total costs in a synchronized supply chain will be lower than those in an integrated supply chain by a factor $K^{C^{III-II}}$ equal to the factor for inventory in equation (3.46).

Table 3.2: Overview of trends relative to reference situation I Non-integrated Supply Chain

Situation	I Non-integrated	II Integrated	III Synchronized
Production batch	□	=	↑
Order size	□	↑	↑↑
System inventory	□	↑	↓
System costs	□	↓	↓↓

Wrap up

The findings have been summarized in Table 3.2 relative to situation I Non-integrated as reference situation, which is indicated with the symbols □.

3.6 The multi-buyer modeling framework

The modeling framework from the former section can be extended into a multi-echelon divergent single supplier - multiple buyers framework. This modeling framework is shown in Figure 3.9.

As can be seen in this figure, the distribution cost component C has been split up in sub-components C_{ij} in accordance with the number of buyers per supplier in the divergent distribution network, with index i indicating the echelon number and index j the j -th buyer. Each of these cost components represents that part of the distribution costs that is attributable to the respective buyer and in the same way as in the former paragraphs describing the one-supplier-one-buyer situation, the cost component C_{ij} of the supplier at echelon i together with the order costs $A_{(i+1)j}$ of the j th buyer at echelon $i + 1$ form the transaction costs $T_{(i+1)j}$.

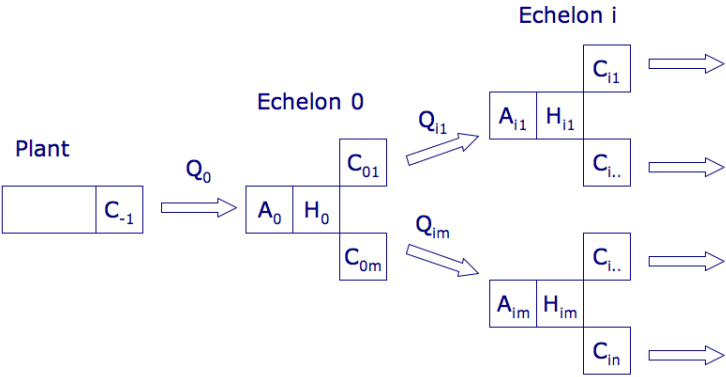


Figure 3.9: Multi-buyer EOQ-modeling framework

3.7 Analysis

Based on the contents of this chapter the following observations can be made:

Observation 14

Most handling goes into breaking bulk

On their way from production to consumer, goods are packed in units that along the supply chain decrease in size. Over and over again larger units are broken down into smaller units. This process of breaking down larger units and reassemble them into other units, the spread over the various locations, the storage at every stage, plus the fact that it is an order driven process that is constrained in time, is the dominant cost element in retail distribution.

Observation 15

Moving cheaply means moving large quantities

From an integral supply chain perspective moving goods from one point in the supply chain to the next point in the supply chain should be done in as few shipments as possible and in full truckloads with full pallets.

Observation 16

Synchronization increases the production batch size

In a synchronized supply chain, the size of the production batch is a trade-off between the overall transaction costs and the holding cost at the downstream node k where the inventory will be positioned. If the product value P_i and the inventory holding costs $v_i r$ are fairly constant across the supply chain, The optimal production batch is larger than currently.

Observation 17

Synchronization reduces overall inventory

In the (extreme) situation of currently one delivery per production interval, synchronizing the supply chain will reduce the overall cycle stock in the supply chain by 50%, whilst the number of transactions remains the same.

Observation 18

Synchronization shifts inventory down stream

In the(extreme) situation of currently many deliveries per production interval, synchronizing the supply chain will leave the overall cycle stock in the supply chain intact, but will shift it from manufacturer to retailer.

Observation 19

Synchronization does not require to ship all at once

Synchronization does not require to ship everything at once, as long as goods are being shipped synchronous to them becoming available and as is needed to assure efficient handling and transport and sufficient coverage of clients' needs. A good strategy might be to ship twice per production interval. See section 2.4.6

Observation 20

Synchronization reduces the transaction volume and handling But more importantly, in the (extreme) situation of currently many deliveries per production interval, synchronizing the supply chain will reduce the number of transactions, so goods can be more easily consolidated into full pallets and into full truckloads.

Observation 21

Synchronization takes away the time pressure

The time pressure inherent with frequent reordering in small quantities, disappears with synchronization, because goods are shipped as soon as they become available prior to urgent need.

'Do not wait till you have to, but ship when you can'

Observation 22

Manage synchronization centrally or de-centrally

Synchronization can be achieved both by centralized planning and by de-centralized planning. Centralized planning requires the willingness to cooperate, or the power to enforce cooperation. De-centralized planning might use a price discount to entice cooperation.

Observation 23

Decentralized planning allows 'Forward Buying'

Decentralized planning is easier to implement, with less IT-interaction. It does not block the possibilities for forward buying. It even facilitates forward buying without special price offer, by exploiting the suppliers service based pricing scheme.

Observation 24

Fixed prices give higher re-ordering frequencies

As long as suppliers include the cost of distribution in their product price, retailers will order frequently and in small quantities. As a result the total supply chain costs are significantly higher than would have been necessary.

Observation 25

Alternative is service based pricing or VMI

Those who try to overcome this problem, either follow the service based pricing discount approach or go the vendor managed inventory route.

These observations lead to the following design elements:

Design choice 7

Synchronize

Synchronizing distribution to productions leads to larger shipment volumes per product. This reduces the most important cost elements, those of order picking and distribution.

Based on observations 14 - 20

Design choice 8

Level the workload over the day and over the week

Synchronization means that goods can be shipped as soon as they become available, prior to urgent needs. This means that the workload can be leveled and there is time to stage inventory for consolidation purposes.

Based on observation 21

Design choice 9

Choose centralized management with large retailers

Centralized management, as described in Table 7.1, is harder to implement than decentralized management. It fits better with large retailers with the power to shift the supply chain management burden and its responsibilities to the suppliers. These responsibilities might go as far as shelf availability and turn over per shelf meter.

Based on observation 22

Design choice 10

Choose decentralized management with small retailers

Decentralized management, as described in Table 7.1, is easier to implement than centralized management. It leaves freedom to the retailer. It fits better with the current practice of smaller retailers. They feel that they need forward buying, because they lack the power to get a lower price otherwise.

Based on observations 22 and 23

Design choice 11

With centralized control, go VMI

Centralized control automatically implies vendor managed inventory. the supplier might or might not own the inventory at the retailer. The supplier is responsible for product availability in the retailer's distribution centers.

Based on observation 25

Design choice 12

With decentralized control, go service based pricing

Fixed all inclusive sales prices lead to frequently ordering in small quantities. With decentralized control a good service based pricing scheme will entice the retailer to a correct ordering behavior, including synchronization.

Based on observations 24 and 25

Chapter 4

Network structure

4.1 Introduction

The design of the distribution network is of crucial importance to a retailer. A good and appropriately designed distribution network, with a well aligned supply chain control structure, is a prerequisite for offering adequate logistic services to the retail outlets. The number and size of the network facilities, however, is a major cost driver and should therefore be selected carefully. Traditionally the question of distribution network design was primarily seen as finding suitable locations for the stock keeping distribution centers. This so-called facility location problem has received considerable attention in operations research literature. See e.g. (Bramel and Simchi-Levi, 1997). The design question was, subject to several constraints, to find the distribution network with the overall lowest costs. The literature describes several algorithms, heuristics and simulation approaches to solve the facility location problem. It is outside our scope to discuss these approaches here. Tompkins et al. recognize three roles for a warehouse: (1) holding inventory to balance and buffer between supply and demand, (2) consolidating products from various sources and (3) by distributing the warehouses in the field shortening the lead-time to the client. (Tompkins et al., 1996) Today it is being recognized, that a distribution network might not only consist of stock keeping distribution centers that are serving retailers, but that facilities might also be organized as shipment consolidation points, cross docking centers or pick-to-zero platforms. In other words the network-design problem is broader than finding the locations for the facilities and comprises also of determining the function of the various facilities and the design of the supply chain control structure to manage the flow of goods in an efficient manner. There exists literature on each of the elements of a distribution network, only few articles deal with distribution networks comprising of different elements in an integrated fashion (Gümüs and Bookbinder, 2004). The network design may be seen as a multiphase problem. The number and location of distribution centers and cross-dock platforms and the logistics control structure are strategic decisions. The allocation of the demand to the network facilities, determining stock levels, transport consolidation volumes and production scheduling can be seen as tactical decisions (Smits, 2003). Managing the actual flow of goods through the network then is an operational decision (Fleischmann, 2000), (Jayaraman and Ross, 2003).

When it comes to the number of stock keeping distribution centers within a retail distribution network, a first constraint is the order lead-time to the stores. The question then is to find the minimum number of distribution centers able to serve the area of concern. Operating less distribution centers saves the cost of inventory and facilities. Safety stock reduces in the order of the square root of the number of distribution centers that have been combined. (A rule described by Gary Eppen) In case of normally and independently, identically distributed demand, total safety stock costs for N warehouses are proportional to $k\sigma N$; when these N warehouses are combined into one warehouse, the total costs for the safety stock in this one central warehouse are proportional to $k\sigma\sqrt{N}$ ¹ (Eppen, 1979). A second constraint is the maximum capacity of a warehouse, mainly determined by the order picking process. Above a certain volume the efficiency drops and it might become necessary to split up the warehouse. The alternative would be to increase the efficiency of the order picking process and save on costly warehouses.

The essence of Supply Chain Synchronization is the alignment of distribution and production schedules. When in this chapter we talk about network design, we are not so much interested in actual facility locations, but more in the basic supply chain structure and its tactical management, starting from the production schedule.

In section 4.3 we describe the various network structures that exist in a world without Supply Chain Synchronization. Then section 4.4 discusses the effects of synchronization on the network structure. Subsequently section 4.5 deals with the possibilities for consolidation in a synchronized supply chain. After that section 4.6 deals with the network structures that might exist in a world with Supply Chain Synchronization. But prior to all that, in the next section we pay attention to the fact that changes in a retailer's distribution structure not only have internal consequences for the retail organization itself, but almost always also have "external" consequences as well.

4.2 The internal and the external trade off

Prior to a change in his distribution structure, a retailer will make a trade-off in terms of costs, space requirements, lead times etc. Frequently such a trade-off only considers arguments that are internal to the retail organization. Therefore one could call this an *internal* trade-off. But fast every change in the retail distribution structure does have consequences outside the retail organization itself, in the supply chain as a whole. These consequences should be taken into account as well. The retailer should also make an *external* trade-off.

Take as an example the decision to close one of three regional retail distribution centers (RDC's). The suppliers instead of delivering at three distribution centers, from now on will have to deliver at two distribution centers. So instead of three there will now be only two delivery points (reducing the supplier's costs of transportation) and order volumes per product will increase (reducing the supplier's costs of handling). The savings that this change from 3 to 2 distribution centers will bring the suppliers, can be easily calculated using standard figures like the ones in Appendix A. As a result of these changes the retailer should be able to negotiate better prices from suppliers. These price reductions should be part of the trade-off.

¹See also the discussion on inventory management from a service level perspective in Chapter 2

Another example might be the decision whether an article should be stored in a central slow mover distribution center or in each of the regional distribution centers. Moving an article from a regional distribution center to the central distribution center saves on inventory costs and on storage space. If an article is located in each of N regional distribution centers, the overall cycle stock (at each location on average half the order size) will be N times larger and the overall safety stock will be \sqrt{N} larger.

For perishable goods that are subject to deterioration (fresh, chilled), not so much the costs of inventory, as well the costs of marking down goods that have passed the “best-before” or “use-by” date are the discriminating factor. As a rule of thumb retailers often allow 1/3 of the time till the best before date to be consumed in their distribution centers. The time that goods sit in a distribution center can be calculated by dividing the average inventory (cycle stock + safety stock) by the average consumption. Goods that pass the 1/3 of the time rule of thumb if stored at the regional distribution centers should move to the central distribution center.

An article in the central distribution center needs only one bulk pallet storage location and only one pick location, vs N bulk storage and N pick locations if located in each of the N fast mover distribution centers. If an article’s pick location is moved from the regional distribution centers to the central distribution center, the overall driving time inside the N regional distribution centers decreases and the distribution center efficiency in terms of the pick time/drive time ratio for the N regional distribution centers improves. Conversely the ratio for the central distribution center gets worse. Furthermore there are extra costs associated with transporting the goods from the central distribution center to the N regional distribution centers. In order to preserve category grouping, some retailers make the location trade-off not at the level of the individual article, but at category level. For example: all chocolate is stored in and delivered from the central distribution center.

But the decision to move an article from a fast mover retail distribution center to the central slow mover distribution center has external consequences. For a manufacturer it is much cheaper to deliver a full pallet than a broken pallet. if for a certain article the consumption in the area served by a regional distribution center within the production period (or within 1/3 of the best before time with a perishable article), is less than a pallet, shifting that article to the central distribution center might facilitate delivery in full pallets. if shifting such an article from a regional distribution center to the central distribution center means a shift from delivery in broken pallets to delivery in full pallets, the retailer needs to negotiate the cost difference from the supplier. Not only for the supplier, but also for the retailer receiving full pallets is cheaper, whereas the costs of goods reception and of bulk storage both shrink.

Almost every change internally within the retail distribution network has external consequences as well. The retailer should not base his decisions on an *internal* trade-off only considering consequences within the retail distribution network itself, but should base his decisions on an *external* trade-off. And the retailer should not forget to negotiate and to cash upon the savings at the suppliers.

4.3 Without Supply Chain Synchronization

Figure 4.1 shows the four supply chain structures that are being used in retail today with their characteristics listed on the right side of the picture. See e.g. (Whiteoak, 1999) and (Thönemann et al., 2005). The first thing to be noted regarding these current structures is, that they all start at the manufacturer's warehouse. They are supply chain variants invented by retailers, with stringent delivery requirements posed upon the supplying manufacturers. The manufacturers are forced to keep stock and are requested to deliver within strict time lines. The manufacturing plants (also called sourcing units SU's) for that reason ship their production (in full truckload of course) to their regionally operating warehouses. The retail clients are being served from these warehouse inventories.

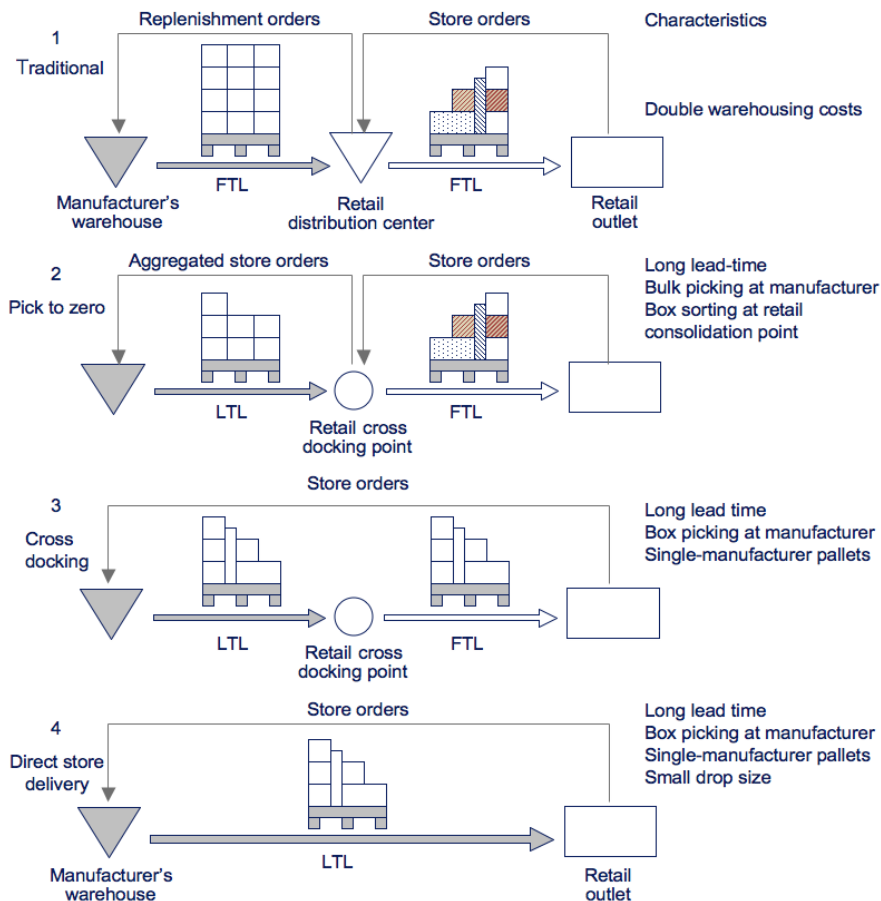


Figure 4.1: The current 4 retail supply chain variants

Structure 1, Traditional

Structure 1, the Traditional one, is the structure that most retailers operate. Here both manufacturer and retailer are keeping stock at their distribution centers. The structure is most advantageous for the stores, with nearby inventory at the retail distribution centers. The stores experience a short lead time, get the goods assembled by category and get them delivered with reasonable drop sizes, because the retail distribution center consolidates the goods from all manufacturers into the same shipment. All these advantages however go at the price of inventory and running storage operations at both retailer and manufacturers. Structure 1 in Figure 4.1, the Traditional structure, suggests that the retail distribution centers receive replenishment in full pallets. In real-life however the situation often is worse and retailers reorder replenishments in much smaller quantities, because manufacturers failed to create adequate financial incentives to seduce retailers to order full pallets only.

Structure 2, Pick-to-zero

In Structure 2, Pick-to-zero, the retailer has done away with inventory at his distribution centers and operates a cross docking process at box level instead; the retailer assembles on store order the store ready pallets from the incoming goods. The manufacturers deliver the goods in such bulk quantities as are specified in the aggregated store orders. The lead times to the stores are longer than in structure 1, because the manufacturers need to collect the aggregate store orders and deliver these at the retail distribution centers, all within the store order cycle. Only when the goods from all participating suppliers have arrived at the retailers cross docking point, the pick-to-zero process can start. When the shops are allowed to order everything every day, the pick-to-zero process actually becomes a full-fledged order picking process. Pick to zero -by the way- has the peculiar effect of doubling picking errors.

Structure 3, Cross docking

In Structure 3, Cross docking, the retailer not only has done away with inventory, but also with order picking at the cross docking points. Instead of that he now operates a simple cross docking platform where pallets from different manufacturers are being consolidated into the same truck to replenish the stores. This structure offers slightly better lead-times to the shops than structure 2 with pick-to-zero, because cross-docking at pallet level is an easy process. The manufacturers now need to operate a full box picking process and the store receives separate pallets per manufacturer, which makes it harder to stock the shelves. Due to the fact that pallets from different manufacturers are being consolidated into the same truck, trucks can run reasonably well loaded to the stores. This is the structure advocated by Wal-Mart (Stalk et al., 1992). The costly inventory and order picking operation is shifted upstream the supply chain towards the manufacturers and Wal-Mart operates a relatively simple and straightforward pallet cross docking process.

Structure 4, Direct store delivery

In Structure 4, Direct store delivery, the stores order directly from the manufacturer's warehouse; the manufacturer picks the store orders and delivers the goods straight to the

store. This structure has some clear disadvantages. There is a long lead-time with those manufacturers that have remotely located warehouses. As in structure 3, the manufacturers should be able to operate a box picking process at their warehouses, where individual boxes can be picked and assembled onto store ready pallets. Also in this structure stores receive pallets originating from a single manufacturer, which pallets thus might contain articles from various categories. The major drawback of this structure however - unless the stores are very large - is that drop sizes from a single manufacturer are small (less than truckload LTL), resulting in many trucks visiting the store. A typical retailer has virtually hundreds of suppliers; it is physically impossible that all these many manufacturers separately send a truck to deliver directly to the stores. Letting the manufacturers replenish the stores less frequently will increase the drop sizes and reduce the number of trucks, but that would require the re-introduction of a back-room storage at the shop.

4.4 The effects of synchronization

As indicated already in previous chapters, synchronizing the supply chain can save substantially on the costs of both handling and inventory, by synchronizing deliveries to the moments products become available from production. As a result goods will be moved in larger quantities, upstream inventories will disappear, downstream inventories will increase and overall inventory will go down. Synchronizing the supply chain however can also reduce the costs of transport as will be shown now. Consider as a starting point the first structure in Figure 4.1, the traditional one, with a retailer operating stock keeping distribution centers, as is most often the case in practice today. Without changing the transport and distribution structure, with Supply Chain Synchronization there will certainly not run more trucks than before. The total number of trucks (if full) depends only on the total consumption. But with Supply Chain Synchronization the trucks will contain different goods. Where a full truckload from a supplier currently is loaded as specified by the order from a regional retail distribution center RDC and might contain e.g. 50 order lines, with Supply Chain Synchronization this truck will contain those products that have been produced today and it might contain only 1 or 2 order lines.

The first and most obvious positive effect of Supply Chain Synchronization is consolidation into full pallets and into full truckloads. Under the current regime, where retailers send their replenishment orders at the latest possible moment, they will have great difficulty to amend these orders in such a way that they result in full pallets and in full truckloads. Take for example a retail order currently resulting in a shipment of 28 pallets, some of them homogeneous full pallets with one and the same product; others mixed pallets, resulting from a case pick process. When a full truckload is 26 pallets, the manufacturer will then be forced to run a separate truck to transport the 2 pallets that are left over, because the whole shipment was ordered with the same urgency. With Supply Chain Synchronization that is completely different. Let us assume that directly after production of a product, a batch of 28 pallets, all homogenous pallets containing the same product, is ready for shipment from a manufacturer to one of the warehouses of a retailer. When a full truck brings the first 26 pallets, that truckload will cover the needs of that warehouse for quite some time. It is no problem whatsoever to let the 2 pallets that are left over wait for consolidation into a full truckload the following day or so. So Supply Chain Synchronization is a powerful tool to run full truckload throughout. In most practical cases this alone will already lead to savings of several percent on the transportation budget.

But much greater savings can be achieved by adapting the structure of the transport and distribution network. Supply Chain Synchronization leads to larger volumes per product per shipment and leads to more inventory positioned downstream at the retailer, with less time pressure. This alone might be a reason to seriously reconsider and possibly redesign the overall supply chain distribution structure. An implicit reason for reconsidering the current supply chain distribution structure is the extra space required to store the larger volume per product at the retailer. A retailer currently in most of his distribution centers will not have the space available to stock this excess inventory and even in the long run might not be able to extend all of his facilities.

Manufacturers concentrate production into product-focused plants. They do so to be able to run larger batches and produce more efficiently. These plants replenish regionally positioned warehouses that supply the distribution centers of retailers in that region. Manufacturers may not keep finished goods stock at the production location itself, although, the more they concentrate production in product focused plants, the more they tend to keep a little staging inventory in order to more easily consolidate into full truckloads to their own regional warehouses.

In the following paragraphs the 4 basic structures that were shown in the beginning of this chapter in Figure 4.1, will be extended with 3 new variants, that become realistic when the supply chain is being synchronized. These new variants will be discussed and for a better comparison of the variants, a rough cost comparison will be made. In Appendix C the cost calculation will be explained in more detail. The costs are calculated from leaving the factory gate till entering the retailer's warehouse. Driving distance is included in the cost calculations, but appears to be not the discriminating factor between the various structures; the distance affects all structure variants in more or less the same way. Storage costs are not included; from a supply chain perspective storage costs are determined by the total inventory in the supply chain and not so much by the location where the inventory might be actually stored. The equations in the Appendix include a scale factor, to adapt the outcomes to a larger geographical area or to increased kilometer-prices.

Far more important discriminators between the various structures are the number of intermediate warehouses between manufacturing plant and retail distribution centers and whether or not trucks run full load and whether they can unload at one destination or have to unload in multiple drops. Therefore we will first develop a consolidation model, to further analyze transport consolidation.

4.5 Consolidation

4.5.1 Introduction

A well-known way to lower the costs of transportation is the introduction of consolidation terminals and direct shipments. The former to get improved loading of the transport equipment and the latter to obtain shorter routes. The use of consolidation in distribution has been discussed at length in literature. Most of the authors treat consolidation strictly from a transport optimization perspective. In that perspective, consolidation via a consolidation terminal offers the possibility to consolidate parts from different origins into one truckload to a destination. And the inventory costs taken into consideration are the costs of staging

inventory, waiting to be consolidated. Here we address the use of consolidation and direct shipments in supply chains where distribution is synchronized to production. To that end we take an integrated view on supply chain management, comprising decisions on production, inventory, handling and transportation. Early contributions on consolidation are those of (Blumenfeld et al., 1985), (Hall, 1987) and (Daganzo, 1996). Blumenfeld et al. discuss synchronizing production to distribution, but they do so at the "micro level" of synchronizing production batches to the departure of individual trucks, again with the purpose of limiting the costs of staging inventory (Blumenfeld et al., 1985). Similarly Bookbinder and Higginson, when developing probabilistic models for freight consolidation, only take into account staging inventory that is waiting to be consolidated (Bookbinder and Higginson, 2002).

Managing inventory levels in the supply chain, with shipment schedules synchronized to production, might mean that distribution will be managed by the suppliers. This principle, known as Vendor-Managed Inventory (VMI) has already been described in Chapter 3. An interesting article regarding stock replenishment and shipment scheduling for Vendor-Managed Inventory Systems is the one from Çetinkaya and Lee complemented with a more concise mathematical model by Axsäter (Çetinkaya and Lee, 2000)(Axsäter, 2001). Also Disney et al. address the impact of vendor managed inventory on transport operations. They conclude that considerable transport costs can be escaped with VMI as trucks will be running fuller and less frequently (Disney et al., 2003). Savings through running trucks fuller and less frequently might to a certain extend also be achieved when not the vendor, but the retailer manages the transport, as is shown in a recent analysis of the opportunities for Factory Gate Pricing (FGP) in Dutch Retail Distribution (le Blanc et al., 2005). Speranza and Ukovich describe algorithms for the consolidation of products on a single link into full truckloads. When all trucks run full truckload, one cannot save on the transportation budget, but one still can save on the inventory costs by smartly selecting shipment schedules such that expensive products get less consolidation time (Speranza and Ukovich, 1994). Fumero and Vercellis present a multi period multi product LP optimization model for the integrated development of production and distribution schedules in a single-supplier - multiple-retailer setting. (Fumero and Vercellis, 1999). They describe two model-variants: (1) a coordinated approach where transportation decisions may lead to changes in the production schedule and (2) a decoupled approach where transportation planning is not allowed to modify the production plan. They conclude that the integrated approach behaves slightly better. It would be interesting to modify and run their model to cover Supply Chain Synchronization and compare the results. With respect to the use of consolidation in synchronized supply chains, we also refer to (Van der Vlist and Broekmeulen, 2006). A fairly broad overview of the field of distribution and transport planning can be found in (Fleischmann, 2000).

4.5.2 A transport consolidation model

Figure 4.2 shows a retail consolidation network that is limited to that part of the supply chain that runs from the sourcing units (SU) of a manufacturer to the distribution centers of a retail chain. We consider two types of consolidation centers: a Manufacturing Consolidation Center (MCC) and a Retail Consolidation Center (RCC). In our analysis we assume that these consolidation centers are stockless cross docking terminals. In our model an MCC is dedicated to a manufacturer and an RCC to a retail chain. The MCC might receive goods from several manufacturing plants or sourcing units (SUs); the RCC might re-

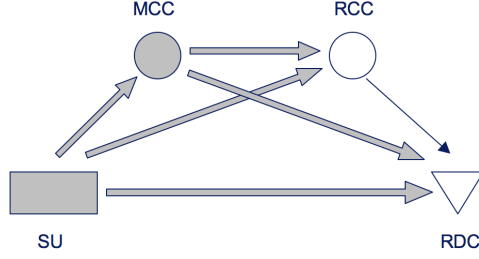


Figure 4.2: Retail consolidation network

ceive goods from several suppliers. The MCC might be at the location of the manufacturer's regional warehouse or might be co-located with one of the sourcing units; the RCC might be co-located with one of the retail distribution centers. The introduction of direct links in the network that skip hubs allows for possible savings in transportation and handling costs.

In each period, we have to transport volume v_{ij} from sourcing unit SU_i to retail distribution center RDC_j . This transport volume originates either from RDC orders or from production batches at the sourcing unit allocated to the RDC. When we do not allow delays in the distribution, we have two possibilities for the shipment of this volume: (1) direct shipment, and (2) indirect shipment through a hub.

The decision to use direct or indirect shipment depends upon:

1. the capacity of the vehicle (or other transport equipment);
2. the location of the hub relative to the location of the sourcing unit and the RDC;
3. the volume that will be available at the hub for consolidation towards the RDC;
4. the costs function or rates structure for less than truckload shipments.

We assume the availability of a sufficiently large fleet of homogeneous vehicles. The capacity of each vehicle is W . Since we allow a mix between direct and indirect shipments (no single sourcing constraint for the RDCs), we can split the transport volume in a full truckload part v_{ij}^F and a less than truckload part v_{ij}^L .

$$v_{ij} = v_{ij}^F + v_{ij}^L = \lfloor \frac{v_{ij}}{W} \rfloor \cdot W + \left(v_{ij} - \lfloor \frac{v_{ij}}{W} \rfloor \cdot W \right) \quad (4.1)$$

The full truckload part will always be shipped directly to the RDC. We define the cost of moving a full truck from location i to location j as d_{ij} . Further, we assume that handling costs are included in the cost parameter d_{ij} . Based on d_{ij} , the cost function for single stop routes becomes

$$c_{ij}(v) = d_{ij} \cdot \lceil \frac{v}{W} \rceil \quad (4.2)$$

If we allow multi-stop routes, where a full truck delivers several retailers in a multi-drop trip or where loads are consolidated by a third party using additional loads from other locations,

we can approximate the costs for a less than truckload shipment by

$$c_{ij}(v^L) = d_{ij} \cdot \left(\frac{v^L}{W} \right)^{1-r} \quad (4.3)$$

where the shape parameter $0 \leq r \leq 1$ expresses the efficiency of the vehicle routing. Our approximation is a generalization of the functions used by logistic service providers, which are based on regression modeling. See e.g. (Koeman, 1997) for the function used at Frans Maas and (Cheung and Lee, 2002) for the function used by DHL Hong Kong. For $r = 1$ the cost function represents single stop routes, and with $r = 0$ the transportation costs are linear with the volume.

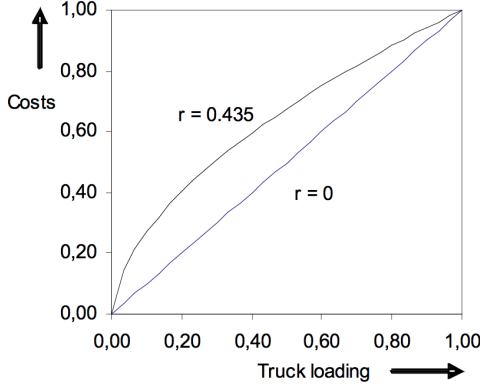


Figure 4.3: Routing efficiency with $r = 0.435$

For example, a value of the shape parameter r of 0.435 means that moving half of a full truck load requires two-third of the cost of moving a full truck load. The shape of the cost function for r is 0.435 is shown in Figure 4.3.

When we require that the costs for full truckloads obey the triangle inequality, then for a hub h holds

$$d_{ij} \leq d_{ih} + d_{hj} \quad (4.4)$$

We want to determine the volume v_{ij}^L above which it is cost efficient to send the shipment directly from the sourcing unit i to the RDC j instead of routing it through a hub h . We express this value as a fraction of the vehicle capacity, i.e. $\alpha_{hij} = v_{ij}^L/W$. If the distance or cost required to reach the hub is greater than the distance or cost required for a direct shipment, then indirect shipment is not interesting from a cost perspective, regardless of the volume. We assume that at the hub h a consolidated shipment w_{hj} can be sent to RDC j , which includes the transport volume under consideration. We define this shipment available for consolidation also as a fraction of the vehicle capacity, i.e., $\beta_{hj} = w_{hj}/W$.

The break-even point between direct and indirect shipment is:

$$\frac{c_{ij}(v_{ij}^L)}{v_{ij}^L} = \frac{c_{ih}(v_{ij}^L)}{v_{ij}^L} + \frac{c_{hj}(w_{hj})}{w_{hj}} \quad (4.5)$$

Using the cost function 4.3 and assuming that $w_{hj} \leq W$, we get

$$\frac{d_{ij}}{v_{ij}^L} \left(\frac{v_{ij}^L}{W} \right)^{1-r} = \frac{d_{ih}}{v_{ij}^L} \left(\frac{v_{ij}^L}{W} \right)^{1-r} + \frac{d_{hj}}{w_{ij}} \left(\frac{w_{hj}}{W} \right)^{1-r} \quad (4.6)$$

Substituting $v_{ij}^L/W = \alpha_{hij}$ and $w_{hj}/W = \beta_{hj}$ results in

$$\frac{d_{ij}\alpha_{hij}^{1-r}}{v_{ij}^L} = \frac{d_{ih}\alpha_{hij}^{1-r}}{v_{ij}^L} + \frac{d_{hj}\beta_{hj}^{1-r}}{w_{hj}} \quad (4.7)$$

This can be rewritten to

$$\alpha_{hij} = \beta_{hj} \cdot r \sqrt[r]{\frac{d_{ij} - d_{ih}}{d_{hj}}} \quad (4.8)$$

The value of α_{hij} gives the fraction of a full truckload at or above which we can send the shipment cost-efficiently directly to the RDC. If $d_{ij} - d_{ih} < 0$, equation 4.8 has lost its validity, but we can still argue that the shipment should be sent directly, since the hub cannot offer any gain. If hub h is directly on the route from SU i to RDC j and has negligible handling costs, i.e. $d_{ij} = d_{ih} + d_{hj}$, we can always send the shipment through the hub, since in that case $\alpha_{hij} \leq \beta_{hj}$ by definition.

The value of β_{hj} depends on the volume that is actually shipped through the hub. Equation (4.8) holds only for $\beta_{hj} \leq 1$, since for larger fractional values of β_{hj} the cost for sending the consolidated volume w_{hj} increases again, due to the non-linearity of the cost function. The size of the increase depends on the shape parameter r . In the extreme case, with $r = 1$, the cost increases per unit with a factor of b_{hj} .

We determine the consolidated volume w_{hj} using an iterative procedure, starting with $\beta_{hj} = 1$. Given a value for β_{hj} , we determine the actual shipped volume \hat{v}_{hij} through hub h with

$$\hat{v}_{hij} = \begin{cases} v_{ij}^L & \text{if } v_{ij}^L < \alpha_{hij} \\ 0 & \text{otherwise} \end{cases} \quad (4.9)$$

For an MCC, we sum over those sourcing units that have been assigned to the MCC under consideration. With $MCC(i)$ the function that gives the unique assignment of a sourcing unit to an MCC h , we get.

$$w_{hj} = \sum_{MCC(i)=h} \hat{v}_{hij} \quad (4.10)$$

Equally for an RCC, we have to sum over all sourcing units, i.e.

$$w_{hj} = \sum_i \hat{v}_{hij} \quad (4.11)$$

Next, we update $\beta_{hj} = w_{hj}/W$. If β_{hj} more than one or has not changed since the previous iteration, we can stop the procedure. If the initial β_{hj} stays below 1, the actual shipped

volume through the hub will get lower or remains the same with each iteration, since the factor α_{hij} will be updated downwards in subsequent iterations. A proper functioning of the hub depends on sufficient volume for consolidation. Due to the nonlinearity of the costs function described above, for values of β_{hj} above 1, the situation is not so clear and we need a more extensive model. In general, we argue that a hub requires a considerable consolidation volume to make indirect shipments interesting. Interestingly, a retailers RCC has more potential sourcing units that can make up this volume than an MCC of a single manufacturer, but an MCC can still be more interesting as a hub if $\alpha_{MCC,ij} > \alpha_{RCC,ij}$ which would be the case if the MCC is located closer to the sourcing units than the RCC is.

Based on the cost function, described in equation (4.3), that depends on shape parameter r , we conclude that a mixed consolidation strategy that uses direct and indirect shipments through a hub outperforms pure direct shipment strategies and pure indirect shipment strategies. These conclusions are consistent with the results of Liu et al. (Liu et al., 2003). With low volume allocated to the hub, a hub becomes under-utilized, which could eventually lead to abandoning the hub. Increasing the number of assigned sourcing units can circumvent this if these new sourcing units are close enough to the hub.

In current practice, retail distribution centers order (pull) frequently in small quantities from the manufacturers' warehouses. This means that all good flows are routed through a hub: the stock keeping MCC. With Supply Chain Synchronization however the volume to be shipped per article becomes larger, such that bypassing the MCC and shipping directly from a sourcing unit to an RCC or even to a retailer RDC might become interesting. This however causes the remaining volume that still requires an MCC to decrease, making shipments from the MCC less efficient.

A major retailer in general will have more than one distribution center. Such retailers can improve the possibilities for consolidation by not centralizing all product flows on one RCC, but by decentralizing the consolidation function of an RCC over their distribution centers. When such a retailer assigns each sourcing unit to the nearest distribution center, acting as a consolidation point for the products from that sourcing unit, manufacturers will save on driving distance and consequently the transportation costs go down. With a balanced allocation of the manufacturers' delivery volume over the various consolidation points, the trucks that transport the goods from the consolidation points to each of the distribution centers can be running at high utilization levels back and forth. Furthermore, because the RCC's each are co-located with a distribution center, part of the volume does not need to be transported further. We call this structure 'The Carrousel'; it will be addressed further in section 4.6.2 at the end of this chapter.

4.5.3 Case: Direct versus indirect at retailer X

In this section we demonstrate the application of the above theory in a case situation, which is based on a practical situation in the Netherlands. The retailer runs 3 distribution centers for dry grocery (West, North and East) and the manufacturer operates 4 sourcing units (SU1 to SU4) that replenish a centrally located MCC.

Geographically the situation is as shown in Figure 4.4.

The first step is to find a value of r (see Figure 4.3) that gives a good fit with the real cost structure of a multi-drop RDC-delivery. $r = 0.32$ was found to give a reasonably good fit (

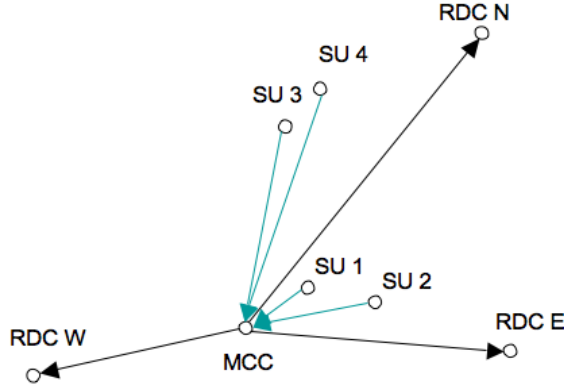


Figure 4.4: Geographical layout of the case situation

$MSE < 1 \text{ in } 10^{-4}$), for drop sizes of a quarter of a truckload and up. As an example we show here the analysis of using the MCC as a hub versus direct shipment from a sourcing unit to a distribution center. Using the MCC is the reference situation. The manufacturer ships goods directly from the production lines in full truckloads towards the MCC. Trucks leave the MCC whenever possible in full truckloads. They will be running a multi-drop trip whenever a full truckload exceeds the requirements of the respective retail distribution center. With supply chain synchronization goods are cross docked at the MCC and delivered (pushed) to the retailer's distribution centers. Only with supply chain synchronization, where the production schedule is driving the distribution, it is possible to skip the MCC and ship directly from a production plant to a retail distribution center.

It is interesting to calculate from what volume on it becomes profitable to ship directly from a sourcing unit to a distribution center. From each of the sourcing units a representative product sample was selected, comprising fast-moving, normal-moving and slow-moving articles. The total sample was 27 products. Applying Equation (4.8) to this 27 products large sample, gives the results that are shown in Table 4.1. The shaded figures indicate the products that can better be shipped directly instead of via the MCC-hub. For these products the value in the column Alpha (i.e. α_{hij}) is lower than the value in the column Load-factor (i.e. β_{hj}). The results from this product sample analysis need to be scaled to the total distribution volume to get an impression of the total savings.

The findings are remarkable. The geographical representation in Figure 4.4 shows that the manufacturer has a centrally located MCC. The shaded load factors in the analysis results in Table 4.1 show that, even for smaller volumes direct shipment often proves to be cheaper. SU2 is relatively close to RDC East and SU4 is close to RDC North. This results in a zero-value of α_{hij} . Therefore, products from SU2 to RDC East respectively from SU4 to RDC North should always go directly. Everything from SU3 towards RDCs North and East can be shipped directly. And finally everything from SU4 to RDC East can be shipped directly. Furthermore the larger products from SU4 have such a considerable volume, that they should always be delivered directly from the Sourcing Unit to each of the RDCs. The situation for SU1 and SU2 towards RDC West is different. SU1 and SU2 have a high value

Table 4.1: Using the MCC versus direct shipment to an RDC

Article id	Sourcing unit	Current order size in pallets	Average daily demand in pallets			Production cycle in days	Demand per production cycle in pallets			North		East		West	
			North	East	West		North	East	West	Load factor	Alpha	Load factor	Alpha	Load factor	Alpha
1	SU1	1	0,04	0,04	0,04	10	0,42	0,39	0,42	0,02	0,36	0,02	0,04	0,02	0,86
2		1	0,06	0,08	0,08	10	0,57	0,81	0,76	0,02	0,36	0,03	0,04	0,03	0,86
3		2	0,06	0,05	0,04	15	0,92	0,82	0,61	0,04	0,36	0,03	0,04	0,02	0,86
4		1	0,17	0,28	0,22	10	1,66	2,80	2,21	0,06	0,36	0,11	0,04	0,08	0,86
5	SU2	1	0,14	0,14	0,11	10	1,42	1,42	1,11	0,05	0,08	0,05	0,00	0,04	0,86
6		1	0,11	0,09	0,11	15	1,65	1,29	1,58	0,06	0,08	0,05	0,00	0,06	0,86
7		1	0,18	0,17	0,13	10	1,82	1,74	1,33	0,07	0,08	0,07	0,00	0,05	0,86
8		1	0,19	0,18	0,16	10	1,85	1,80	1,63	0,07	0,08	0,07	0,00	0,06	0,86
9		1	0,10	0,11	0,10	20	1,91	2,24	2,05	0,07	0,08	0,09	0,00	0,08	0,86
10		1	0,13	0,10	0,10	20	2,53	2,10	1,91	0,10	0,08	0,08	0,00	0,07	0,86
11	SU3	1	0,05	0,08	0,04	20	0,97	1,68	0,86	0,04	0,01	0,06	0,01	0,03	0,17
12		1	0,05	0,05	0,05	25	1,36	1,19	1,34	0,05	0,01	0,05	0,01	0,05	0,17
13		1	0,09	0,05	0,08	30	2,59	1,47	2,50	0,10	0,01	0,06	0,01	0,10	0,17
14		1	0,09	0,07	0,13	25	2,35	1,66	3,15	0,09	0,01	0,06	0,01	0,12	0,17
15		1	0,19	0,35	0,25	20	3,78	6,98	5,05	0,15	0,01	0,27	0,01	0,19	0,17
16	SU4	1	0,07	0,09	0,08	20	1,39	1,88	1,64	0,05	0,00	0,07	0,01	0,06	0,10
17		1	0,06	0,15	0,06	20	1,26	2,92	1,21	0,05	0,00	0,11	0,01	0,05	0,10
18		1	0,05	0,15	0,10	20	0,91	2,96	2,04	0,04	0,00	0,11	0,01	0,08	0,10
19		1	0,09	0,12	0,12	20	1,83	2,49	2,32	0,07	0,00	0,10	0,01	0,09	0,10
20		1	0,06	0,15	0,06	25	1,55	3,84	1,49	0,06	0,00	0,15	0,01	0,06	0,10
21		1	0,11	0,22	0,12	20	2,28	4,47	2,42	0,09	0,00	0,17	0,01	0,09	0,10
22		1	0,14	0,21	0,28	20	2,83	4,30	5,62	0,11	0,00	0,17	0,01	0,22	0,10
23		1	0,32	0,37	0,38	20	6,33	7,44	7,69	0,24	0,00	0,29	0,01	0,30	0,10
24		1	0,30	0,38	0,46	20	6,09	7,65	9,12	0,23	0,00	0,29	0,01	0,35	0,10
25		1	0,30	0,58	0,46	20	5,93	11,62	9,25	0,23	0,00	0,45	0,01	0,36	0,10
26		1	1,17	1,78	1,00	10	11,67	17,80	10,00	0,45	0,00	0,68	0,01	0,38	0,10
27		1	1,04	1,57	1,63	20	20,78	31,41	32,68	0,80	0,00	1,21	0,01	1,26	0,10

for α_{hij} , namely 0.85. So, only full trucks can be profitably shipped directly. The reason for the high α_{hij} is that on the way from SU1 and SU2 towards RDC West trucks almost pass by the MCC, as can be seen in Figure 4.4.

4.6 With Supply Chain Synchronization

Using the consolidation model of section 4.5, the distribution structure variants shown in Figure 4.5 can be created. The current distribution structures, without synchronization, shown at the beginning of this chapter, all started with the inventory at the manufacturers warehouse. When designing distribution structure variants, where distribution is synchronized to production, as shown in structures II and III in Figure 4.5, one should start at a manufacturing plant/sourcing unit.

In the pictures at the left hand side of Figure 4.5 the manufacturer delivers at an RDC; the pictures on the right hand side show delivery via an RCC, where the retailer moves the goods on to the RDC's. A retailer's consolidation center (RCC) is assumed to be always collocated with one of the RDCs.

Table 4.2 gives an indication of the costs in Euro per pallet in case of a retailer with 3 regional distribution centers (RDC's), serving an area of around 20,000 km^2 . These figures comprise the costs of handling and transporting pallets and not order picking of individual cases and assembling these onto pallets. The calculations can be found in Appendix C.1 on

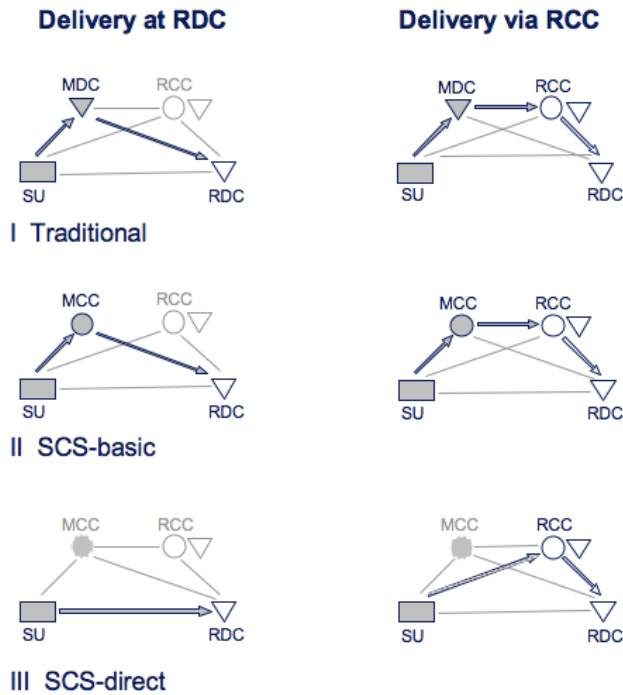


Figure 4.5: Possible distribution structure variants

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The left-hand table-column gives a cost indication per pallet, when the trucks from a supplier to an RDC will on average drop 1/3 of their volume at that RDC and make 2 further stops at the distribution centers of other retailers. The right hand column shows the costs per pallet for delivery via a retail consolidation center (RCC). It is assumed that trucks to an RCC drop all of their volume at that RCC; the retailer then is supposed to pass on part of that volume to 2 other RDC's. The figures show that when a manufacturer only has the volume to drop 1/3 of a truckload at each of the 3 RDC's, he at the same costs runs a full truckload to the RCC and let the retailer pass on 2/3 of the volume, with the other 1/3rd remaining at the collocated RDC. The middle table-column gives the costs per pallet when the manufacturer can run a full truck directly to an RDC, which of course is always cheaper than delivering in 3 stops or via an RCC.

Whenever inventory levels in their distribution centers drop below reorder points, retailers currently request immediate replenishment of their distribution centers, resulting in mixed truckloads most often not full, containing many order lines and even mixed pallets, in most cases assembled by hand. This is the traditional structure I. If retail orders are small, manufacturers have to make round-trips to several other retail clients, in order to run their trucks efficiently. If a truck has to make 3 stops or more (drop sizes of 8 pallets or less),

Table 4.2: Average costs per pallet fast movers

Euro per pallet		Delivery at RDC		Delivery via RCC
		A	B	C
		3 drops	FTL	66% transit
I	Traditional	28	24	27
II	SCS	23	19	22
III	SCS-direct	17	13	16

it might become attractive for a retailer to let the manufacturer deliver at a consolidation point and negotiate a price reduction, as Table 4.2 shows. However, due to the extra step in the supply chain introduced by the RCC, with consolidation the replenishment lead-time to the destination warehouses gets longer. This makes consolidation structures impractical under the current way of working, with retailers often requesting mixed pallets with inherent short lead-time requirements. In a synchronized supply chain though, shipping/pushing products on full pallets directly after production, lead-time is much less of an issue. So, with Supply Chain Synchronization, the use of a retail consolidation center (RCC) becomes feasible and is often advantageous with smaller suppliers. The use of a retail consolidation center might even be relevant for the larger part of a retailers supplier base.

There is a fundamental difference between replenishing retailers from a manufacturer’s regional warehouse or straight from production, either via cross-dock at a manufacturer’s consolidation center (MCC) or directly from the production plants. From their regional warehouses manufacturers can deliver their whole assortment from stock. Which means that they can handle all sorts of retail orders, even small ones, with short lead times. But directly from production, manufacturers can only deliver those products they are producing at that specific moment and only in full pallets. Lead times then will be long, as they depend upon the production schedule. But delivery in large quantities directly after production is the heart of Supply Chain Synchronization. Structures II and III become very realistic with Supply Chain Synchronization. Table 4.2 shows that structure II is 5 Euro cheaper than the current structure I. Because in Structure III the manufacturer delivers directly from the production plant and skips the regional warehouse, as Figure 4.5 shows, the costs are as much as 11 Euro lower than Structure I. This is a significant saving. Purchasing prices vary per product, but assuming an average purchasing price of 800 Euro per pallet, Structure III saves well over 1% of the purchasing price.

Starting from the current practice, Figure 4.1 in the subsequent structures shows the variants that have been conceived to improve the retail supply chain. They all have in common that they are designed from the perspective of the retailer and tend to shift expensive operations and inventory from the retailer to the manufacturer. Structure I, the top one structure at the left in Figure 4.5, again is the current practice at most retailers. Although represented differently, it is identical to the 1st structure in Figure 4.1.

The 3 left hand side structures in Figure 4.5, i.e. those with direct delivery at the RDCs, are repeated in Figure 4.6, but now in the same representation as in Figure 4.1.

In the SCS-structures II and III in Figure 4.5 and in Figure 4.6 the number of stock points

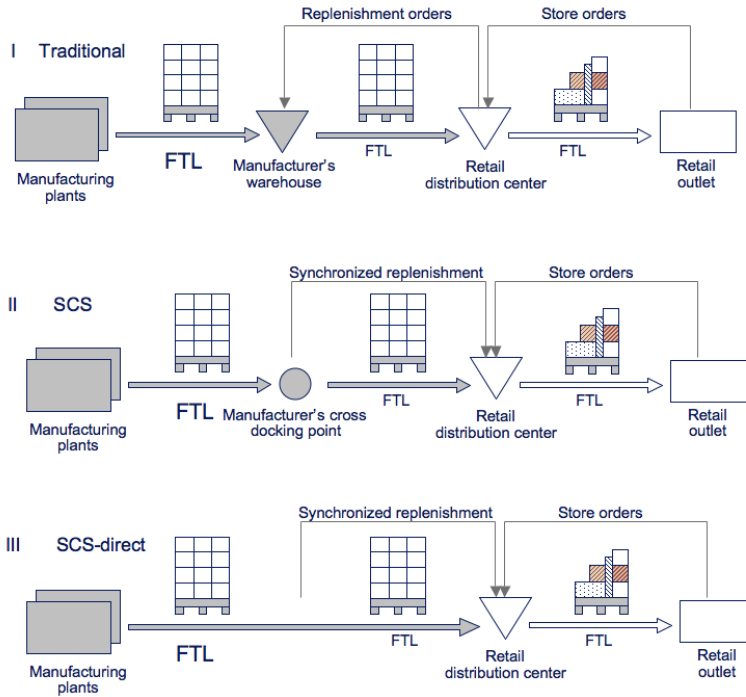


Figure 4.6: Distribution structure variants (with delivery at the RDCs)

has been reduced to one decoupling point, where the downstream demand driven part of the supply chain meets the forecast driven upstream part of the supply chain; see (Hoekstra and Romme, 1992). But where Wal-Mart has shifted this decoupling point upstream, resulting in a long lead time to the stores, with Supply Chain Synchronization this decoupling point is shifted downstream, to the retail distribution center, which keeps the short lead-time to the stores intact.

The new SCS-distribution structures also are different from the current structures in Figure 4.1, because these new structures (see Figure 4.5 and in Figure 4.6) seek for the overall cheapest solution; with the complicating factor, that special contractual or discount arrangements will be necessary to ensure that supply chain partners get their fair share of these savings.

If the costs per kilometer would double, or the area served by the retailer would be twice as wide (4 times as large in km^2) the figures in Table 4.2 would become those in Table 4.3.

4.6.1 Central and regional distribution centers

Many retailers in addition to their regional retail distribution centers (RDCs) operate one or more central distribution centers (CDC's) dedicated to specific types of goods. (See e.g.

Table 4.3: Average costs per pallet: 3 RDC's, current and double km-price

Euro per pallet		Current km-price			Double km-price		
		Delivery at RDC		Via RCC	Delivery at RDC		Via RCC
		A	B	C	A	B	C
		3 drops	FTL	66% transit	3 drops	FTL	66% transit
I	Traditional	28	24	27	37	31	33
II	SCS	23	19	22	32	26	28
III	SCS-direct	17	13	19	25	19	21

(De Koster and Neuteboom, 2000), in Dutch)

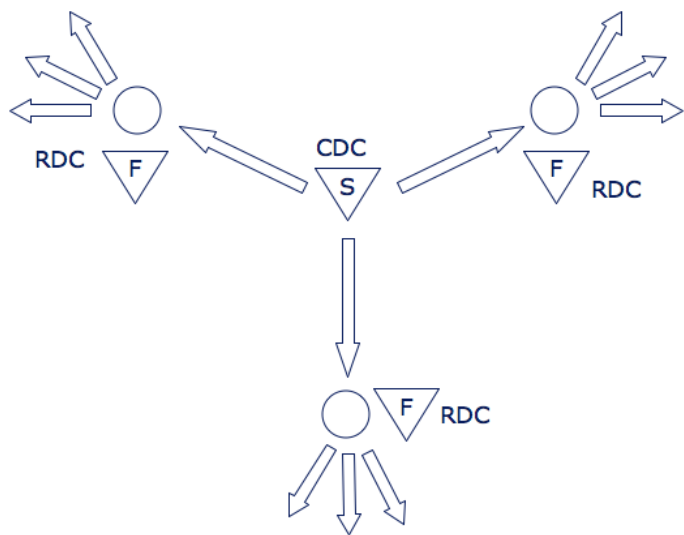


Figure 4.7: Retail distribution network with a central slow mover distribution center

Figure 4.7 shows the distribution network of a retailer, operating three fast mover (regional) distribution centers serving stores within an area, and one central slow mover distribution center. In such a network, incoming shop replenishment orders are being split. Order lines concerning slow moving articles are picked and assembled in the central slow mover distribution center. The pallets (or cages) with the slow-moving articles are routed to the fast mover distribution centers, are cross-docked and are being shipped to the stores jointly with the pallets (or cages) with fast-moving articles. With this way of working, it is taken for granted that the lead-time to the stores for slow-moving articles might be longer than the lead-time for fast-moving articles. But if the procedures are properly designed and prioritized, lead-times for slow moving articles still might be acceptable.

4.6.2 Distributing the slow mover distribution center: ‘The Carrousel’

Alternatively, a retailer might distribute any central distribution center (for instance a slow mover distribution center) and any retail consolidation centre (RCC) over the regional distribution centers.

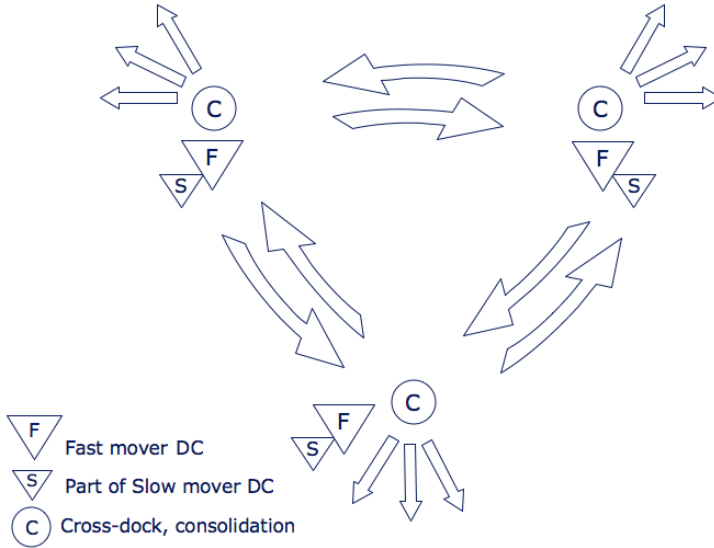


Figure 4.8: Retail distribution network with a distributed slow mover distribution center

Suppliers, with a retailer operating this structure, do not need to deliver slow-moving articles at a separate slow mover location, which saves costs at the supplier. Again the retailer should negotiate a price-reduction from the suppliers.

Table 4.4: Average costs per pallet (3 RDC’s and 1 CDC)

Euro per pallet		CDC		Carrousel	
		D	E	F	G
		3 drops	FTL	3 drops	FTL
I	Traditional	30	28	27	25
II	SCS	25	23	22	20
III	SCS-direct	(19)	-	19	13

Transport from the slow-mover distribution center to the regional distribution centers now becomes inter-distribution center transport. For reasons of cost efficiency and lead-time it might be advantageous to run this ‘Carrousel’ in both directions. This distribution structure

with a ‘Carrousel’ of internal inter-distribution center transport makes it feasible to let a supplier deliver at only one location; a supplier then delivers all of the slow-moving articles and 1/3 of the fast-moving articles (in the example in Figure 4.8) already at the right location and the carousel will move on the remaining 2/3 of the fast moving articles, with each of the distribution center locations acting as a consolidation center (RCC) for the fast-moving goods that need to be moved on. In a way lateral transshipment now becomes the norm, rather than the exception. The same carroussel moves the store ready picked slow moving goods to the respective fast mover locations for consolidation in one and the same shipment to the stores. With a proper allocation of suppliers over the distribution center locations, the carroussel can run full truckload back and forth. Again the retailer should negotiate from the suppliers a cost-reduction for moving on 2/3 of the fast-moving articles.

Table 4.2 above gave an overview of pallet prices in a retail distribution network with three fast-mover RDC’s.

Table 4.4 gives an overview of the average costs per pallet, but in a retail distribution network consisting not only of three RDC’s, but also of a slow mover DC. Scenarios D and E deal with a central slow mover CDC; scenarios F and G deal with a distributed slow mover DC and the carroussel running. The supporting calculations can be found in Appendix C.2.

There is a further advantage to the carroussel. Supply Chain Synchronization requires more inventory storage space at the retailer’s distribution centers. In the short term the retailer might be confronted with serious capacity limitations. These limitations might not be the same for all of the retailer’s distribution centers. Smart allocation of the supplier volumes over the various distribution centers and operating a carroussel means that available space can be optimally used.

4.7 The retail distribution center operation

Shifting inventory downstream from the supplier’s facilities towards the distribution centers of the retailers, requires these distribution centers to have adequate bulk storage capacity. But retailers frequently still run warehouses where orders are picked manually from pallets on fixed floor locations with a single order picking process, as presented in Figure 4.9. Such a distribution center however only has limited bulk storage capacity above each of the pallet pick locations, meant as a forward reserve to replenish the pick locations underneath. This type of warehouse just has not been designed to store larger bulk volumes. This traditional distribution center setup has some significant drawbacks: Because the bulk and pick operation share the same aisle, the bulk handling and the order picking processes constantly block one another. The type of bulk handling equipment and safety reasons limit the height of the racks. With fixed pick positions, the size of the warehouse floor space limits the breadth of the assortment that can be handled by the warehouse. A final drawback is the fact that the poles of the racks hinder the order picking.

Most of the scientific literature on warehouses with fixed pick positions concern the layout, the positioning of fast moving and slow moving goods, the possible use of batch-picking and algorithms that calculate the shortest path for order pickers to travel through the warehouse. For an overview see e.g. (De Koster et al., 2006)

Our approach however is different. The retail distribution center is part of the retail supply chain. It might well be that some simple rules guiding the ordering process at the stores

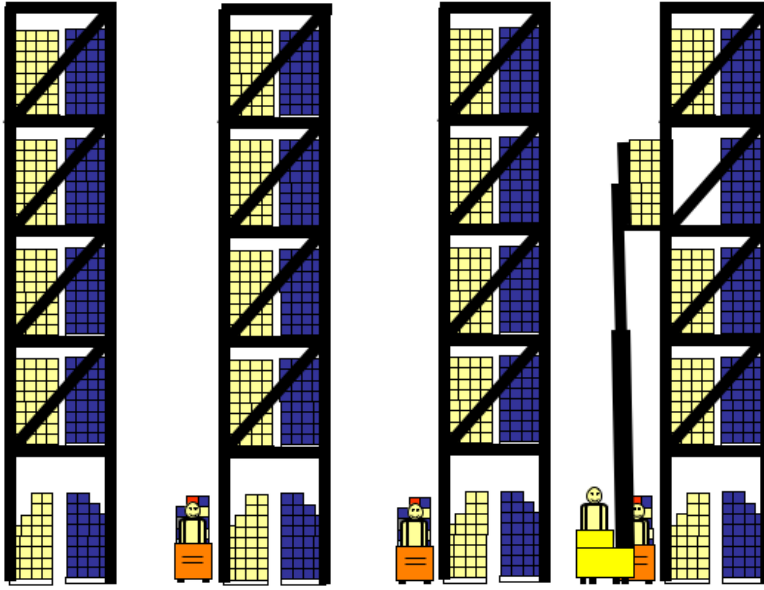


Figure 4.9: Traditional retail distribution center operation

allows for another type of improvement. This will be discussed in Section 5.4.

There exist many designs for retail distribution centers with adequate bulk storage. Just one example of a different and in many respects better operation is the one shown in Figure 4.10. In this case order picking and bulk handling have separate aisles. Even with the same height, this type of warehouse already has almost 50% more bulk storage capacity. In the separate bulk handling aisle one can operate now equipment, that can handle a much higher bulk storage rack; it might even become cost-efficient to run automatic cranes.

On the same floor space, this warehouse set up has some 30% less picking locations, but the bulk cranes in Figure 4.10 more easily can rearrange the picking locations, making them dynamic instead of fixed, which improves the order pick efficiency and reduces the number of locations needed. And if the automated storage and retrieval system (AS/RS) crane is human operated (man-on-board), the man on board the crane can order pick slow-moving articles from pallet locations not on the floor, which reduces the number of pick locations needed on the floor. In such a warehouse setup order picking is not blocked by the bulk operation and even the poles do not anymore hinder the order picking process at floor level that much. A true floor pick operation, without any poles that hinder the picking can be achieved by putting the order pick aisles on the top of the racks instead of underneath.. But there are many more solutions and only careful calculations will show which solution fits best in a particular situation.

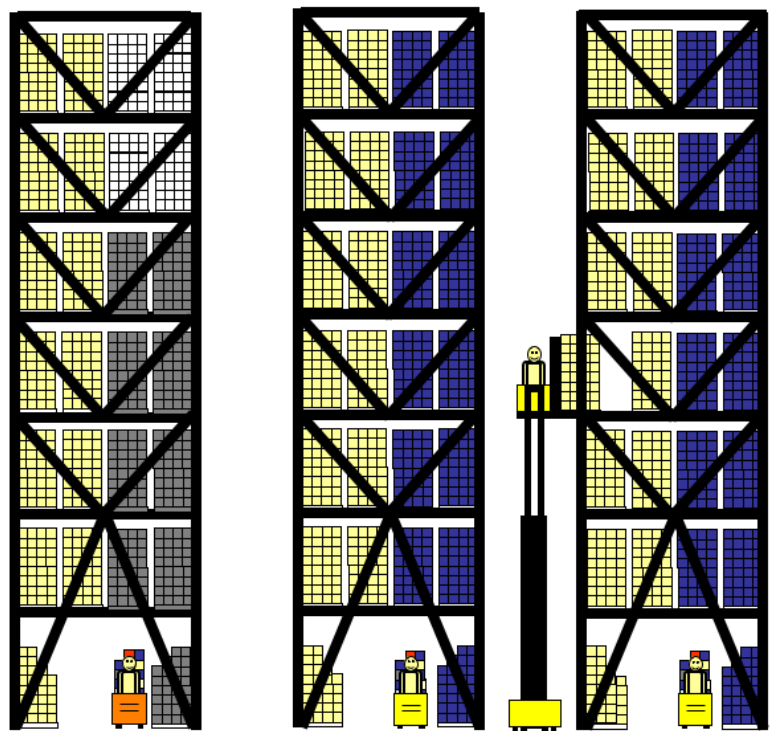


Figure 4.10: Highbay operation

4.8 Wal-Mart vs. Supply Chain Synchronization

It is an interesting exercise to compare the supply chain structure advocated by Wal-Mart (number 3 in Figure 4.1) with the Supply Chain Synchronization basic structure (number II in Figure 4.6).

For ease of comparison, the two supply chain structures, together with the current traditional structure, are repeated in Figure 4.11

Cost-wise the two structures are remarkably comparable, because they both keep inventory at only one place in the supply chain, pick and assemble shop orders at that same location and they both cross dock pallets at the other location. But there are some remarkable differences too, as is shown in Table 4.5:

Summarizing one could say, that the great strength of the Wal-Mart solution is that, once they have enforced their scheme upon a supplier, the savings to Wal-Mart are immediate, because all costly operations shift to the supplier; but at the price of heavy time pressure, workload peaks and lower service to the shops.

Supply Chain Synchronization is more of a partnership approach with in essence more potential than the Wal-Mart solution, but it needs good contractual arrangements between

Table 4.5: Supply Chain Synchronization vs. Wal-Mart

Synchronized	Wal-Mart	Discussion	SCS
Inventory at retailer	Inventory at supplier	SCS: Less inventory through forward positioning. Extra space in RDC difficult	+ / -
Order picking at retailer	Order picking at supplier	SCS/WM: Total order picking costs equal: Number of order lines is the cost driver	=
Short lead time to the shops	Long lead-time to the shops.	WM: More inventory needed in the shops. Complicated store ordering when lead times overlap	+
Store ready pallets per category with goods from all suppliers	Store ready pallets per supplier	SCS: Fuller pallets and easier stocking of shelves with pallets per category	+
Minimum order size might be at item level	Minimum order size at box level, but might not fit on shelf	WM: Back-room when contents of a full box do not fit on the shelves (e.g. drugs, beauty-or health-care products)	+
Level workload from production to RDC	Whole WM supply chain within order cycle and thus under time pressure	WM: Heavy workload peaks complicate personnel scheduling	++
Consolidation to full truckload. Not necessarily truck every day	Goods must be shipped every day, whether a truck is full or not.	WM: High transport costs with small suppliers	++
With fast moving products, suppliers might skip their own warehouse and drive FTL to RDC/RCC	All products from production go into storage at the manufacturer's warehouse	SCS: savings at 5 Euro per pallet	++
Savings are with the manufacturer. Retailers fair share to be negotiated	Costs shifted to manufacturer. WM-savings inherent with supply chain structure	SCS: Negotiation needed When not properly secured, diluted by commercial discounts	- -

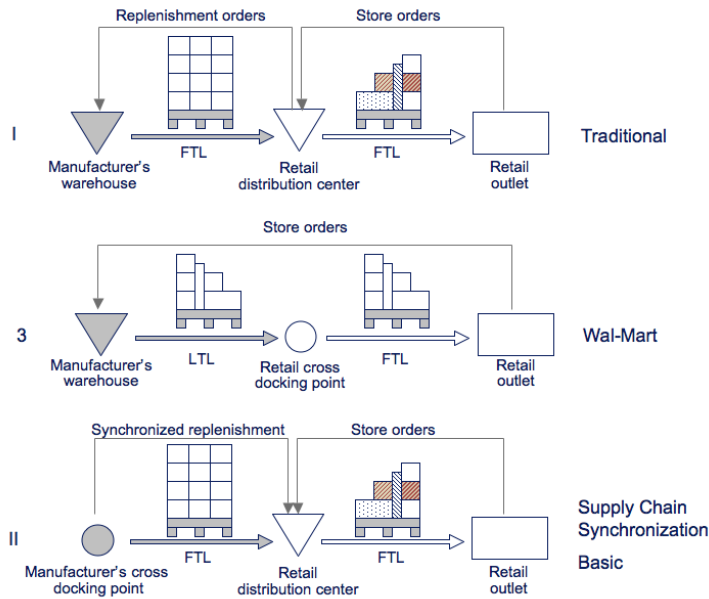


Figure 4.11: Wal-Mart vs. Supply Chain Synchronization

supply chain partners to assure that each one gets its fair share of the savings.

Bramel and Simchi-Levi also discuss Integrated Logistics Models, taking into account both inventory and distribution. The respective chapter in their book is very relevant to the situation described here. They also describe the situation, where suppliers of supermarkets adopt the complete inventory management function of their retailer customers. Bramel and Simchi-Levi conclude, in line with the Wal-Mart practice, that the retailer's distribution center should become a zero inventory consolidation terminal, operating in a "cross-docking" strategy. From the perspective of the retailer, this certainly is a viable strategy. However taking an integrated view of the supply chain, encompassing also the supplier, along the same line of reasoning we are able to conclude that the supplier's warehouse should become a consolidation terminal operating cross-dock, with inventory positioned at the retailer's distribution center. That conclusion is exactly the opposite of the conclusion reached by Bramel and Simchi-Levi by not including production in their reasoning. See (Bramel and Simchi-Levi, 1997) and (Chan and Simchi-Levi, 1998).

4.9 Analysis

Comparing the current structures in Figure 4.1, the following observations can be made:

Observation 26
Traditional structure keeps stock at every point

The Traditional Structure 1 keeps inventory at all locations.

Observation 27**One stock point is enough**

Actually, to decouple the demand driven downstream part of the supply chain from the forecast driven upstream part of the supply chain, one decoupling point would be sufficient; see (Hoekstra and Romme, 1992).

Observation 28**Supplier's stock decouples production and distribution**

The forecast driven (= push) production part of the supply chain is decoupled from the demand driven (= pull) retail part of the supply chain by the inventory in the manufacturer's warehouses.

Observation 29**Traditional structure has short lead times**

It is directly clear, that Structure 1, the Traditional one, with its short lead-time to the shops, serves the retail outlets better than the other structures, but at a price.

Observation 30**Traditional structure often ships boxes**

In the current Traditional structure the retail distribution centers often order boxes instead of full pallets, because the manufacturers have not created an adequate service base priced pricing scheme.

Observation 31**Pick-to-zero is hardly better**

The service to the shops in Structure 2, pick-to-zero, is slightly better, but with pick-to-zero the manufacturers still need to operate a limited box-picking operation, because the aggregated demands from the stores do not round to complete pallets.

Observation 32**Wal-Mart does better, but with longer leadtime**

Wal-Mart in Structure 3, cross docking store ready pallets, has greatly simplified the supply chain, by indeed reducing the number of stock points to only one. Because this one decoupling-point has been shifted upstream towards the supplier, the shop order lead-time has increased and thus the service to the shops has dropped.

These observations lead to the following design choices:

Design choice 13**Cross dock at the manufacturer's warehouse**

Cross dock at the manufacturers warehouse, instead of at the retail distribution center. This way the supply chain is being synchronized down to the retail distribution centers. The distribution center replenishment is in full pallets only and is synchronized to production. This replenishment can be operated either in 2 shipments (e.g. 50/10, where 10% of the inventory is held back at the manufacturers warehouse for allocation halfway the production cycle) (See section 2.4.6) or the complete production batch is pushed/allocated down the supply chain to the retail distribution centers.

Based on observations 8, 26 and 27

Design choice 14

Shift decoupling point to RDC

By shifting the inventory from the supplier's warehouse to the RDC, the decoupling point moves to the RDC as well. Stores now get a short lead time and a better customer service. Based on observations 27, 28 and 29

Design choice 15

Position inventory downstream

Positioning inventory downstream is a positive direct consequence of synchronizing the supply chain, because it shortens the lead-time to the stores and increases customer service. Based on observation 29

Design choice 16

Replenish retail distribution centers in full pallets

Manufacturers produce goods on full pallets. These pallets move in full truckloads from production to the manufacturer's warehouses. The height of the pallets is such, that a truck to such a warehouse is fully loaded. These pallet heights are designed to optimize the transport to the manufacturer's warehouse only, without considering the consequences of these pallet heights further downstream. For "smaller" slower moving products a full pallet of this size might be too much for retail distribution center replenishment. In such cases it is advisable to produce pallets of half the height and stack the one on top of the other; downstream the supply chain they can then be easily split, without a costly box picking operation.

Having done so, the manufacturers warehouse operation is being reduced to a full pallet operation.

Based on observation 30

Design choice 17

Choose locations that consumes more than a pallet

Only those articles should be allowed in a regional distribution center where the demand within the production interval exceeds a full pallet. When demand is less, the article belongs in a slow mover distribution center. When the retail organization as a whole within a production interval demands less than a full pallet, it is questionable whether the retail organization should to sell this article at all. That way one ensures that goods can be delivered in full pallets.

Based on observation 30

Design choice 18

Try to move things further and in larger quantities

To achieve structural savings in the costs of break bulk, the challenge would be to

- try to move the larger units one step further down the supply chain than currently
- do away or structurally simplify one or more of the stages in the process
- break the time constraint by preparing the larger part of the work outside the order cycle

Based on observation 30

Design choice 19

Round aggregate shop orders to full pallets

Round aggregate shop orders for products with enough volume if possible to full pallets and

push/allocate the surplus/shortage to the shops. That opens a way to change the order pick process for those products into a pick-to-zero process.

Based on observation 31

The section on Consolidation leads to the following observations:

Observation 33

Retailers also use central DC's

Retailers frequently use central distribution centers for slow-moving articles or articles with a limited shelf life. In these central distribution centers goods are picked on store order and shipped on store ready pallets or rolling cages to the respective RDCs for consolidation with fast moving articles and onward shipment to the outlets

Observation 34

Synchronization facilitates consolidation

Supply Chain Synchronization facilitates the use of consolidation centers by taking away time pressure. This lowers the costs of transportation.

Observation 35

A mixed consolidation strategy is better

A mixed consolidation strategy that uses direct and indirect shipments through a hub outperforms pure direct shipment strategies and pure indirect shipment strategies.

Observation 36

Synchronization facilitates direct shipment

Supply Chain Synchronization increases the possibilities for direct shipments because shipping larger volumes from production is the essence of SCS. This lowers the costs of transportation.

Observation 37

Even at low volumes direct shipment can be cheaper

Depending on the geographical situation and the volumes to be transported, a case study showed that even for smaller volumes direct shipment can be profitable.

Observation 38

Structure changes often have negotiable effects

Changes in the retail distribution network structure, not only affect internal cost elements at the retailer, but also external cost elements at the suppliers. When designing or redesigning the retail distribution network structure, a retailer should make an integral supply chain cost trade-off and should negotiate with his suppliers an adequate price reduction.

These observations lead to the following design choices:

Design choice 20

Distribute central DC's and set up carrousel

An interesting retail network structure, that merits further research is:

- distribute central warehouse functions over the regional distribution centers
- set up a carrousel of inter-warehouse transport to move goods to the other distribution centers

Based on observation 33

Design choice 21

Distribute central RCC and use carrousel

Distribute the central RCC over the RDC's. That means: make each regional distribution center also a consolidation center (RCC)

Based on observations 33 and 34

Design choice 22

Concentrate supplier's deliveries at nearest RCC

Concentrate supplier's deliveries at the RCC that is closest to the supplier's production plant and move goods on with the carrousel.

Based on observations 33 and 34

Design choice 23

If possible, drive directly

Driving directly from a production plant to one or more retail distribution centers and a skipping to the supplier's warehouse is cheaper.

Based on observations 35, 36 and 37

Design choice 24

Negotiate lower price from supplier

Structure changes at the retailer, that lower the costs at the suppliers, should be negotiated to assure if there share for the retailer

Based on observation 38

Chapter 5

Order fulfillment

5.1 Introduction

In most supermarket chains, shop replenishment is organized so as to timely replenish the inventory on the shelves, whilst at the same time keeping shop inventory low. With short lead-times, high delivery frequencies and small order sizes, retailers try to minimize downstream inventory, without letting the consumers face empty shelves. In the popular ECR-philosophy (Efficient Consumer Response) consumer purchases drive the supply chain. Scanning a package of candies at the checkout counter triggers replenishment of the shelf. The whole concept is based on frequent, most often daily replenishments of all articles in the assortment, in order to guarantee satisfactory consumer service levels with the lowest possible inventory. See Section 7.5, (Whiteoak, 1999) and www.ecrnet.org.

It is however highly questionable whether this focus on inventory reduction downstream the supply chain in the retail outlet is wise. From handling and transport perspective such pull concepts are costly.

In this chapter we will deal with some concepts to improve the order fulfillment process. These concepts are:

- Larger volumes to the stores
- Standard mixed loads
- Excess shelf space

5.2 Larger volumes to the stores

In earlier chapters it was shown that upstream the supply chain one should synchronize distribution to production and move (either pushed or pulled) inventory downstream, immediately after it becomes available (from production). Ideally the inventory is being shifted all the way down to the retail outlets, holding back at a retail distribution center only so much as cannot be ‘stored’ at the ‘stores’.

In the retail cost breakdown in Figure 1.3 the costs of order picking are almost 20% and the costs of distribution to the stores cost as much as 30% of the logistics costs. This is far more than the tiny 2% interest costs of the capital tied up in inventory. One way to reduce the costs of order picking, is shipping larger volumes per item to the stores; for fast-moving products, ideally this means shipping full pallets. Not only this will eliminate the costly case picking process, but it will also increase the customer-service level at the stores.

The basic idea of Supply Chain Synchronization, as described before, is that once goods have been produced, holding costs are being incurred. From a supply chain perspective the goods then better be positioned at the only location where they can satisfy consumer demand and that location is the outlet.

If more inventory is positioned downstream at the stores, this means that just after production there is excess stock (cycle stock) in the store. Due to consumer demand this cycle stock will diminish during the production interval and reach its lowest point at the end of the production interval just prior to receiving a new batch.

This means that, if indeed the whole production batch is being pushed all the way down to the retail stores, most of the time there will be excess stock in the stores. As a consequence the need for safety stock is lower or alternatively customer service levels are higher than before. The cycle stock ‘helps’ the safety stock to serve the customer better.

5.3 Standard Mixed Loads

5.3.1 Introduction

In most of the earlier chapters, with the exception of Section 4.5 on consolidation, we have taken a single product view of the retail supply chain. In fact we have de-composed the multi-product distribution problem into single-product problems, ignoring commonality, which in practice might have dominating effects on distribution. In the forecast driven upstream supply chain echelons a single-product view might be suitable, but in the mostly demand driven lower echelons a multi-product point of view is much more appropriate. By synchronizing review periods of different products, handling can be reduced and resources can be shared.

A typical multi-product activity is order fulfillment, be it gathering individual items in boxes or crates, or picking boxes and placing them on pallets and rolling cages, or retrieving and collecting pallets and rolling cages to let them form together a truckload. It is nothing else, but an order driven production activity. And the resulting mixed loads can be considered as a customer specific product. The various goods are the components of the assembled product, with the client’s replenishment order as bill-of-materials. From an inventory point of view this activity should be shifted to an echelon as far *down*-stream the supply chain as possible. That way inventory of goods (the components) remains generic, which minimizes inventory requirements. However, from a handling point of view, multi-product loading devices should be assembled at an echelon as far *up*-stream the supply chain as possible. That way, downstream stages only handle the larger mixed-product loads, which reduces handling.

The standard mix concept allows for separating order assembly and order allocation. The standard mixed loads can be assembled at an echelon upstream the supply chain and be

assigned to customer orders at an echelon downstream the supply chain. Where needed pack sizes can go up and shipment-sizes of individual products can go down. Larger packaging sizes save on the costs of handling and distribution and smaller shipment sizes of individual products reduce the costs of deterioration. As a side effect, standard mixed loads reduce the effect of order pick errors on individual products.

5.3.2 The standard mixed loads concept

If retailers for a given set of products, solely could order a fixed combination of these products, a fixed mix based on the average combined usage, they would not be able to control their inventory, because demand is stochastic and even long term average combined usage happens to be quite different per region or per store. The following solutions seem fit to overcome this problem:

1. One solution would be to indeed use fixed Average mixes AM that contain a fixed combination of the n products from a product cluster, in quantities that are proportional to their average usages. Retailers then should be allowed, in case of shortage of a certain product within that cluster, to order that product separately, in order to properly manage their inventory. One would expect the retailers then to pay a higher price for those products that are ordered separately. If the bulk of the goods is shipped via the ‘Average mix’, the savings still can be considerable.
2. Another solution would be to define upon a product cluster of n products not just one fixed Average mix AM , but a set of n complementary standard mixes $\{CM_1, CM_2, \dots, CM_n\}$, with every mix containing a different combination of product quantities, such that when ordering, the most appropriate standard mix CM_i is being delivered. That way inventory levels can be controlled even when ordering mixes only. Relative to the average joint consumption, each Complementary mix CM_i contains one of the product types, the trigger product P_i in overdose

There is not much literature on multi-product mixes. An example of the use of Average mixes can be found in (Chao et al., 2005). Freimer et al. give optimal inventory control policies when a retailer can buy both Average mixes and against a higher price also individual items (Freimer et al., 2006). Complementary mixes are described in (Teulings and van der Vlist, 2001).

The remainder of this section is structured as follows: In the next section we describe Average mixes. In the subsequent section we discuss the basic principles of the Complementary standard mix concept. In Section 5.3.5 we offer some mathematical modeling of the Complementary mix concept. Then in section 5.3.6 we give three typical examples of the use of standard mixed loads in order to identify the logistic advantages, both in inventory reduction and in handling reduction. The subsequent sections describe the effects on the inventory at the various points of the supply chain. In the last sections of this chapter we give some considerations for choosing standard mixes and show some simulation results.

5.3.3 Average mixes

The typical purpose of an Average mix is handling reduction. Instead of ordering individual items, a store now orders a box or bag containing the n different items from a product cluster

in quantities proportional to their average usage. Or the store orders a pallet or rolling cage that is preassembled with a standard mixed load of boxes.

Because actual demand varies and almost always will differ from the proportional content of the Average mix the retailer either should get rid of the leftovers via price promotions or sales via other channels or on other markets, or he should be able to order individual items separately, but most likely against a higher price. Average mixes are very common in apparel. But where a dry grocery retailer has products with relatively long life cycles with products that replenished frequently, the apparel retailer -like the newsboy- often can order only once. So in dry grocery one might expect additional ordering of individual items to supplement the content of an Average mix, whereas in apparel one might expect to see price promotions with seasonal leftovers.

One reason for using Average mixes could be that assembling, ordering and handling the mix simply is cheaper than ordering, picking and handling the individual items. Another reason might be a lack of capacity in a retail distribution center to pick the shop orders of individual items timely within the order cycle. By pre-assembling some mixes outside of the order cycle, one levels the workload. The Average mix in that case would be defined such, that a store normally would not have leftovers after the foreseen usage period. A smaller store might order just one Average mix of a certain type, a larger store might order more than one Average mix. One could even think of the situation that stores still order individual items, but whenever this fits within the store order the retail distribution center delivers and Average mix plus the remaining individual items. A good example of the use of such Average mixes is described by Chao et al. in (Chao et al., 2005).

The larger the size n of the product cluster, an Average mix is defined upon, i.e. the greater the number of different products in that Average mix, the more the actual consumption will differ from the average product usage ratio of the Average mix. But on the other hand the savings in handling depend upon the size of the mix.

Typical examples of Average mixes might be:

- A pre-packed mix in apparel containing one type of product (style) in one color in an average mix of sizes.
- An assortment box containing the greater part of the range of shampoos from a certain brand.
- An assortment box with the larger part of the private-label drugs at a chemist store
- A promotion display-box, filled with the first intake on a promotion
- A pre-assembled pallet with a mixed load of drinks.

5.3.4 Complementary mixes

Complementary mixes differ considerably from Average mixes. With Complementary mixes one cannot order individual items to supplement the standard mix, but one orders different Complementary mixes. Where an Average mix in a certain application might contain even ten or more different products, a Complementary mix will contain a very limited cluster of products, most likely only two different products. Where on a cluster of n different products one typically might define only one Average mix with the products in quantities proportional to their average usage, one should define upon a cluster of n products not just

one, but a set of n Complementary mixes, each with one of the products in overdose relative to the average usage.

In our further analysis we assume that the products in a product cluster are equally sized and that the packages or loading devices containing a Complementary mix are always filled up, such as of that the total number of units in every Complementary mix within a set is the same.

In each type of complementary standard mixes in a set, one product is the trigger. The trigger product is the one that is present in an overdose compared to the long-term demand ratio of the cluster products. The standard mix types together form a complementary set of mixed loads located around the long-term average demand ratio of the product types within the cluster, where the set of standard mixes has been defined upon. The size of a cluster is the number of product types in a set of complementary standard mixes. Whereas each of the products in a cluster is in overdose in one of the Complementary mixes within a set, the size of the cluster is equal to the size of the complementary set. In other words there are as many Complementary mixes defined upon a product cluster as there are products in that cluster.

Whenever a customer order is received from a downstream echelon in the supply chain, the standard mix (or combination of standard mixes) that suits best is delivered. Managing the supply chain with pre-picked standard mixes instead of assembling loading devices on customer order in a way resembles to working with ready-made clothing instead of tailor-made clothing.

Some considerations

Because every product in a cluster is trigger product in one of the Complementary mixes, the use of complementary standard mixes does not pose extra warehousing requirements: every Complementary mix within a set, just takes the place of the trigger product that is no longer delivered outside the mixes.

The number of products in a cluster should be limited in order not to over-complicate the management of the supply chain. Instead of one cluster with four products it is better to define two clusters with two products each, or one cluster with two products combined with an Average mix with the other two products.

Demand is variable, but with a proper selection of the products in a cluster, the usage ratio of the cluster products might be much more stable and easier to forecast than their individual product demand. The products therefore should have the same seasonality. The demand ratio is certainly stable, when the products differ in demand. So it is advantageous to combine a fast mover with a slow mover in a cluster. This has the further advantage, that one of the mixes can be homogeneous, containing solely the fast mover. This further simplifies the inventory management.

Graphical representation

The diagram in Figure 5.1 visualizes the standard mix concept for a set of two Complementary mixes, *CM1* and *CM2*, to be defined upon a product cluster of size two, Product 1 and Product 2.

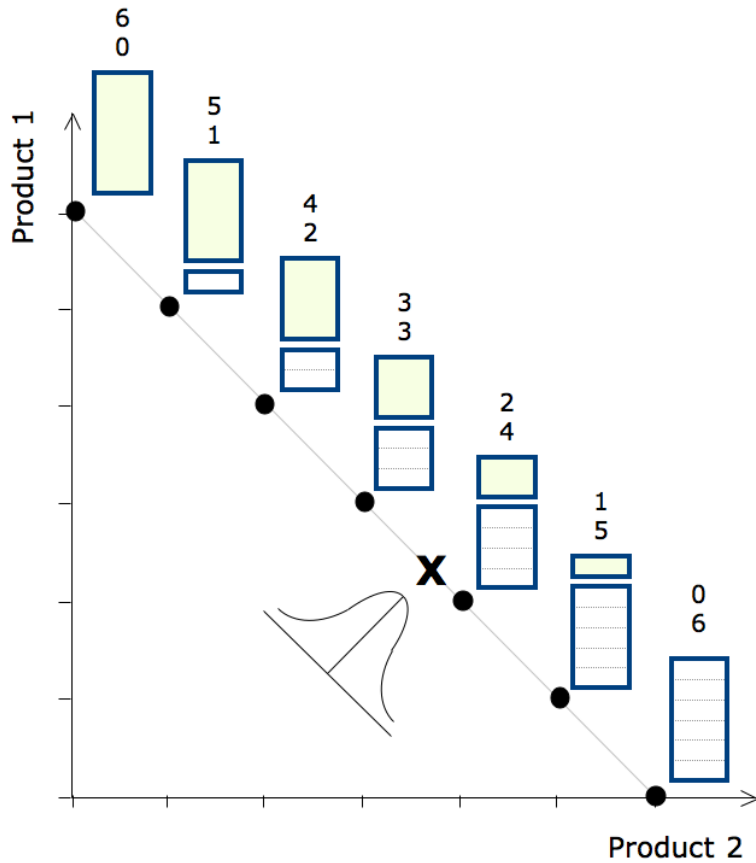


Figure 5.1: Possible Complementary mixes of a cluster of size 2 around the average demand ratio X , with six units in a box.

Due to limitations in packaging, in practice only certain discrete combinations of product 1 and 2 are possible, indicated by dots on the diagonal line. Each dot represents a certain mix of the products 1 and 2 that together fill up an entire loading device of 6 units in this example. Let X on the diagonal line represent the long-term average demand ratio of products 1 and 2, scaled to a full loading device. Dots up-left of X represent mixed loading devices with an overdose of product 1. Dots down-right of X represent mixed loading devices with an overdose of product 2.

In case of a cluster with two products, like in this example, one has to choose two com-

plementary types of standard mix loading devices: one up-left of the average product mix X , with an overdose of product 1 and one down-right of X with an overdose of product 2. Depending on the variability of the product demand ratio X , suggested by the bell curve in the figure, one should select two mixes, that well enclose the product demand ratio. One could select the closest mixes in a set, e.g. CM_1 at 3-3 and CM_2 at 2-4, or when the variability of X is larger, farther apart, e.g. 4-2 and 1-5, or even 0-6. The complementary standard mixes CM_1 and CM_2 that are selected, are not necessarily the closest or not even on the same distance from X . The farthest dots for one or more of the mixes represents a mix with only one product. If both mixes are chosen on the farthest dots 6-0 and 0-6, the system degenerates to ordering loading devices filled up, homogenously with only one product. As product demand differs from one buyer to another and fluctuates over time, the standard mix types should be chosen with care, i.e. not too close to the average product demand ratio X . In that respect 4-2 and 1-5 might be a better choice than 3-3 and 2-4.

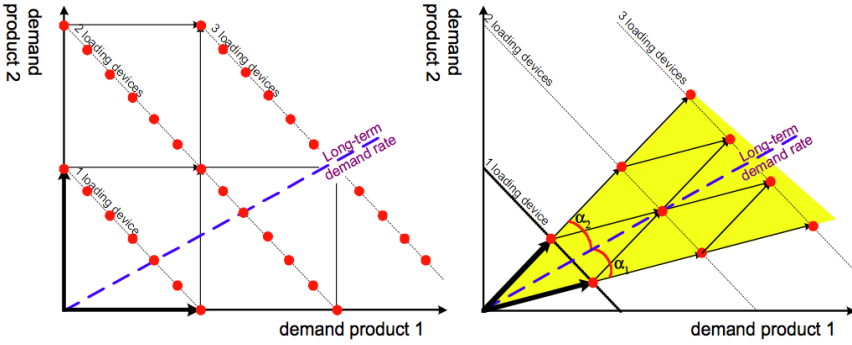


Figure 5.2: Vector representation, without (left) and with (right) Standard mixes. The product needs indicated by the dots can be satisfied.

Without Standard mixes a buyer is free to order any combination of product types in any rate, within the limits of a minimal order quantity and packaging sizes; this is shown on the left-hand side in Figure 5.2. In this example, packages can contain any combination of six items; these combinations are represented by the bullets on the diagonals.

Often however, this flexibility is not used as demand of many products is correlated. Product types are often ordered in more or less fixed combinations at rates that are concentrated around the long-term average demand rate. The advantages of the complementary standard mix concept are at the expense of a part of this flexibility. After all, using complementary standard mixes, products can only be ordered in fixed rates. The complementary standard mixes define a vector space, which covers all product demand ratios that can be satisfied (bullets in the vector space, right hand side of Figure 5.2) Due to roundings of demand rates to complementary standard mixes, the customers demand is only met by approximation.

5.3.5 Modeling complementary standard mixes

Because each product in a complementary standard mix is in overdose once, the number of complimentary standard mix types in a set equals the size of a product cluster. Let P_{ij}

denote the number of units of product type j in complementary standard mix i . In a cluster of size n , the set of standard mixes can be denoted in an $n \times n$ -matrix: the complementary standard mix matrix CM . Each row represents a standard mix in the set.

$$CM = \begin{bmatrix} CM_1 \\ CM_2 \\ \vdots \\ CM_n \end{bmatrix} = \begin{bmatrix} \mathbf{P}_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & \mathbf{P}_{22} & \cdots & P_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & \cdots & \mathbf{P}_{nn} \end{bmatrix}$$

The trigger products in each Complementary standard mix are printed in bold. As each Complementary standard mix in a set is assumed to have a unique trigger product, there are no interdependencies between the rows in the Complementary standard mix matrix, such that the matrix is non-singular. It is assumed that products of different product types are equally shaped and have the same volume.

Let us define:

- C : number of product units in a loading device
- n : number of product types in a complementary standard mix, i.e. the size of the cluster
- Y_{jt} : demand of product type j in period t , with $j = 1, 2, \dots, n$; $t = 1, 2, \dots$; assume Y_{jt} is normally distributed $Y_{jt} = N(\mu_j, \sigma_j^2)$
- μ_j : average demand per period, product j
- σ_j : standard deviation of the demand per period, product j

The Standard mixes are derived from the long-term demand rates of the combined product types. The long-term demand rates of the combined product types, normed by the number of product units in a loading device C , is denoted as a vector X with dimension n . The vector X corresponds with the X in Figure 5.1.

$$X = (X_1, X_2, \dots, X_n)^T \quad (5.1)$$

in which

$$X_i = \frac{\mu_i}{\sum_{m=1}^n \mu_m} \cdot C \quad i = 1, 2, \dots, n \text{ and } \mu_1 \geq \mu_2 \geq \dots \geq \mu_n$$

Obviously, $\sum_{m=1}^n X_m = C$ holds.

The elements P_{ij} of the Standard mix matrix are derived from X_i by offsetting with a certain deviation Δ_i . The Δ indicates the extent to which the trigger product is in overdose. The presence of the trigger product in CM_i is

$$P_{ii} = \lceil X_i \rceil + \Delta_i \quad (5.2)$$

The overdose of the trigger product is at the expense of the non-trigger products, which are (more or less) present according to their long-term demand rate in CM_i :

$$P_{ij} = (C - P_{ii}) \cdot \frac{\mu_j}{\sum_{\substack{m=1 \\ m \neq i}}^n \mu_m} \quad i \neq j \quad (5.3)$$

As the elements of the Standard mix matrix should be integers, the results should be rounded. Besides, the number of units in each Standard mix type should count up to C . Finally, the value of Δ_i should respect the constraints $P_{ii} \leq C$ and $P_{ij} \geq 0$ for $i = 1, 2, \dots, n$ and $j = 1, 2, \dots, n$

In case of $n = 2$, the Complementary standard mix matrix is

$$CM = \begin{bmatrix} CM_1 \\ CM_2 \end{bmatrix} = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix} = \begin{bmatrix} \left\lfloor \frac{\mu_1}{\mu_1 + \mu_2} \cdot C \right\rfloor + \Delta_1 & \left\lfloor \frac{\mu_2}{\mu_1 + \mu_2} \cdot C \right\rfloor - \Delta_1 \\ \left\lfloor \frac{\mu_1}{\mu_1 + \mu_2} \cdot C \right\rfloor - \Delta_2 & \left\lfloor \frac{\mu_2}{\mu_1 + \mu_2} \cdot C \right\rfloor + \Delta_2 \end{bmatrix}$$

Graphically, the $\Delta_{1,2}$ are positively correlated with the angles $\alpha_{1,2}$ in Figure 5.2. Note that a proper choice of Δ_1 or Δ_2 reduces a standard mix to a homogeneous loading device. As the number of product units of a product type in a standard mix should be non-negative and should not exceed C either, the following constraint should be satisfied:

$$0 \leq \Delta_i \leq \min \left(C - \left\lfloor \frac{\mu_i}{\mu_1 + \mu_2} \cdot C \right\rfloor, \left\lfloor \frac{\mu_{(3-i)}}{\mu_1 + \mu_2} \cdot C \right\rfloor \right), i = 1, 2; \Delta_i \in \mathbb{N}$$

5.3.6 Typical applications using complementary standard mix loads

Hoekstra and Romme have called the point where the upstream forecast driven part of the supply chain meets the downstream demand driven part of the supply chain: the Customer Order Decoupling Point (CODP) (Hoekstra and Romme, 1992). At this point customer orders are both assembled and allocated to customers. The basic idea of the complementary standard mix concept is to disconnect the assembly process from the allocation process, i.e. to create a separate Load Assembly Point (LAP) upstream of the Customer Order Decoupling Point (CODP). The LAP then is the point where multi-product loading devices, meant for client delivery, are assembled. The CODP becomes the point where the loads are allocated to customer orders (the customer is for instance a retail store or a retail distribution center). Originally, the LAP and the CODP coincide. Under the Complementary standard mix concept the LAP is upstream of the CODP. In a traditional 2-echelon divergent inventory system, where a supplier supplies a central distribution center that supplies several retail stores, both the LAP and the CODP are at a retail distribution center. Disconnecting the LAP and the CODP is either accomplished by shifting the LAP upstream (application 1), or by shifting the CODP downstream the chain (application 2). This results in two different possible application areas of the Complementary standard mix concept. The main advantages of an application-1 situation are handling reduction at the central distribution center or inventory reduction at the retail store. The main advantages of an application-2 situation are inventory reduction at the retail store and enabling longer lead-times, e.g. intermodal transport, to the supplier. These two applications are illustrated by the following examples.

Example 1 Assortment boxes (Application 1)

A retail organization specializes in fresh ready made salads. The assortment comprises of 40 different salads, all from one supplier: 10 fast movers ($A_1 - A_{10}$) that account for 50% of the turnover, 20 medium movers ($B_1 - B_{20}$), accounting for another 40% and 10 slow movers ($C_1 - C_{10}$) contributing the remaining 10%. An average store sells from each fast mover 10 a week, from a medium mover 4 a week and from the slow movers each only 2 per week. The supplier packs the salads in boxes of six the same salad each. When the salads arrive at the stores, the remaining time before reaching the ‘best-before’ date on average is 2 weeks. Consequently a considerable percentage of the slow movers has to be marked down or even written off, as they are not sold in time. Smaller shops for that reason do not sell the whole assortment and leave out the slow movers. The stores complain that a pack-size of 6 is too large for the slow movers. From the point of view of handling in the distribution centers, the boxes with 6 salads actually are rather small; they would not like the pack-size to go down.

The retail organization arranges with the supplier to switch to the use of Complementary standard mix assortment boxes and to stick to the pack-size to six salads a box. They define 20 sets of two Complementary mixes each, as visualized in Figure 5.3.

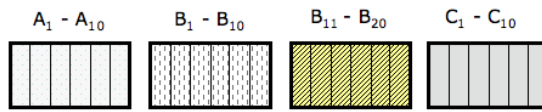
- The 10 fast movers ($A_1 - A_{10}$) are combined with the 10 slow movers ($C_1 - C_{10}$). Shops can order either a box with six fast movers A or a box with two slow movers C and 4 fast movers A . For the shops this means, that the minimum order quantity for the slow movers C has dropped from six salads to two salads, which radically solves the current decay problem.
- The 20 medium movers ($B_1 - B_{20}$) are split into two groups of 10, that are combined to form complementary sets of two boxes.

In the old situation mixed boxes did not exist. The LAP, where these mixed assortment boxes are assembled is at the supplier. The CODP, where the assortment boxes are assigned to shop orders in this example is at the central depot, the retail distribution center, see Figure 5.4. At the same time the handing efficiency in the retail distribution centers has been increased due to the larger pack-size. Smaller shops still can leave some of the slow movers C_i out of their assortment, because the corresponding Complementary mix for that reason has been defined to contain only fast movers A_i . This way the Complementary standard mix concept can be used to upgrade to larger loading devices and thus reduce handling and to lower order sizes of individual products and thus reduce cycle stock in the retail outlet and to broaden the product assortment in the shop.

Example 2 Store ready pallets (Application 1)

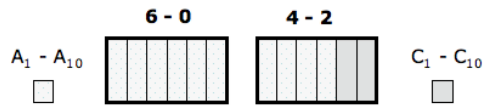
In this example, suppliers originally shipped goods to a retail distribution center on full pallets, each containing one product, with delivery time L_1 (Figure 5.4). At the retail distribution center products are stocked. Inventory levels at the retail distribution center on average are half the shipping volume plus a safety stock to cope with excess demand during lead time L_1 and review period R_1 . Whenever a retail outlet places a replenishment order, the products are picked and assembled onto one or more loading devices (rolling cages or pallets) and shipped to the outlets. The outlets experience delivery lead time L_2 (order processing and assembly time plus transportation lead time). Inventory levels at the

Old situation situation



New situation with complementary mixes

10 fast movers combined with 10 slow movers



10 medium movers combined with 10 medium movers

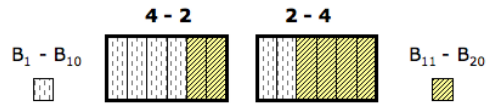


Figure 5.3: The use of standard mix assortment boxes

retailers on average are half the shipping volume plus a safety stock to cope with excess demand during lead time L_2 and review period R_2 .

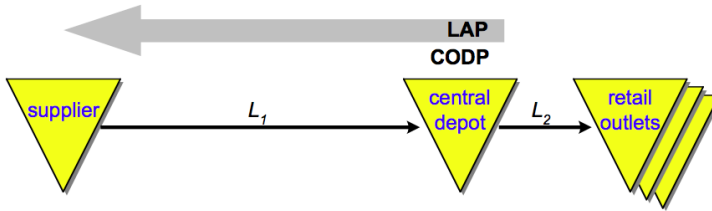


Figure 5.4: Shifting the load assembly point upstream

To squeeze out inventory out of their part of the supply chain, retail organizations like Wal-Mart force suppliers to assemble store ready loading devices, all of them different and assembled on the basis of individual store orders. At the retail distribution center these store ready loading devices are cross-docked, without any intermediate storage at the retail distribution center (both the LAP and the CODP are moved to the suppliers site). However, this procedure has two disadvantages: a) suppliers are forced to operate a costly order picking process to assemble the individual store orders, and b) inventory levels at the stores tend to rise as the safety stock at the outlets now has to cope with demand uncertainty during a cumulative lead time of L_1 plus L_2 and review period R_2 .

Under the Complementary standard mix concept, only the LAP shifts upstream to the supplier's site, i.e. suppliers produce complementary series of identical store ready standard mix loading devices. The individual store orders are used at the retail distribution center (i.e. the CODP) to allocate the appropriate type of Complementary standard mix to a store. The outlets experience delivery lead time L_2 as in the original situation (in fact even less than L_2 , as order assembly is removed from the order cycle).

Example 3. Shift to intermodal transport (Application 2)

In this example large stores (or regional distribution centers for that matter) currently order certain high-volume products directly in full truckloads from the supplier. Inventory levels at the stores on average are half the truckload plus a safety stock to cope with excess demand during lead time L_0 and review period R_0 (Figure 5.5).

Under the Complementary standard mix concept, the CODP shifts downstream the supply chain to a central depot. This means that when using Complementary standard mixed containers, suppliers would be able to assemble containers (each the size of a truckload) without store order and ship these to some remote central depot e.g. a remote intermodal container terminal, that for these goods functions as a retail distribution center. Upon receipt of a store order, the Complementary standard mix container that fits best is dispatched from the central depot (the CODP). Safety stock in the stores may drop considerably as this has to cope with excess demand only during lead time L_2 and review period R_2 , as against L_0

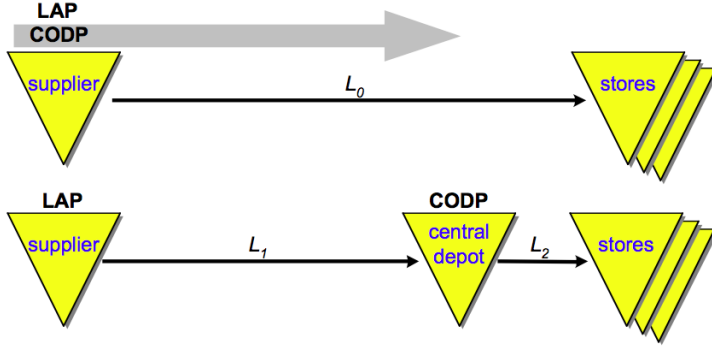


Figure 5.5: Shifting the order decoupling point downstream

and review period R_0 originally $[(L_2 + R_2) < (L_0 + R_0)]$. A safety stock of Complementary standard mix containers at the central depot has to overcome the difference between the supply and the demand at the central depot. A somewhat larger safety stock at the central depot would allow for L_1 being larger and would even facilitate a shift to intermodal container transport via rail or water, whilst the store is still experiencing the short lead time L_2 . If the Standard mix concept is used to increase the number of product types in a container, the stores profit from cycle stock reduction as well.

5.3.6.1 Simulation

To show the viability of the standard mix concept in enabling a model shift from road transport to sea transport, the above example has been extensively simulated. See (Teulings and van der Vlist, 2001). The study dealt with a Dutch brewery and a large retail customer in Spain. The brewery's task is to provide the distribution centers (DC's) of the customer with beer. The customer sells four types of beer. At the current situation the beer is delivered directly by truck with a lead time of a few days. The Standard mix concept enables to design an appropriate intermodal supply chain with a longer traveling time, by shifting the CODP downstream (an application-2 example). Under the Standard mix concept sea-containers filled with beer can be shipped to Spain before the brewery has received customer orders. In the simulation, four types of Standard mix containers, each containing two types of beer, are defined. The containers are shipped by short sea to a central container terminal in the north of Spain. The Spanish DC's order Standard mix containers at the central terminal. As a Spanish DC meets a shorter lead time, (safety) stock reduces considerably compared to the current situation. Due to the Standard mix concept, the Dutch brewery can shift to inter-modal transport. At the same time, the distant Spanish market achieves delivery times that are competitive to a local competitor. As the containers on the short sea vessel are not yet dedicated to a customer, demand variations are consolidated over the pipeline lead time. Besides, the brewery faces a highly reduced capacity usage of its Dutch warehouse. The total stock in the supply chain remains comparable, which means that the

products are as fresh on the shelves as in the current situation.

5.3.7 Downstream stock points

This section covers the logistical consequences of working with Complementary mixes at stock points at the end of the supply chain. In these points, both standard mixes and product units are involved, as sales are on product level, while ordering and replenishment is on complementary standard mix level. The ordering algorithm is important here.

Development of the inventory position over time

In a stable demand situation, the different complementary standard mixes are being ordered more or less alternately. If the standard mix with overdose of product 1 is delivered, product 1 will be ordered less in the following order cycle, such that the complementary standard mix will be ordered. The development of the inventory position in case of two product types

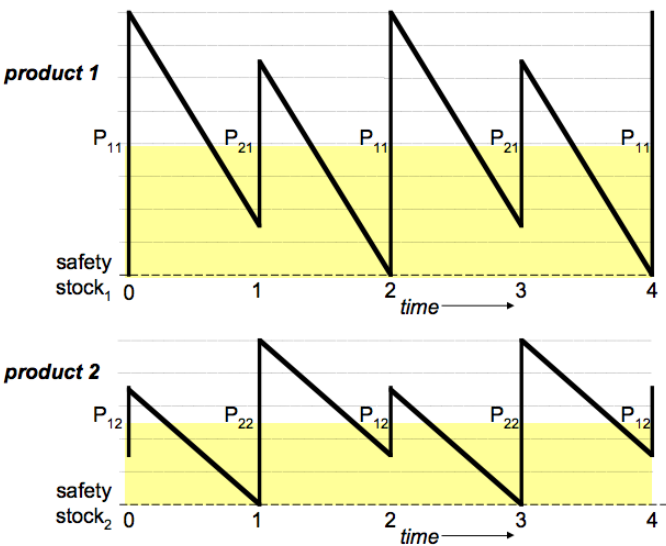


Figure 5.6: Inventory level with complementary standard mixes containing two products

is shown in Figure 5.6. In reality the Standard mixes will not always be ordered alternately, due to fluctuations in demand and due to the fact that X most probably is not exactly in the middle of the standard mixes.

Cycle stock

It is noteworthy, that in the deterministic case where complementary standard mixes are being ordered alternately, which means that demand is constant and that X in Figure 5.1

is exactly in the middle of the Complementary mixes chosen, the average cycle stock CS_i of cluster product i is equal to half its 'trigger'- batch-size P_{ii} , i.e. the batch size that this product has in the Complementary mix, where it is the trigger product, as can be seen in Figure 5.6. So, the average cycle stock $CS_i = P_{ii}/2$. In case the 'trigger' batch size is the same as the order size in the original situation, there is no impact on the average cycle stock. However, if the standard mix concept is used to decrease delivery quantities (for instance if a slow mover 'uses' the volume of a fast mover), the cycle stock will be reduced indeed. Thus in Example 1 in Figure 5.3 the cycle stock of the medium movers $B_1 - B_{20}$ will be $CS_{B_i} = 4/2 = 2$.

Safety stock

If the Standard mix concept is used to shift the CODP downstream the supply chain, the downstream stock points experience a considerable lead time reduction, and thus can reduce their safety stock. If the lead time reduces from L_0 to L_2 (Figure 5.5), the safety stock reduces by $k \cdot \sigma \cdot (\sqrt{L_0 + R_0} - \sqrt{L_2 + R_2})$, or with a factor $1 - \sqrt{(L_2 + R_2)/(L_0 + R_0)}$

Residual stock

Ordering Standard mixes is a kind of coordinated control, or joint-replenishment. In case of joint deliveries (Silver and Peterson, 1985), often a product is reordered while its inventory position is still above its reorder point, because some other product in the mix triggers the replenishment. The excess stock above the reorder point is known as residual stock. Account must be taken of such residual stock because it provides safety stock above and beyond the usual safety stock built into the reorder point. Therefore, the safety stock can be chosen slightly below the normal safety stock, without loss of service. Unfortunately, the probability distribution of the residual stock of a product depends on the inventory position of all of the products in the standard mix.

In a balanced situation in a downstream stocking point, all product types in a cluster have equal run-out times. The ideal order would be X ; then all product types in a cluster still would have equal run-out times after ordering. If a standard mix is received in such a situation, the stock point receives too much of the trigger product and too less of the non-trigger product(s) (Figure 5.6). The resulting excess stock is residual stock.

The excess stock of trigger product i is $P_{ii} - X_i = \lceil X_i \rceil + \Delta_i - X_i \leq \Delta_i + 1$, resulting in an average residual stock of $\leq (\Delta_i + 1)/2$. This is visualized in Figure 5.7. The curve is the development of the stock in case of complementary standard mix deliveries. The surface of the dark area is the average cycle stock. The average residual stock is the surface of the light area (which is equal to the surface of the hatched rectangle in the below left corner). However, the balanced deterministic situation is worst case with respect to the residual stock. Due to demand variations, in practice the need for the one product will always relatively exceed the need for the other. Ordering X will not result in equal run-out times, i.e. ordering X is not optimal. The error by delivering the most suitable standard mix therefore is smaller than derived above. Consequently, the average residual stock due to complementary standard mixes is upper bounded by $(\Delta_i + 1)/2$.

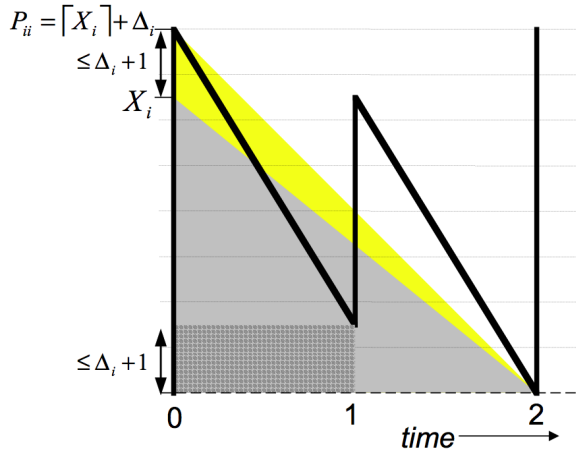


Figure 5.7: Residual stock

Out-of-mix stock

If the combined product need is not within the vector space (for instance left of the cone in Figure 5.8), the customer receives too much of the non-trigger product. At average consumption, the following order will be outside the vector space as well. This leads towards an unstable situation that will only end by sending additional trigger product or by returning some of the non-trigger products. This additional stock component is called here ‘out-of-mix’ stock.

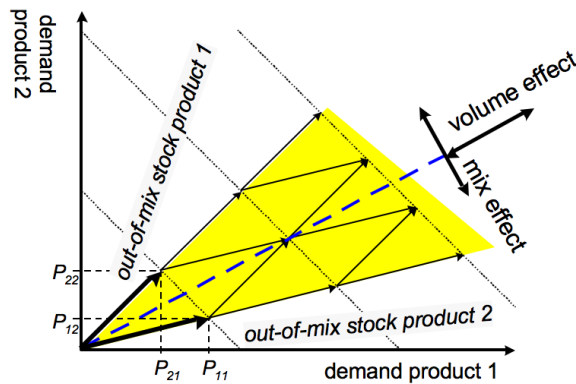


Figure 5.8: Out of mix orders trigger out of mix stock.

Out-of-mix stock occurs in case the extent to which demand fluctuates is beyond the control range of the selected complementary standard mix types. Fluctuations of demand have two

dimensions: fluctuations in volume (for instance due to seasonal patterns in demand), and fluctuations in mix rate. Fluctuations in volume are met by ordering more or ordering less complementary standard mix loading devices. This volume effect does not cause out-of-mix stock. Fluctuations in the mix rate (the mix effect) are met by sending more often the one standard mix type than the other(s). As long as the customer order is within the vector space of the standard mixes, the mix rate fluctuations can be compensated. Otherwise, out-of-mix stock occurs. If out-of-mix stock occurs regularly, one should either change the products in a family, or consider an increase of the Delta's

Combining fast and slow movers

The mix effect plays a smaller role when demands of the one product far exceed demands of the other products, i.e. when fast and slow movers are combined in a cluster. A measure of the size of the mix effect is the extent to which the product ratio fluctuates, i.e. the variance of the mix rate. In case of two products, this is

$$var\left(\frac{Y_{1t}}{Y_{1t} + Y_{2t}}\right) = \underbrace{E\left(\frac{Y_{1t}}{Y_{1t} + Y_{2t}}\right)^2}_I - \underbrace{\left(E\left(\frac{Y_{1t}}{Y_{1t} + Y_{2t}}\right)\right)^2}_{II} \quad (5.4)$$

If product 2 is the fast mover and product 1 is the slow mover, the quotient $Y_{1t}/(Y_{1t} + Y_{2t})$ tends to zero, as do the parts I and II in equation 5.4, and so does the variance. As a result the mix effect gets small. If product 1 is the fast mover and product 2 is the slow mover, the quotient $Y_{1t}/(Y_{1t} + Y_{2t})$ tends to one, as does the parts I and II in equation 5.4. As a result the variance tends to zero, i.e. the mix effect gets small as well. The second result could have been derived from the first, as $Y_{2t}/(Y_{1t} + Y_{2t}) = 1 - Y_{1t}/(Y_{1t} + Y_{2t})$ and thus $Var(Y_{2t}/(Y_{1t} + Y_{2t})) = Var(Y_{1t}/(Y_{1t} + Y_{2t}))$.

Order strategy

In case of complementary standard mixes, buyers order standard mixes instead of products. The first step is to determine the tailor-made order, e.g. by aiming at equal run-out times. In the second step, this ideal order should be translated to Standard mixes, either at buyer side (e.g. retail outlet) or at seller side (e.g. retail distribution center).

One approach to find the most suitable Standard mix (combination) is Integer Programming (IP).

$$\min \sum_{m=1}^n \left| T_m - \sum_{s=1}^n D_s \cdot CM_{ms} \right| \quad \text{such that} \quad \begin{array}{l} D_s \geq 0 \\ D_s \text{ integers} \\ s = 1, 2, \dots, n \end{array} \quad (5.5)$$

The matrix CM is the Complementary standard mix matrix. The vector T represents the tailor-made order from step 1. The vector D is the vector with decision variables, which is output of the minimization. In case availability of one product is more important than availability of the other, the objective function can be adapted with weights.

Another approach is total enumeration. If m or $m-1$ Standard mixes should be ordered, and each Standard mix contains n product types, the total number of possible order combinations

is

$$\binom{n+m-1}{m} + \binom{n+m-2}{m-1}$$

If all possibilities are evaluated, the Standard mix (combination) which is closest to the tailor-made order out of step 1 is delivered.

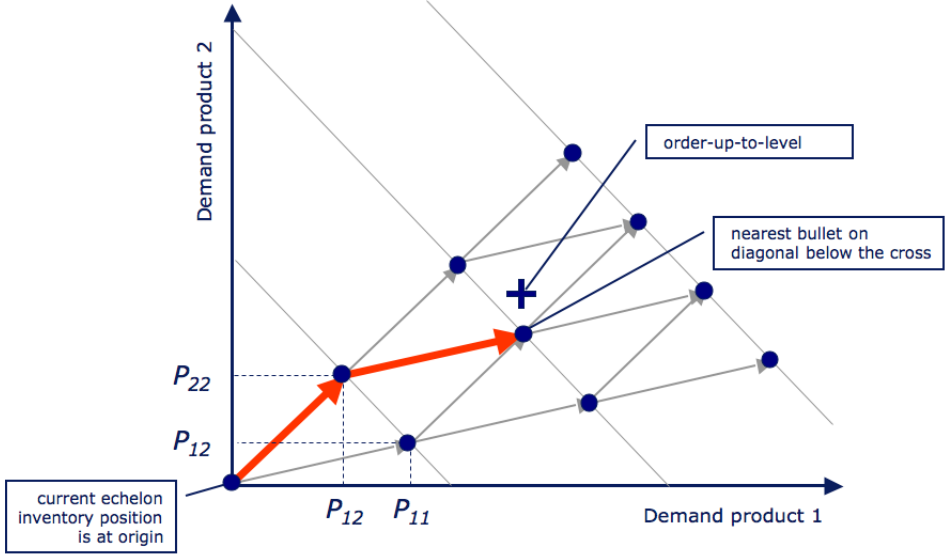


Figure 5.9: Graphical representation of the order strategy

With two products, using order up to levels, the order strategy can be presented graphically as shown in Figure 5.9. The cross represents the target order up-to-levels of the two products, relative to the current echelon inventory position at the origin. One then orders such, that on the diagonal below the cross, the bullet that comes closest to the cross is being reached. In the example shown in the Figure, one should order one mixed load from either type.

5.3.8 Upstream stock points

The Standard mixes are assembled in an upstream stock point. This section treats planning consequences at the LAP and inventory and handling consequences at the central depot (the CODP).

Assembling standard mixes

Under the Standard mix concept, fixed mixed loads are assembled at the LAP. However, there are still several options to locate the LAP (Figure 5.10): as the last step in production, in combination with shipping at the supplier, or in combination with goods reception at the central depot.

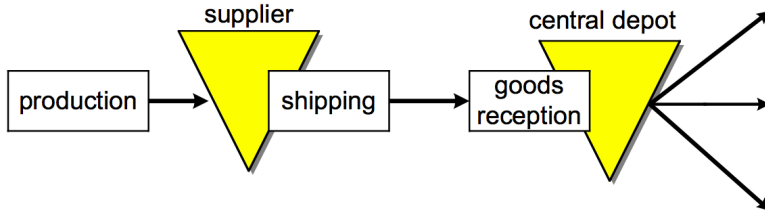


Figure 5.10: Possible locations to assemble standard mixed

LAP at production

From a handling point of view, the standard mixes should be assembled straight from production, preferably in an automated process. The stock at the supplier then becomes a stock of standard mixes. However, this is at the expense of a degree of freedom: products are dedicated to a standard mix in an early stage. In case the demand of the other standard mix type increases, the supply chain is less flexible to react to it. Furthermore, standard mixes for different clients or even for different depots of the same client may differ.

LAP at shipping

In case the Standard mixes are assembled at the call-off at the supplier, stock at the supplier remains at product level. The supply chain is more flexible to react on changes in demand, i.e. less stock is required to perform the same service levels. From an inventory point of view this is recommended.

LAP at goods reception

In case the Standard mixes are assembled at goods reception at the central depot, the Standard mix concept has no consequences for the supplier. An advantage is that product types in a cluster not necessarily need to originate from the same supplier. Compared to the original situation, the added value of the standard mix concept with LAP at goods reception is that part of the order-pick process is taken out of the shop order cycle. Besides, the Standard mixes are fixed mixed loads instead of order specific. This enables the process to be executed efficiently, possibly automated.

Production planning

To produce the right product in the right quantity at the right moment, the supplier could choose to use only local installation stock information and use only local stock norms. However, as stock in the central depot is generic (not yet dedicated to a customer), the supplier may as well use echelon stock information on the pipeline and the central depot and use echelon stock norms ((Magee, 1958), (Van Donselaar, 1990)). The stock at the central depot is a stock on Standard mix level. Using echelon stock norms for production planning, the supplier should be aware that once a product is in one Standard mix type, it can never be used to assemble another Standard mix type. The danger is that a stock-out of the one standard mix type, due to out-of-stock of one of the products, may not trigger production as the stock level of the other Standard mix type, also containing that product, is still high. The echelon stock norm should therefore be defined on the level of the standard mix type instead of the product type, even if the local stock at the supplier is a stock on product level. In other words, the supplier should treat assembled standard mixes as products.

Materials planning

A Standard mix can be described by a Bill-of-Material. Therefore, MRP-like material planning is applicable. To assemble a Standard mix, several materials should be available. If one of those materials is out-of-stock, no Standard mix can be assembled. Therefore, products with low-value and low-volume contribution to a Standard mix (i.e. cheap slow movers) should never be the reason of not being able to assemble a standard mix. The safety stock of these products should be elevated as a kind of option overplanning.

Central depot inventory

The Stock Keeping Units (SKU's) at the central depot are standard mix loading devices. If the length of the review periods controlling the central depot and the retailers' replenishment are R_1 and R_2 respectively, the average cycle stock of standard mix type i at the central depot is $CS_i = (R_1 - R_2) \cdot \mu_{i,c}/2$. The parameter $\mu_{i,c}$ is the cumulative periodic demand of standard mix type i over all buyers (measured in numbers of Standard mix loading devices). In case the review periods are the same (the same replenishment frequencies), no cycle stock would be necessary by synchronizing the outgoing shipment on the production/delivery of standard mixes. Then, apart from the safety stock, the central depot becomes a cross-dock station. Next to the cycle stock, a safety stock of Standard mix type i should overcome differences between delivery and demand at the depot. If the safety factor k corresponds to a pre-determined service level, the safety stock is $SS_i = k \cdot \sigma_{i,c} \cdot \sqrt{L_1} + R_1$. Here $\sigma_{i,c}$ is the standard deviation of the cumulative periodic demand forecast error of standard mix type i over all buyers (measured in numbers of standard mix units).

A strong relation exists between the values chosen for the deviation Δ_i and the standard deviation $\sigma_{i,c}$. Suppose that X_i gets biased due to a temporary shift of the average demand ratio of the products in a cluster. As a result, the standard mix type in which product i is the trigger will be ordered more frequently or less frequently (dependent on the direction of the shift of the demand ratio). If Δ_i had been chosen small, the impact on the order

frequency of that mix will be larger than if Δ_i has been chosen large. Therefore, the choice of Δ_i has an impact on the ratio in which the Standard mix types are ordered at the central depot. A small value of Δ_i could easily lead to a large value of $\sigma_{i,c}$ and thus to the need for a large safety stock of the Standard mix types at the central depot.

As all product types of a cluster are present in all Standard mix types of the set, another Standard mix type of the same set can be delivered in case of a stock-out: the Standard mix types in a set serve as substitutes. Therefore, safety stock in the central depot in a limited way may be treated as a kind of shared resource of a set of Standard mix types. As a consequence, the safety stock levels of the individual Standard mix types can be lowered.

Central depot handling

When using standard mixed loads, an efficient, cheap and possibly automated process at the supplier replaces (part of) the expensive order driven picking process in the central depot. Furthermore the workload at the depot flattens, because the order picking activities disappear out of the shop order cycle. The handling costs in the central depot actually are reduced to the costs of handling Standard mix loading devices. Product handling disappears in the central depot. Handling at the central depot can be even further reduced, if the standard mix concept is used to re-scale to a larger loading device by combining several product types in a standard mix loading device in which each product type keeps more or less its original batch size. The reduction factor of the number of handling units is proportional to the size of the cluster.

5.3.9 Defining complementary standard mixes

Defining standard mixes basically is a two-step process. In the first step, the product types to combine are chosen, i.e. product families are identified. In the second step, the fixed product rates are determined. In the longer term, the product rates of a Standard mix should be monitored and, if necessary, adjusted.

Step 1: Identify a cluster

Product candidates for a Standard mix have enough volume and are in a stable phase of their product life cycle. The units of the product types have the same shape and volume and are stackable. The unit weight of the product types in a cluster should be in the same order of magnitude. Either all product types of a cluster are in the product range of a buyer, or none of the products are. The product types within a cluster should have the same seasonal patterns, such that the product types suffer from the same structural demand fluctuations (volume effect). Preferably, demand of the products within a cluster are correlated on a day-to-day level from an out-of-mix stock point of view (mix effect). Especially routine products, like beer, sodas and other beverages, milk and soaps are suitable. Interesting candidates for a cluster are fast and slow movers of the same product group, for example beer with alcohol and beer without alcohol. In this way, slow movers piggyback on the volume of the fast movers and profit from the high delivery frequency of the fast movers: all products flow with the same speed now. Besides, the mix effect is limited due to small fluctuations of the demand rate of the slow mover (as explained before). In addition, the

wish for the same seasonal patterns is satisfied. The number of product types within a cluster should not be too large (two, three or four). In case of a large number of product types the inventory positions are hard to control.

Step 2: Determine product rates

The choice of the Δ 's in Equation 5.2 determines what Standard mixes to make. The choice depends on a number of aspects. A first condition is that the vector space of the Standard mixes should at least contain the long-term average demand rates at all selling points. One motive to aim at small values of Δ is the substitution function of the complementary Standard mixes in the central depot. Another motive is keeping the residual stock limited. On the other hand, in case of a small Δ , a small distortion of the long-term average demand rate has a large impact on the probability distribution, which implies a large variance of the demand in the central depot and at the supplier. This leads to high centrally safety stocks of the Standard mix types. Besides, small values of the Δ 's imply a large probability on out-of-mix stock in the selling points, resulting in an unstable situation. Especially these last considerations are important.

Long term: coping with shifting demand parameters

In practice, the demand parameters of the product types (average and standard deviation of the period demand) are subject to continuous changes. Therefore, the product demand ratio may shift, which may cause a bias of the set X . To prevent out-of-mix stock, structural shifts of the mutual product demand ratio should be detected in an early stage to make adjustments in the Standard mix types. However, the demand parameters should not be too sensitive for changes of demand rates to prevent for shifts due to incidental changes. The probability of adjusting for an incidental change (type 1 error) should be tuned with the probability of not adjusting for a structural change (type 2 error). To monitor the demand parameters, actual demand information is required. Either the replenishment orders from the central depot at the supplier or the replenishment orders from the retailers at the central depot are required. From a supplier point of view, it may be obvious to use the replenishment orders from the central depot. However, these data suffer from roundings to Standard mixes and there may be even Forrester effects. The original tailor-made orders from the retailers are more accurate, as these are not rounded.

5.4 Excess shelf space

Supermarket outlets should have their shelves adequately stocked, in order to ensure that their customers indeed find all of their needs and are not confronted with empty shelves. An out of stock situation in a retail outlet might mean loss of sales. The consumer might buy a competitor's product and in the future stick to that brand. Or the consumer might decide to do all of his shopping at a competing supermarket. So it is important to guarantee on-shelf availability of products, both from the perspective of the manufacturer and of the retailer.

In this section it will be argued that of course the consumer demand should drive the replenishment of the retail outlet, but in a scheme originating from the warehouse operation, within the limits of the Shelf Coverage of the various products.

In supermarket stores, almost all inventory is on the shelves. Only for very fast-moving and voluminous articles (drinks, toilet paper, diapers) there might be limited backroom space available to keep extra inventory.

When designing the shelf layout plan (planogram), category managers assign to every article in the assortment a 'slot', a fixed location with a defined number of product 'facings' on a certain shelf. Gross profit per shelf meter is leading this shelf design. There exist several merchandising software packages, which support the shelf layout planning process.

The shelf layout planning process only concentrates on the shelf length assigned to a product. It is clear, that this shelf length per product always has to be rounded to an integer number of product facings. This makes it difficult and theoretically even impossible, to design a really optimal shelf layout, that is a shelf layout that generates maximum profit given the available total shelf space: compared with the optimum lay-out, most products either get assigned not enough or too many facings.

Mainly marketing arguments dictate the shelf layout plan. Designing the lay-out plan, not only sets the commercial presentation to the clientele, but also defines the physical logistical space on the shelf behind the products that are facing the client. Logistical arguments hardly ever are taken into consideration, even though the number of facings assigned to a product has great influence on the replenishment possibilities and thus on the replenishment costs. If these costs were taken into consideration, the optimal shelf layout plan would be different.

Figure 5.11 shows the part of the shelf in a retail store that has been assigned as a slot to a certain product. The width of the slot is the number of facings of that product. The depth of the slot equals the depth of the shelf. If as part of the shelf layout planning process the number of facings of a product has been decided upon (e.g. two packages of a type of coffee), then the area on that shelf behind these two packages in front, is the logistics storage area for that product (coffee in this example). If the shelf space S , that has been assigned to a product has been fully stocked, the inventory I_{max} on that shelf space will cover a certain period of forecast demand, called the Shelf Coverage period SC .

Current practice in retail is to reorder at the latest possible moment, which is when just enough product I_{latest} has been left on the shelf, to cover the worst-case demand during the replenishment lead-time. As is shown by the dotted line in Figure 5.11, one could draw a horizontal line, parallel to the front of the shelf, to mark that latest possible reorder level s .

Assuming daily review of the shelf inventory and non overlapping replenishment orders, so

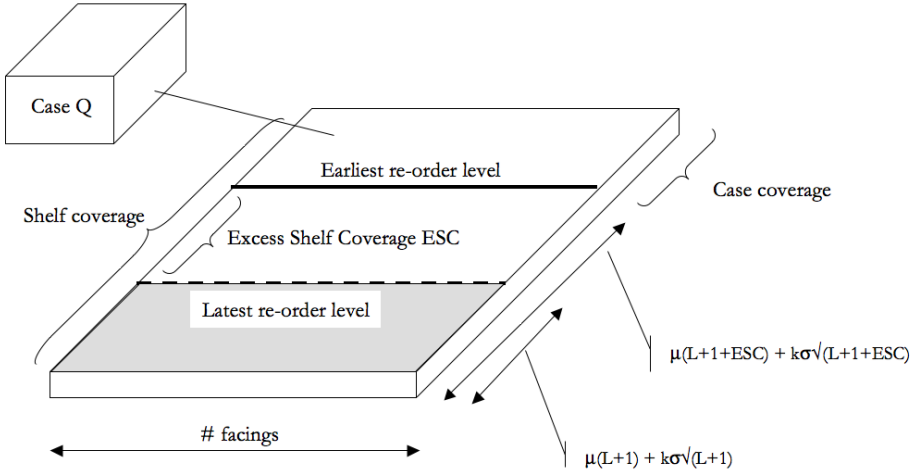


Figure 5.11: Shelf Coverage made visible

the net stock on the shelf equals the inventory position, one gets:

$$\text{reorder level } s = I_{latest} = \mu(L+1) + k\sigma\sqrt{L+1} \quad (5.6)$$

with μ the forecast daily demand, σ the standard deviation of the one day forecast error, k a service factor as described in Section 2.4.1 and L the replenishment lead-time in days.

If replenishing the retail store and filling up the shelves, products always come in some type of box or tray or wrapper, let's call it a case of size Q , containing several consumer packages of the product. The earliest possible moment that a shop can reorder a product, is when so much product has been sold, that the contents of a new case just fit on the shelf, behind the product that is still on the shelf. Earlier reordering might result in a fill rest, as the contents of the case may not yet fit on the back part of the shelf. One could draw a second horizontal line on the shelf, in parallel to the backside of the shelf, to mark the earliest possible reorder point. Let us call the amount of product inventory left on the shelf when the earliest reorder level has been reached $I_{earliest}$.

Most supermarket chains use the latest possible reorder level as a trigger for replenishment of the shops. This results in stringent lead-time requirements, with heavy peaks in the workload at the retail distribution centers over the day. One might expect the reorder policy to be of the (s, S, Q) - type, with s the reorder level from Equation (5.6), S the shelf space assigned to this product and Q the case size. Replenishment orders then will be in multiples of Q .

Actually the two reorder-lines on the shelf resemble the can-order and must-order levels known from joint replenishment systems. See e.g. (Silver and Peterson, 1985)

5.4.1 Exploiting the Excess Shelf Coverage (ESC)

Normally for each product there is some space between the earliest possible reorder level, marking the moment that a retail outlet store might already reorder, and the latest possible reorder level, marking the moment that a retail outlet store must immediately reorder a product. The period of demand, covered by this excess space is called the Excess Shelf Coverage (ESC). The ESC is measured by the number of days of forecast demand that is covered by the product stocked on the shelf in the excess shelf space. See also (Broekmeulen et al., 2006). The excess shelf coverage can then be derived from:

$$I_{latest} = \mu(L + 1 + ESC) + k\sigma\sqrt{L + 1 + ESC} \quad (5.7)$$

The period of forecast demand covered by the excess shelf space, i.e. the ESC-value, has great influence on the flexibility in shelf replenishment, as will be shown underneath.

ESC < 0

If the Excess Shelf Coverage of a product is negative, clearly not enough shelf space has been assigned to that product to prevent out of stock happening. In this situation the shop cannot even reorder the product at the latest possible reorder level, because the contents of a new case will not yet fit in. The shop has to wait until enough product has been sold to let the contents of a new case fit on the shelf and by that time the shelf does not contain enough product to cover the worst-case demand during the replenishment lead-time.

ESC = 0

If for a product the Excess Shelf Coverage is zero, both reorder lines on the shelf coincide. The shop should reorder this product immediately whenever the reorder line is reached and it should be replenished in due course. The replenishment system should be designed such, that this product can be delivered the next day.

ESC > 0

If the Excess Shelf Coverage for a product is positive, the possibility exists to shift the replenishment moment to an earlier point in time. This opens the way to break through the current time pressure, to group replenishments, to improve the distribution centre order pick operation and to level replenishment volumes over the day and over the week.

ESC ≥ 1

If for a product the Excess Shelf Coverage is one day, in principle this product needs not be replenished the next day. If the shop would reorder timely, at the earliest possible reorder level, the distribution center might decide to wait a day before replenishing this product. Products with an Excess Shelf Coverage of one-day can be grouped into product groups that can be replenished every other day.

ESC ≥ 2

If for a product the Excess Shelf Coverage is two days or more, the replenishment scheme for such a product can be based upon an even lower replenishment lead-time. These type of products can be grouped into product groups that will be replenished only twice a week (still assuming that shops reorder timely at the earliest possible moment, or the replenishing warehouse has daily visibility of the stock levels on the shelves in the shops).

ESC ≥ 4

If for a set of products the Excess Shelf Coverage is four days or more, these products might be set on a weekly delivery scheme.

Table 5.1: Replenishment schedules, varying with ESC

$ESC \geq$	Replenishment schedule
0	Daily
1	Every other day
2	Twice a week
4	Once a week
9	Every other week

Table 5.1 gives an overview of the replenishment schedule requirements as determined by the Excess Shelf Coverage. The replenishment schedule in this table sets the constraints for the replenishment system lay-out.

The table shows the replenishment schedule, not the actual replenishment frequency of a given product. The actual replenishment frequency of a given product, as it will happen in practice, depends on the reorder size.

The reorder size should be an integer multiple n of the case size Q of any given product. The period of demand covered by the contents of a case Q , or nQ when reordered in multiple cases, and the period covered by the excess shelf space should be in balance as described underneath.

CC > ESC

If the Excess Shelf Coverage for a product indicates a schedule with delivery twice a week (e.g. on Tuesday and Thursday), but a case contains enough product to cover a months demand, the product will only be reordered once a month, but when delivered, will be delivered on one of the set days (Tuesday or Thursday). Clearly for this product there is an imbalance between the Case Coverage and the Excess Shelf Coverage: a smaller case would have meant a larger ESC and more flexibility.

If the contents of a case cover the demand for a whole month, the product actually will not be reordered more often than once a month. But even then, as long as the Excess Shelf Coverage for that product is zero, the replenishment system should be laid out for next day delivery of that product.

CC < ESC

If the contents of a case cover the demand for just a day and the Excess Shelf Coverage is n days, then the product better be not reordered daily, but alternatively should be reordered every n days with multiple cases nQ at the time. Although the Excess Shelf Coverage is large, when the product is not reordered n cases at a time, the replenishment moment clearly cannot be shifted.

In these cases, the Excess Shelf Coverage and the Case Coverage are out of balance. For a proper balance, the Excess Shelf Coverage should be less than the Case Coverage and ideally almost the same.

The imbalance can be solved by changing the number of facings, which from a marketing perspective might not be acceptable, or by changing the case size. Enlarging the case size can also be achieved, by ordering n cases at the same time. Setting the minimum order quantity to n cases, or changing the case size reduces the Excess Shelf Coverage. So, when enlarging the case size, the balance will be found with a delivery schedule suggesting a shorter lead time.

5.4.2 Exploring possible redesign of the order picking process

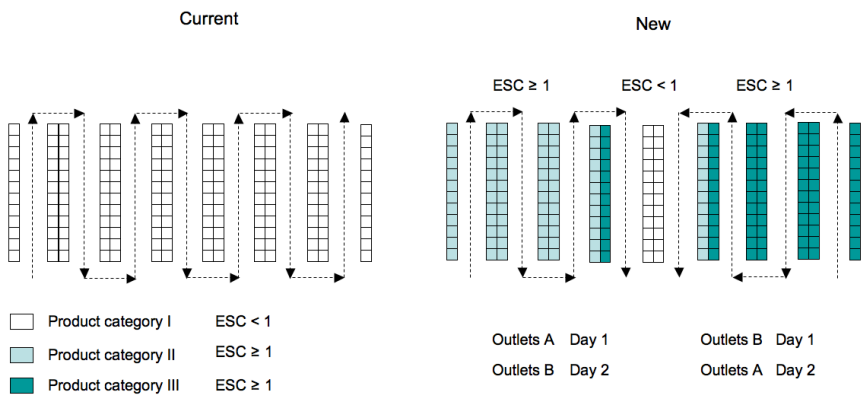


Figure 5.12: Example of a new warehouse layout for delivery every other day

As described in the previous section, for products with $ESC \geq 1$ it is not necessary to replenish them the next day. This means that the delivery moment may be shifted, as specified in Table 5.1. One may thus decide to group products for delivery to certain outlets on certain days of the week in order to enhance the order pick efficiency. The order pick efficiency in many retail distribution centers is relatively low, as many of these distribution centers still use fixed locations. As a consequence is not uncommon that picking a shop order means driving through all of the distribution center and as a result a drive time / pick time ratio as bad as 5:1 or even worse is not uncommon in the mostly manually operated retail distribution centers.

Chapter 4 section 4.7 already addressed other ways of organizing a distribution center. In this section, we stick to traditional distribution centers with fixed pick applications. This section is not a treatment on order picking nor on warehouse design; for that purpose we refer to (De Koster et al., 2006) and (Broekmeulen, 1998). We will only speculate on the sort of changes, that one might expect in a manual pick process when exploiting the ESC. A proper use of the ESC means that when picking goods for outlet replenishment orders, one no longer needs to travel through the entire retail distribution center. In conventional distribution centers this leads to savings in driving time, resulting in a higher order pick efficiency.

As an example, Figure 5.12 shows a possible new warehouse layout, using the ESC. On the left-hand side of the figure the current warehouse layout is given; for every shop order one

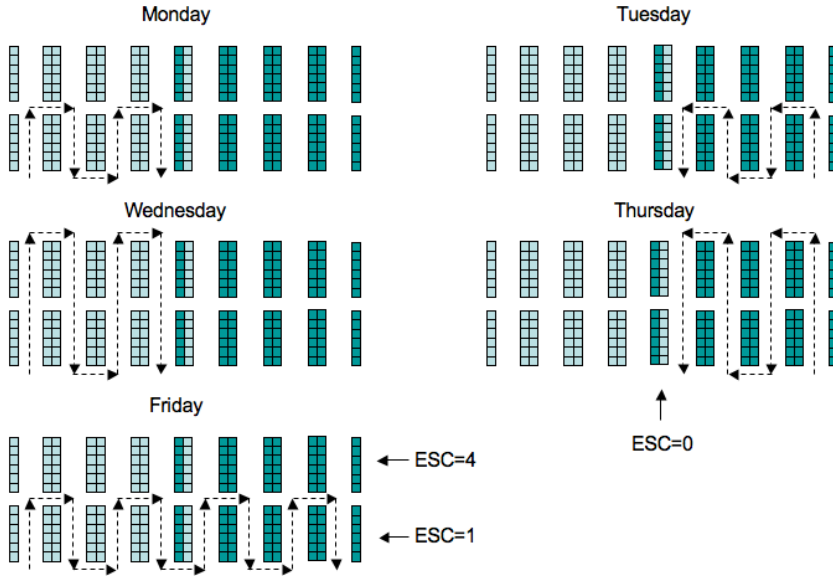


Figure 5.13: More advanced warehouse layout with 3 delivery frequencies

has to travel through all of the warehouse, because currently potentially every article can be reordered every day and because they are reordered at the latest moment, all products have to be delivered with the next shipment. On the right hand side of the figure a possible new warehouse layout is given, based on delivery every other day for part of the assortment. Products now have been divided into three categories: Category I with products with an $ESC < 1$ and categories II and III with products with an $ESC \geq 1$. The products from category I with an $ESC < 1$ are positioned on the racks in the middle (in the figure only one rack is shown). The products from category I are positioned in the left part of the warehouse and the products from category II are positioned in the right part of the warehouse. The retail outlets have been split up in two groups A and B. Outlets A on day 1 get delivered product category II and on day 2 they get delivered product category III, whilst outlets B get delivered in the opposite scheme. By alternating the delivery days per outlets A and B, the warehouse personnel remains evenly distributed over all of the warehouse.

Retailers use family grouping in their warehouse layout. Groups of products that in the retail outlets are presented on the shelves together as a family, are equally grouped together as a family in the warehouse. That way, when products have been picked, filling the shelves in the shops is easier. To conserve family grouping, product families preferably belong in their entirety to one and the same product category. If a whole family has an $ESC \geq 1$ except for a few products, one might in our example in Figure 5.12 duplicate these products in the warehouse by storing them not only with the rest of the family, but also on the top rack of the other part of the warehouse, as is shown in the right hand figure with the racks next to the middle one. Family grouping ultimately can always be achieved by convincing marketing to adjust the number of facings of those few products in a family, that have an Excess Shelf Coverage different from the rest of the family.

Taking the concept Shelf Coverage further and shifting the delivery moments of products with a higher Excess Shelf Coverage to certain days of the week, allows for a completely different layout of the warehouses for both slow moving and fast moving products. Figure 5.13 speculates on such a warehouse layout, exploiting ESC-values of up to 4. the figure shows the picking process for only one group of outlets. The other groups will have opposite patterns. Savings in driving time in this layout are apparent. Because the pick time/drive time ratio becomes much more favorable, flow racks or expensive order pick mechanization might no longer be required. It may even become feasible to work with picking lanes with a dynamic lay out or even with temporary order pick lanes.

The layout shown in Figure 5.13 is just one example of many possible layouts to benefit from the Excess Shelf Space. Further research is necessary to find out what layouts really are workable and what the exact savings will be.

Many retailers have implemented separate warehouses for fast moving products, that replenish outlets directly and warehouses for slow moving products, that replenish outlets indirectly by cross docking store ready shipments at the fast mover warehouses. The Excess Shelf Coverage (ESC) value however, offers an additional selection criterion, when deciding whether a product should be delivered from a slow mover warehouse or from a fast mover warehouse. If Figure 5.13 is the layout of a fast mover warehouse, then all products with an Excess Shelf Coverage of 5 or more could go to a slow mover warehouse.

5.5 Case: Excess Shelf Coverage at retailer Y

A case study performed at retailer Y gave the following results. Figure 5.14 shows practical

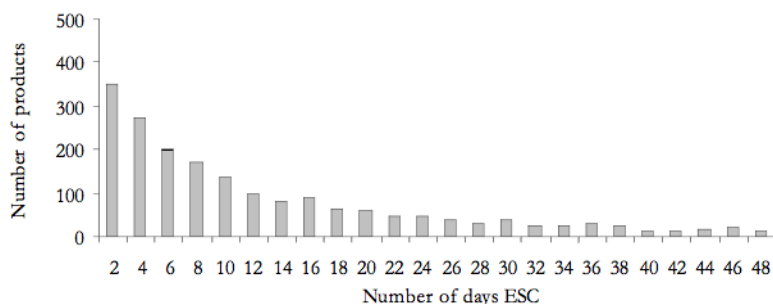


Figure 5.14: Excess Shelf Coverage in a supermarket outlet

values of the Excess Shelf Coverage based on measurements in a sample of three supermarket outlets (a big one, a small one and a middle size one)¹. The assortment analyzed consisted of over 3000 articles. Almost half of this assortment had an $ESC \leq 0$; without extra measures these products will regularly go out of stock. The ESC of the other half of the assortment is shown in Figure 5.14 (truncated at 48 days shelf cover).

As can be seen in Figure 5.14 the Excess Shelf Coverage values for many products in practice

¹The values in the figure are the minimum values found in the sample

happen to be rather high. This means that (provided the Excess Case Coverage is large enough), large parts of the assortment can be easily grouped into delivery schemes on fixed days in the week. In the shop this will mean a better spread of the workload over the week. In the warehouse it will not only lead to a better spread over the week, but also to a better warehouse layout with increased productivity.

Even within the same supermarket chain, the Excess Shelf Coverage of a product will vary per retail outlet. Not all shops have the same size, nor have the same shelf layout plan. Furthermore sales vary per outlet and vary over time and so will the ESC-values. When designing the warehouse layout and the picking procedures based upon the Excess Shelf Coverage, one needs to stay on the safe side when determining the Excess Shelf Coverage value. The Excess Shelf Coverage value chosen should be the lowest foreseeable during the design period in any of the shops served by that warehouse. But even then, large parts of the assortment still have very high ESC-values.

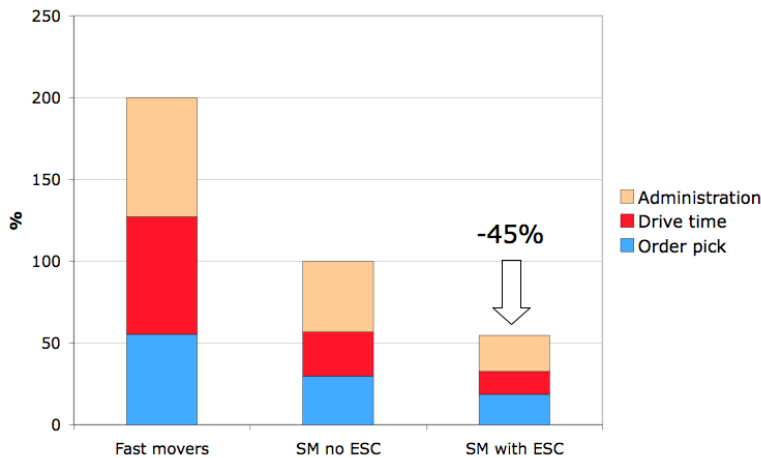


Figure 5.15: Savings in the order pick process with ESC

The retailer in the case study operated a fast mover warehouse and a slow mover warehouse. For the sake of this case study, we called products with an $ESC \geq 4$ slow movers. These products we assumed to be delivered only once a week. All other products in this study were called fast movers. This division between fast and slow movers mapped almost 1 - to - 1 on the current division between fast and slow movers..

The results of the warehouse calculations are shown in Figure 5.15. The figure displays the hours spent by the order pick crew in percentages. The hours currently spent in this slow mover warehouse are set to 100%. The hours currently spent on collecting the fast movers are twice as high as the hours spent on picking the slow movers. The use of the ESC will save 45% of the hours spent in the slow mover warehouse. This is 15% of the total order picking budget, because the use of the ESC has no effect on the hours spent on picking fast movers.

An interesting finding of this case study was that the store managers that we interviewed found it no problem whatsoever, to be limited to ordering the slow movers only once a week.

5.5.1 Reducing the number of order lines

With many products, the excess shelf coverage is larger than the case coverage, meaning that more than one case fits on the shelf. This indicates that, both in the distribution center and in the store, handling can be reduced when replenishing these items, by ordering more than one case at the time, thus by filling up the shelf completely. Broekmeulen et al. report that such a full shelf strategy in one supermarket chain gave an 11% reduction in order lines. See (Broekmeulen et al., 2006).

The savings found by Broekmeulen et al. are maximal, when the store waits with reordering till the latest reorder level is being reached. We have suggested above not to wait till the latest moment, but to use the excess shelf space to group the replenishment of products, in order to improve the warehouse operation. The good thing is, that when the excess shelf space is being used to improve the warehouse operation, to a certain extend a ‘full-shelf’ is still possible. This will give additional savings on top of those achieved already by the improved warehouse operation. But these remaining additional savings will be less than the savings claimed by Broekmeulen et al.

5.5.2 Dynamic warehouse layouts

The Shelf Coverage concept could also be used to drive ‘dynamic’ goods picking. Basically there are two options:

- working with temporary picking lanes
 - manual goods collection
- working with a goods sorter
 - automated goods distribution

When working with temporary picking lanes, the actual coverage in the shops is used as a driver to create the temporary picking lanes. If the coverage of an article in one of the shops has reached the lower reorder limit, a pallet with that article will be placed in the temporary picking lane. That article will be picked for all those shops where the coverage of that article has already passed the upper reorder limit, ideally till the pallet is empty (pick to zero). Even when the coverage of an article has not yet reached the lower reorder limit in any of the shops, but a full pallet can already be picked to supply those shops where the coverage has passed the upper reorder limit, even then a pallet might be placed already in a temporary picking lane, to level the workload, or to get better loaded distribution pallets or rolling cages. The pallets are placed in the temporary picking lanes in such order, that family grouping is preserved. If the temporary picking lanes have been created this way, i.e. with coverage as a driver, picking will be highly efficient, with a good drive time/pick time ratio. The efficiency will be much higher than can ever be achieved with fixed layouts such as shown in Figure 5.12 and Figure 5.13.

An alternative to picking the goods from pallets, is using a goods sorter. The concept is very similar. This time however a pallet is not placed in a temporary picking lane, but (part of) its contents will be placed on a goods sorter. Ideally again all pallets will be emptied (pick to zero). Pallets are selected on the Shelf Coverage criteria just as above. Again they are selected in such an order, that family grouping is preserved.

In both cases, either with manual order picking in a temporary lane or with automatic sorting, ideally only full pallets are retrieved from the warehouse and those pallets ideally will be emptied completely, i.e. picked-to-zero. This would render the bulk warehouse operation a full pallet handling process.

5.5.3 Demand forecast

The way the concept to Excess Shelf Coverage has been presented above, worked with average demand figures and with safety stock to cope with demand variability, as shown in Figure 5.11, where shelf coverage was made visible. In many cases however one might be able to do much better than that, by forecasting the variation of demand over time. In that case safety stock is not needed to cope with the variation of the demand, but only to cope with the variability of the demand forecast error. If demand varies over time in a reasonably predictable way, one will find much higher Excess Shelf Coverage figures, but they will vary over time.

Take for example the daily demand variation over the week. This variation might be periodical. When working with average demand figures, the week-pattern is considered to be demand variability and safety stock is needed to handle this variation. If forecasting demand over time one will consider this week-pattern in the demand forecast and there will be no safety stock needed to handle the week-pattern. The resulting Excess Shelf Coverage will be larger than found with average demand figures, but will vary over the week.

Actually, as soon as inventory has passed the earliest reorder level on the back of the shelf, one should constantly calculate what period of forecasted demand is covered by the remaining inventory on the shelf. Subtracting from that figure the replenishment lead-time, gives the Excess Shelf Coverage. With a weekly pattern the Excess Shelf Coverage will vary per day; early in the week the Excess Shelf Coverage will be rather high; later in the week it will be lower.

Fixed warehouse layouts cannot be designed to handle varying Excess Shelf Coverage figures. But on the contrary dynamic warehouse layouts easily can.

5.6 Analysis

Based on the contents of this chapter the following observations can be made:

Observation 39

Put more inventory in the stores

Supply Chain Synchronization suggests to shift inventory as far downstream as possible. Ideally all inventory is being shifted to the retail outlets, holding back at a retail distribution centers only so much as cannot be stored at the stores. From a supply chain perspective positioning more inventory in the stores does not mean higher inventory costs, because once a batch of products has been produced, the inventory exists and its associated costs already are being incurred. And as long as the inventory is not in the store, it simply is in the wrong place.

Observation 40

Picking individual items and cases is costly

The high costs of order picking can be reduced by delivering larger units, even to the stores

Observation 41

Standard-mix fits with synchronization In a synchronized supply chain, directly after production there is abundant inventory. This inventory can be used to assemble assortment boxes or pre-picked rolling cages, outside the order cycle. Assortment boxes can be assembled at the supplier, at a third party re-pack service, or at the retail distribution center.

Observation 42

Standard-mixes can reduce order pick costs

The costs of picking individual items can be reduced with assortment boxes. The costs of picking individual cases can be reduced with pre-picked rolling cages

Observation 43

ESC reduces picking costs for slow-moving articles

Many articles, especially slow-moving ones, happened to have excess shelf space. This excess space can be used to reduce the costs of order picking, because it facilitates more efficient warehouse operations.

Observation 44

Full shelf strategy reduces transaction volume

Additional savings in handling, both in the warehouse and in the store, can be achieved by a 'full-shelf' strategy for all those products where more than one case fits on the shelf. This strategy means that whenever a product is being replenished, as many cases are being replenished as fit on the shelf, thus reducing the number of orderlines.

Observation 45

Dynamic order pick layouts are efficient

Order picking becomes even more efficient with dynamic warehouse layouts, where either the picking lanes are adapted to distribution needs, or goods are sorted by an automatic sorter. In both cases ideally full pallets are picked or sorted to zero.

These observations lead to the following design elements:

Design choice 25

Deliver fast-moving articles on full pallets

Deliver cheap voluminous fast-moving articles on full pallets to the stores. This of course requires shops to be able to handle pallets.

(Based on observations 39 and 40)

Design choice 26

Use pre-assembled mixes

Wherever practical, use pre-assembled mixes like assortment boxes and pre-picked rolling cages. It reduces the costs of order picking and takes workload out of the order cycle.

(Based on observations 41 and 42)

Design choice 27

Deliver slow movers on scheduled days

When the shelf space allocated to a given article has just been re-stocked, the shelf inventory for most articles will cover the demand for far more than just one day. Retailers should organize shop floor replenishment into schemes that are based on shelf coverage, in line with an adapted warehouse layout to reduce the order pick cost..

(Based on observation 43)

Design choice 28

When reordering: Fill the shelf

Whenever reordering a product, or as much cases as fit on the shelf. This reduces the transaction volume and increases the order pick efficiency.

(Based on observation 44)

Design choice 29

Consider the use of dynamic order pick layouts.

Consider the use of dynamic order pick layouts, like temporary picking lanes or a goods sorter

(Based on observation 45)

Chapter 6

Sharing the cost benefits

6.1 Introduction

Supply chain synchronization aims at the lowest costs for the retail supply chain as a whole, whilst increasing customer service. It can achieve this lowest cost operation because it consistently reduces all main logistics cost components. But the major cost components can only be fundamentally beaten if the downstream supply chain partner is prepared to synchronize his processes to the upstream operation, as follows:

- The retailer's distribution operation should be synchronized to the supplier's production schedule, with not the supplier, but the retailer stocking the major part of the supply chain inventory. It is clear that current capacity restrictions cannot be resolved overnight; but savings are such, that it pays off to extend existing facilities or move to new facilities.
- The stores should align their order and replenishment processes to a simplified warehouse operation and accept to be forced into predefined replenishment schedules for items with sufficient shelf space. Furthermore the stores should, where necessary, align shelf layout plans to logistics' needs and receive the majority of smaller items in assortment boxes.

In other words, Supply Chain Synchronization paradoxically requires downstream supply chain partners to invest, in order to allow upstream supply chain partners to save costs. It is evident, that downstream supply chain partners will only be prepared to such investments, if adequate mechanisms exist to get an equal share of the cost savings. These 'mechanisms' to share the cost savings are the subject of this chapter.

6.2 Separate negotiations

Regularly, e.g. every year, retailers happen to have commercial negotiations with each of their suppliers. The result of these negotiations is a new price, or some revenue sharing arrangement for some time to come for those goods the supplier delivers.

Whenever a supplier and a retailer agree to improve their supply chain structure, that new structure will have an impact on the cost-breakdown at both supplier and retailer and should thus lead to a different price. Different however from commercial negotiations, where the intention is to make a good ‘deal’, negotiations on changes in the supply chain can be fact-based. Using rather simple logistic models (see e.g. (Daganzo, 1996)) and some simple cost figures, like the ones in Appendix B, both supplier and retailer can make a fairly good estimate of the cost structure and the savings at the other party. Preferably retailer and supplier should have these fact-based negotiations separate from the commercial negotiations and should agree upon a discount on top of the commercial arrangement. If this discount is not kept separately, it might get absorbed in the commercial transfer price deal during the next commercial negotiations round, where-after the savings disappear as a separate figure and are forgotten about.

Figure 7.14 on page 155 in the next chapter shows a typical logistics cost breakdown at a dry grocery supplier. Starting from the factory gate price, on the left in this figure, that includes all production related costs and the commercial margin, the various logistic cost components add up to the supplier’s sales price, or the retailer’s purchase price on the right.

The regular commercial negotiations between retailer and supplier most often tend to concentrate on the supplier’s sales price, including the logistics cost. In that case, logistic improvements should lead to a discount on this sales price.

Instead of basing their commercial negotiations on the supplier’s sales price, they better base their commercial negotiations on the so called factory gate price, in which case the retailer would be charged separately for the logistics costs. The good thing of this latter way of working is that retailer and supplier have to agree upon the height of the logistics costs. Because these costs now are known and remain visible, both parties will be inclined to search for supply chain improvements to reduce these costs.

When starting from the supplier’s sales price, logistics improvements rapidly will be shared between supplier and retailer. When starting from the factory gate price, it is quite natural that the retailer will benefit from the improvements; because why should he pay a surcharge higher than the costs?

It should be noted, that the factory gate price on the left in Figure 7.14 is the real factory gate price ex works the production plant and not the ex warehouse price, that confusingly so often is being called the factory gate price. See (le Blanc et al., 2005).

Taking the factory gate price as the basis for the commercial negotiations does not at all mean that the retailer actually should collect the goods at the supplier’s factory gate instead of the supplier delivering them at the retailer’s distribution centers.

6.3 Three separate subjects

Supply chain savings basically concern three subjects: inventory, handling and transport. As the natural way to compensate each of these three topics differs, it is good to treat these three subjects separately in the logistics’ negotiations. This is illustrated in Figure 6.1

Savings on inventory and storage With supply chain synchronization, the inventory levels at the supplier will go down or disappear and inventory at the retailer will go up. The total inventory in a synchronized supply chain normally is less than

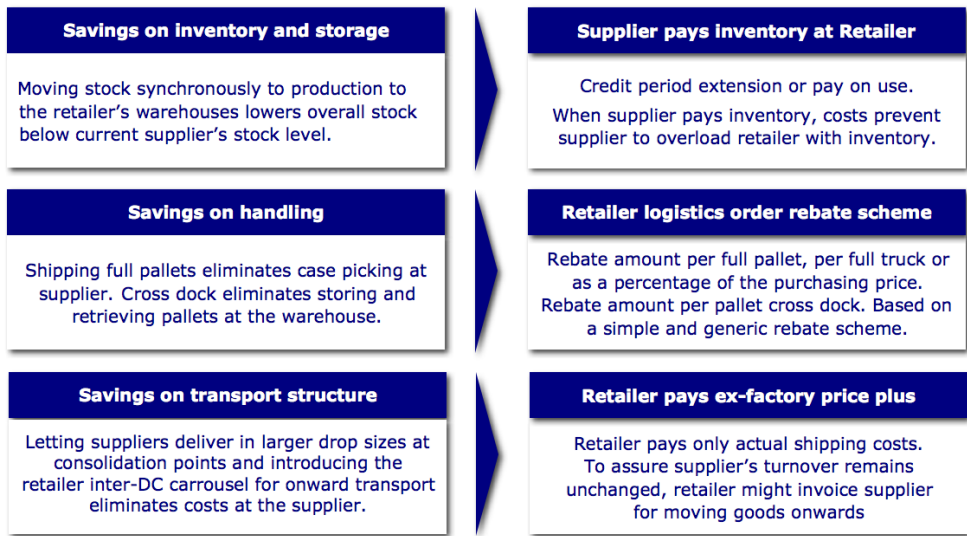


Figure 6.1: Savings on handling, inventory and transport should be negotiated separately

the inventory at the supplier's warehouse in a non synchronized supply chain. A quite logical way to compensate the retailer, is to let the supplier bear the inventory costs at the retailer. Possible ways to arrange this are extension of the retailer's credit period, or considering the inventory at the retailer as consignment stock and let the retailer pay on actual use. The length of the credit period extension should be equal to the period of demand that is covered by the average increase in inventory. When extending the credit period, the retailer owns the stock and without further arrangements bears the risks of spoilage and obsolescence. With consignment stock the supplier remains owner of the inventory and consequently also takes the inventory risks. An important reason why the supplier should pay for the inventory increase at the retailer is that this in a natural way withholds the supplier from overloading the retailer with inventory. If the supplier would bear the inventory costs all the way down till the stock on the shelves in the stores, the retailer will be more easily prepared to fill the stores and the shelves better. This leads to a better customer service and higher sales, to the benefit of all supply chain partners.

Savings on handling When goods are being delivered in larger quantities, there will be order pick savings: e.g. when delivering in full pallets, case picking disappears. When the commercial negotiations concern the suppliers sales price, the logical way to treat savings in handling is to agree upon a rebate scheme between supplier and retailer, see e.g. 'Service based pricing' as described in Section 3.5.3 and in Figure 3.7 on page 61.

Savings on transport The retailer should pay the actual shipping costs. These will go down when the supplier can deliver in larger drop sizes and at less remote locations. The larger drop sizes not only result from the larger delivery quantities in a synchronized supply chain, but also from changes in the supply chain structure, like delivery at consolidation points. This has been discussed at length in Chapter 4; see e.g.

section 4.6 on page 86.

6.4 Literature

Most of the literature on sharing benefits between retail supply chain partners, concerns the commercial arrangements and not so much sharing benefits resulting from logistic improvements. Examples of such commercial arrangements are contracts e.g. on Revenue-sharing. See (Cachon and Lariviere, 2005) and (Chauhan and Proth, 2005). For an extensive treatment of supply chain coordination with contracts see (Cachon, 2003) in chapter 6 in (De Kok and Graves, 2003). Narayanan and Raman stress the importance of aligning the incentives for the supply chain partners such, that the supply chain as a whole makes the highest overall profit: (Narayanan and Raman, 2004).

A basic incentive to stimulate logistics improvements is working with quantity discounts. A seminal paper in this area is (Monahan, 1984), see equation (3.41) in Chapter 3

An interesting article concerning logistics improvements is the one from Lee and Whang. They describe a scheme \tilde{A} , with the following elements (translated into our retail environment) (Lee and Whang, 1999):

1. Transfer Pricing. The retailer pays a transfer price at actual cost, because adding margin to the transfer price lets make the retailer sub-optimal quantity decisions.
2. Consignment stock. The supplier bears the costs of inventory at the retailer and the retailer pays on use.
3. Backlog penalty. In case an article of a supplier goes out of stock in the stores, the retailer pays a backlog penalty to the supplier.
4. Shortage reimbursement. The supplier pays a shortage reimbursement to the retailer whenever he fails to deliver.

6.5 Analysis

Based on the contents of this chapter the following observations can be made:

Observation 46 (Commercial and logistic negotiations differ)

Commercial and logistic negotiations differ. The commercial negotiations strive for a new price for some time and volume to come. The logistic negotiations is based on real and verifiable cost savings.

Observation 47 (Logistic negotiations can be cost justified)

In a synchronized supply chain the retailer helps suppliers to save costs. Already with simple logistics models, fairly good estimates can be made of these cost savings. This means that negotiations to secure a fair share of the savings can be fact based.

Observation 48 (Stock, handling and transport are compensated differently) In these negotiations the savings in handling, inventory and transport should be dealt with separately, as the natural ways to compensate them differ.

These observations lead to the following design choices:

Design choice 30 (Separate logistic and commercial negotiations)

The logistics negotiations should be kept separate from the regular commercial negotiations.
(Based on observations 46 and 47)

Design choice 31 (Logistic negotiations per subject)

The logistics negotiations should deal separately with inventory, handling and transport.
(Based on observation 48)

Chapter 7

Supply Chain Synchronization: Putting the pieces together

7.1 Introduction

The purpose of this chapter is to give a conclusive description of Supply Chain Synchronization in all of its elements, based on the observations and design choices that have been made in the previous chapters.

The basic idea behind Supply Chain Synchronization is relatively simple, almost trivial. It was developed in a project with some major grocery manufacturers, a logistics service provider, two retail chains and two universities¹. In that project retailers and suppliers sat together, with the intention to invent the retail supply chain with the absolute minimum overall cost. The results were astounding. Why was this not current retail supply chain practice? Why was not at least part of the potential savings realized? The answer is because it requires supply chain partners to cooperate and share the benefits. But reality is that everyone is sub-optimizing their own fragment of the supply chain. The overall result is a supply chain that is far from optimal.

In grocery retail supply, currently goods are being delivered from one point in the supply chain to the next downstream point on a daily basis, under stringent lead-time requirements, just in time and in small quantities. But it is obvious, that a manufacturer with an assortment of several hundred articles cannot produce every article type, every day. If a given article is being produced in batch only once a week, then just after production the manufacturer is keeping a full week of inventory for that article. Why would a retailer call off daily in small quantities under stringent lead-time requirements, something that could

¹Unilever, Procter & Gamble, Nestle, Masterfoods, Nutricia, Campina, Hays Logistics, Jumbo supermarkets, C1000 supermarkets, Eindhoven University of Technology, Erasmus University Rotterdam and Deloitte; partly funded under the Klic-program.

have been shipped earlier in larger quantities without any time pressure at all? Why not ship when you can, instead of wait until you have to? Why hold back inventory at the manufacturer, when the only place in the supply chain where inventory is of value is the retail outlet store? That is where the consumers are and that is where out of stock means loss of turnover.

If a manufacturer bottles product X on Friday, he should preferably ship that same Friday the whole production batch, all of the cycle stock, out to his clients. What is the purpose of having product X standing at the manufacturer's warehouse, until at unpredictable moments during the week retailers start reordering small quantities to replenish their inventory in great haste? There is little use in replenishing inventory down stream at the retailer in small quantities at the latest possible moment, when upstream the supply chain, at the manufacturer that same inventory is already waiting. From a supply chain perspective one should not replenish downstream inventory points for every product several times a week, but directly after production and preferably enough to cover the needs during the production interval all at once. The costs of the inventory that currently is waiting at the manufacturer, one way or another, is already part of the product price. So it is better to distribute the already available inventory across the supply chain in the most efficient way and negotiate better transfer pricing schemes.

That sounds logical enough for cycle stock, but how about safety stock ? On top of cycle stock we need safety stock, because demand is unpredictable and might exceed our expectations. We have always been told that you should hold back safety stock upstream in the supply chain in order to be able to allocate it at the latest possible moment when and where the need may arise (risk pooling); only by holding safety stock a manufacturer can guarantee his customer service levels. But from a supply chain perspective it is not the service level at the manufacturer that counts, but the consumer service level at the retail outlet store. From that perspective it is better to push all safety stock as far downstream the supply chain as possible. With only a few percent more safety stock, one achieves the same downstream service levels, without any hasty and disruptive last-minute delivery at all and thus overall cheaper.

With Supply Chain Synchronization, downstream the supply chain, volumes per product go up such, that for quite some fast moving product, manufacturers can replenish retail distribution centers directly from the production line, with significant savings on the transport and handling budget. Due to the larger volumes the costs of handling drop. Supply Chain Synchronization undoubtedly requires more bulk storage space at the retailer distribution centers, but less than one would expect, because the inventory that was previously there disappears. The extra storage requirements might in the short run seem to be a major stumbling block in synchronizing the supply chain. But when retailers decide to concentrate most of their goods receipts for each supplier on one of their distribution centers, acting as a consolidation point for goods from that supplier, the extra bulk storage space is only required at those centers that act as consolidation point. Working with Supply Chain Synchronization via a consolidation point, enables running full truck loads throughout, even from small manufacturers. The savings on transport appear to be impressive, especially when incoming and outgoing goods flows are being combined.

And then finally down to the shelves: retail outlet stores currently can re-order every article every day, based on scanning data at the checkout points. In practice however they will of course not re-order every item every day. When the shelf space allocated to a given article has just been re-stocked, the shelf inventory for most articles will cover the demand for

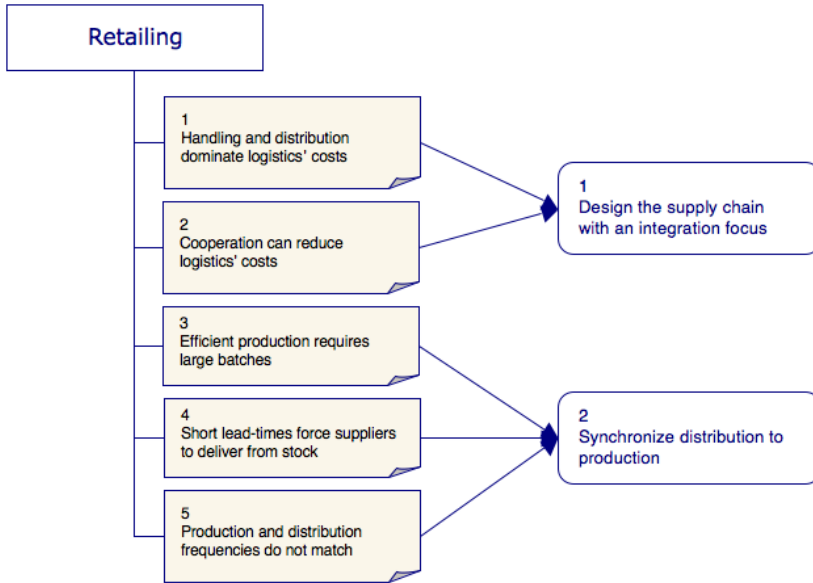


Figure 7.1: Retailing design choices

far more than just one day. Retail organizations should organize shop floor replenishment into schemes that are based on shelf coverage, in line with an adapted warehouse layout to reduce the order pick cost.

7.2 Case: Fresh ready cooked meals at retailer Z

Retailer Z orders all of his fresh ready cooked meals in a certain category from supplier M. The assortment encompasses 60 different types of meals. On average the manufacturer cooks 15 different types per day. Which means that the average meal is being cooked every four days. Each day, early in the morning the manufacturer ships the meals that are produced the last day and night to his warehouse. In that warehouse he stocks all 60 different meals under chilled conditions. The meals arrive at the warehouse mid-morning. Based upon the inventory in his warehouse, the manufacturer decides upon which meals to produce.

One of the greatest problems with chilled fresh food in general and certainly so with ready cooked meals, is deterioration. To save on code date, the retail distribution centers (RDC's) therefore do not hold inventory of meals. The current supply chain structure is shown in Figure 7.2

The stores reorder early in the morning. They can reorder any of the 60 variants. The store orders are aggregated per retail distribution center (RDC) and are sent to the manufacturer's warehouse. At the manufacturer's warehouse during the morning the meals are picked from inventory in the aggregate quantities per RDC. Early in the afternoon the meals are shipped

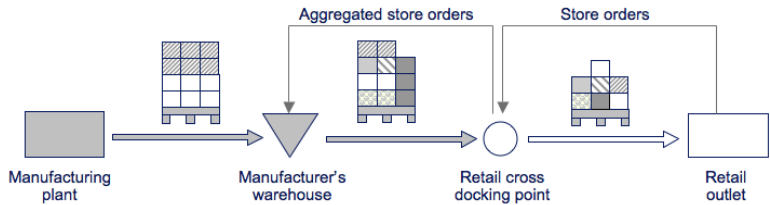


Figure 7.2: Case Z. Current supply chain structure for meals.

to the RDC's, but just prior to them leaving the warehouse, the new meals arrive from the plant. If a type of meal was out of stock and that type happens to be one of the types just arriving, the shipments to the RDC's can be completed. The following morning the meals are cross-docked at the RDC's in a pick-to-zero process. Consolidated in the same trucks with pallets with goods from the RDC's, the meals arrive at the stores later in the morning or early in the afternoon.

The problems with the current situation are;

- High levels of deterioration. Sometimes already at the manufacturer's warehouse meals have to be thrown away.
- Overlapping lead times, because the total order lead-time for the stores is longer than a day. The stores have to reorder early in the morning already new meals prior to the arrival of the previous order later that morning or early in the afternoon. Stores without an automatic store order system, that still order by hand, make mistakes with overlapping lead times, because they do not keep track sufficiently of what has been ordered already. As a result meals go either out of stock or can be thrown away.

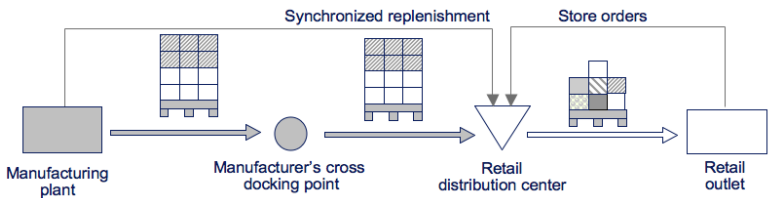


Figure 7.3: Case Z. New supply chain structure for meals.

To get rid of these problems, the supply chain was synchronized. For the time being this means that meals no longer are being cross-docked at the retailer, but at the manufacturer's warehouse. The interim structure is shown in Figure 7.3. The manufacturer in a VMI-setting gets insight in the stock levels at the 3 RDC's and based upon these levels decides which meals to cook in what quantities. The RDC's do not order anymore, but each afternoon get delivered those 15 odd meals cooked the former day and night, in quantities decided upon by the supplier.

The stores no longer are facing overlapping lead times. They now can order at the end

of each day the meals together with everything that is distributed via the RDC's and get delivered the next morning or early afternoon.

The interim structure is cheaper on handling, because the case handling at the manufacturer's warehouse disappears and the order pick process in the RDC's is simpler than the former pick-to-zero operation. Savings on handling are around 3% of the meals turnover. There is also a slight decrease in overall inventory of meals and consequently a slight improvement in the average code days available to the stores.

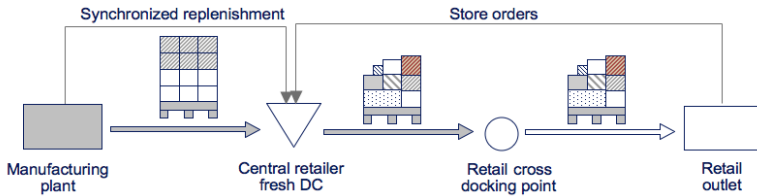


Figure 7.4: Case Z. Target supply chain structure for meals

But this was considered to be only an interim situation that could be realized almost overnight. The target situation is shown in Figure 7.4. In this target structure, the manufacturer bypasses his warehouse and delivers the goods at only one point at the retailer, the central fresh distribution center, or a decentralized part of it. In this central distribution center goods are picked on store order and assembled on store ready pallets, together with goods from other suppliers. These store ready pallets than are shipped to the RDC's, that for the meals are operating as a center for cross docking and consolidation. In a way this target structure resembles the structure where it all started with in Figure 7.2, but it is not quite the same.

7.3 The elements of Supply Chain Synchronization

After the short description of Supply Chain Synchronization in the introductory paragraph of this chapter, we will now go over each of the elements of Supply Chain Synchronization in a more structured way. We will do so based on the observations and design choices made throughout the previous chapters. The four figures 7.1 through to 7.7 give a summary of the observations and the design choices. Subsequently figures 7.8 to 7.13 give an ordered overview of the design choices, clustered into the following themes:

- Synchronization and structure
- Management
- Shop replenishment
- The 'Carrousel'
- Sharing the benefits

In the following sections the design choices will be translated into a comprehensive description of Supply Chain Synchronization, grouped around these themes.

7.3.1 Synchronization and structure

It is taken for granted here that the manufacturing industry (at least those manufactures who deliver to grocery retail) is equipped with process type production lines. These lines need to produce in large batches in order to produce at low cost. Hence the majority of articles will be produced at scheduled times with certain intervals. It was shown in Chapter 3 that with Supply Chain Synchronization it is even advantageous to increase the production batch size.

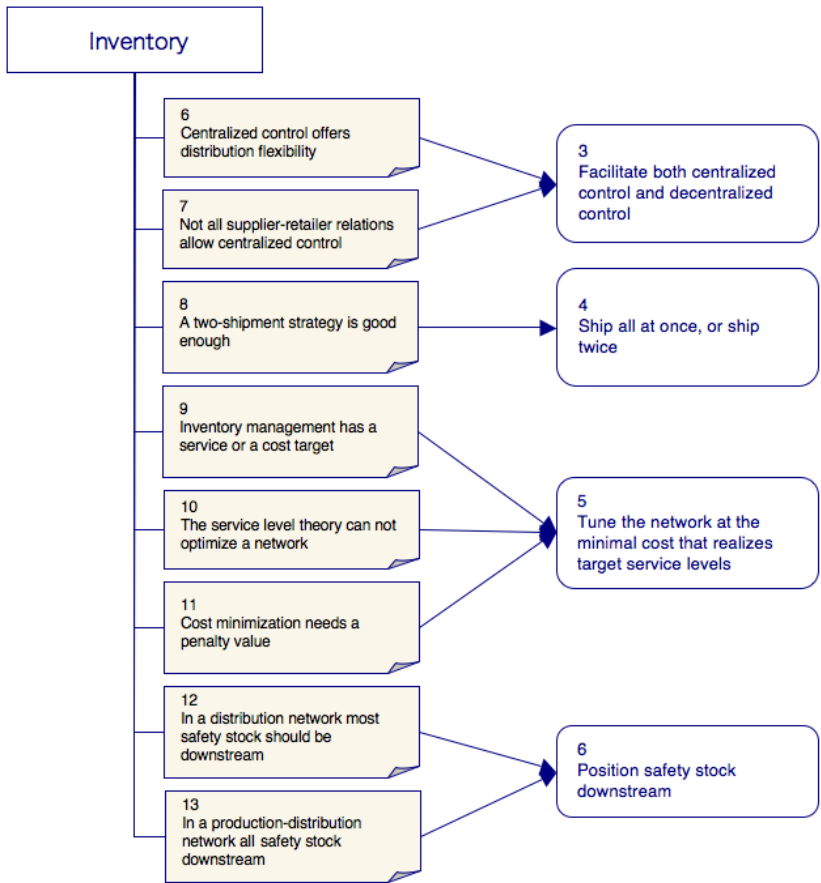


Figure 7.5: Inventory design choices

A certain product might be produced once or twice a week, biweekly, once a month, or even less. From a supply chain perspective, once a batch of products has been produced, the inventory is there and somehow or another it's costs are borne. The situation of such an integrated supply chain, where costs and benefits are shared at supply chain level was modeled in Chapter 2 by systemwide holding costs. The inventory theory and supporting simulations showed that in such a supply chain all inventory should be positioned down-

stream as close as possible to the customer. But Chapter 2 also modeled the more complex situation where goods are owned and are bought at a purchase price from an upstream node and sold with a margin at a sales price to the next downstream node. The surprising outcome of the theoretical modeling was that even in this configuration that fits better with current administrative practice it is better to position most of the inventory downstream.

To make inventory effective as soon as possible, it should be moved downstream the supply chain immediately after production (or immediately after becoming available). This means that the production schedule is leading and that distribution should be synchronized to production.

By moving goods immediately to the retail clients, the cycle stock at the manufacturer disappears. The main decoupling point, the one that separates the production process from the distribution process, then moves to the retailer's distribution centers. There it will replace all inventory that is currently being kept by the retailer. As a result the overall supply chain inventory drops to the minimum, at or even below the inventory level that is currently kept at the supplier alone. This means that should the supplier in a synchronized supply chain bear the total supply chain inventory costs, his inventory costs would be comparable to his current inventory costs.

The manufacturer's warehouse then might become a consolidation point where goods are cross docked, on full pallets only. The sole purpose of this cross docking platform will be to consolidate goods from separate plants into full truckloads to the retail distribution centers: it becomes a manufacturing consolidation center. The only inventory kept is to temporarily stage goods for consolidation into a full truckload or as second shipment in the two shipment strategy described in Section 2.4.6 on page 21.

The inventory should be moved along the supply chain in the cheapest possible way. Thus it should be moved in the largest possible quantities, i.e. preferably in full pallets and in full truckloads. That way both handling and administrative overhead will be minimal. The quantities to be moved should at least cover the retailers' needs during the production interval.

Furthermore, when goods are being moved as soon as they become available, prior to urgent needs, time pressure will be minimal, which creates optimal conditions for consolidating goods into full truckloads and for leveling workload over time.

It is not strictly necessary to move all inventory immediately after production. As much inventory should be shipped immediately, as is needed to achieve the inventory reduction effect and the lowest transport price. It might be a deliberate strategy to ship the production quantity in two shipments, even though this might cost extra storage handling.

As said already, according to the latest in supply chain inventory management, all supply chain inventories (both cycle stock and safety stock) should be positioned downstream close to the customer and so improve customer service.

The transport and distribution structure should be rationalized accordingly. The challenge is to move things further in larger quantities and to eliminate or bypass parts of the supply chain. Wherever possible one should drive directly from production to one or more retail distribution center, bypassing the manufacturer's warehouse. It was shown in Chapter 3, that this might be cost-effective even with 'small' products.

Moving things in larger quantities, means moving full pallets only. When a retailer cannot receive a full pallet at a certain distribution center, because a full pallet contains more than

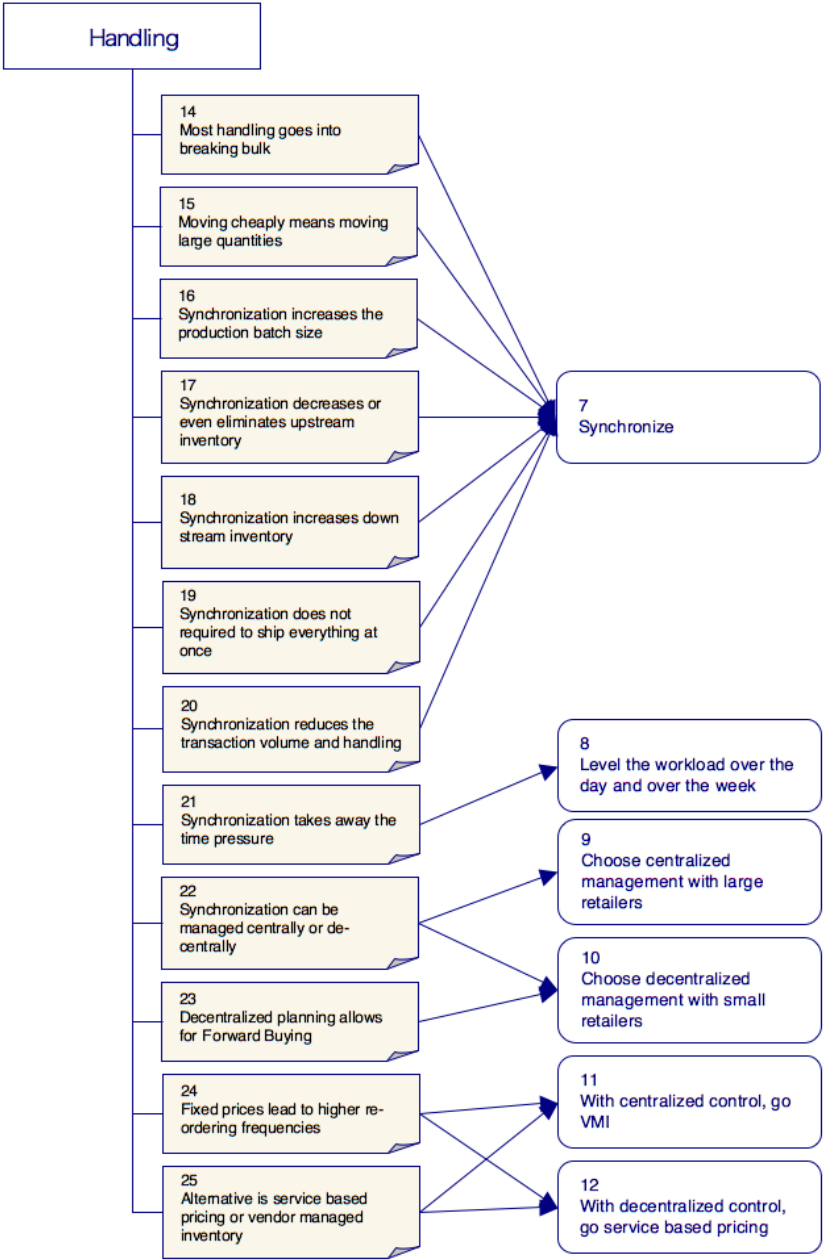


Figure 7.6: Handling design choices

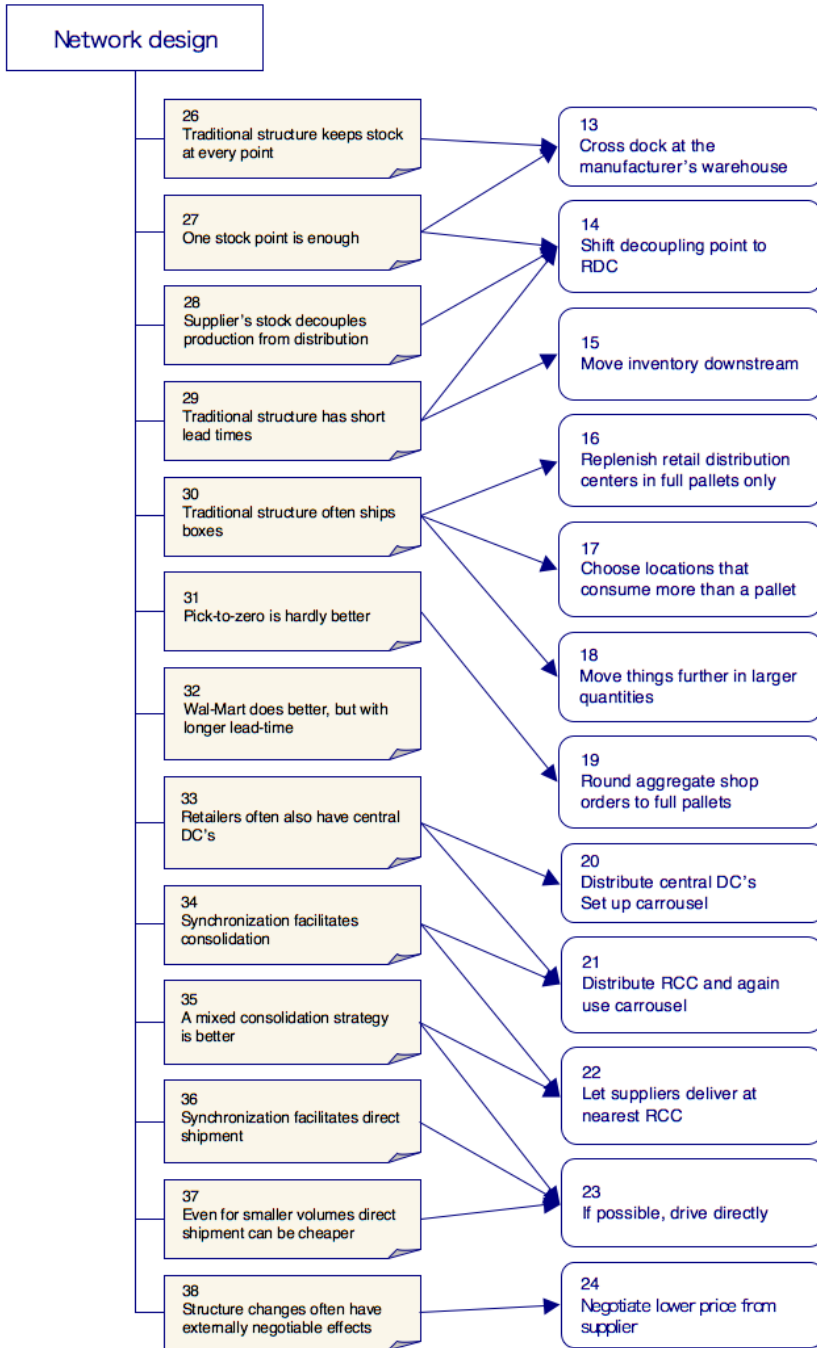


Figure 7.7: Network design choices

Synchronization and structure

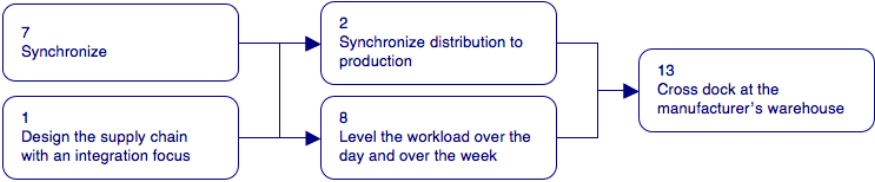


Figure 7.8: Synchronization and structure design

the needs of that distribution center during the production interval, these goods should not be stored in that distribution center, but at a more central distribution center, that services a larger area. If the retailer cannot accept a full pallet at such a central distribution center, because a pallet even then covers more than his total needs during the production interval, either the retailer should not sell this product at all, or the manufacturer should assemble less product per pallet and stack two or three of these ‘lower’ pallets on top of each other at production.

Because goods are being shipped now in large quantities as soon as they become available, time pressure disappears and the workload at the manufacturer’s warehouses and retail distribution centers can be leveled over the day and over the week.

Centralized and decentralized management



Figure 7.9: Management design

7.3.2 Managing Supply Chain Synchronization

Synchronization is a form of supply chain coordination, that requires alignment of the downstream distribution processes to the upstream production or order picking schedule. The primary distribution between manufacturer and retail distribution centers can be managed either centrally by the supplier or de-centrally by the retailer. The secondary distribution between the retail distribution centers and the retail stores can be managed centrally by the retail organization or de-centrally by the retail stores. See section 3.4.4 on page 54.

Centralized planning and de-centralized planning might be organized as described in Table 7.1.

Table 7.1: Managing Supply Chain Synchronization

	Centralized planning	De-centralized planning
Primary distribution	Supplier has visibility of retailer's downstream inventory and manages replenishment of retail distribution centers (= vendor managed inventory) Contractual arrangement on benefit sharing	Supplier publishes production schedule to retail clients. Retailers are enticed to order against that production schedule by a service based price discount scheme.
Secondary distribution	Retailer's central organization has visibility of store inventory levels and manages the replenishment of the stores	Retailer's central organization publishes warehouse order picking schedules to the stores and stores order against that schedule. Stores decide upon quantity.

Centralized planning is not always easy to implement. A suitable form of implementing synchronization with central management is vendor managed inventory (VMI), where the supplier manages the inventory at the retailer. In order to function properly, it requires information exchange on stock levels, forecast demand and planned deliveries. It requires investment in the relationship, which increases switching costs and thus is only fit for situations where the retailer has enough bargaining power to negotiate good commercial conditions. And it requires both retailer and supplier to be adequately equipped with IT-systems. The supplier's system should facilitate managing the inventory levels at each of the distribution centers of each of his retail clients, with flexible rule setting for the generation of shipment orders. The inventory levels and replenishment rules will be different for each of the retail clients.

Decentralized planning is easier to implement and gives more flexibility to the retailer. It requires far less data exchange. The supplier daily publishes his production schedule for the next period, on a restricted site on the Web or via e-mail. The inventory planners at the retailers check the published production schedule and order for each product a quantity enough to cover the needs till the next production run. The workload for the inventory planners at the retailer is less than currently: instead of checking the inventory status of all products every day, they now only check those products scheduled for production. The supplier can entice the retailers to order against his production schedule by offering a discount on timely ordered goods. When this discount is in the form of a decent service based pricing scheme, it will guide the retailer to the correct ordering behavior. If the production system has enough volume flexibility on the yet published production schedule, the supplier virtually can produce on order.

Many retailers perform so-called 'Forward Buying', by ordering more than they need on special price offers. Those retailers experience centralized planning by the supplier as a means to block their possibility for forward buying. With decentralized planning however they still can perform forward buying. They even can perform forward buying

on products without special offers, by ordering a quantity larger than the needs till the next production run, whenever this generates a large enough discount; for instance when ordering 3 pallets extra might mean running a full truckload.

Note that there is great commonality between the primary and the secondary distribution part. In both cases the replenishment per item will be less frequent than currently and will be scheduled on certain days.

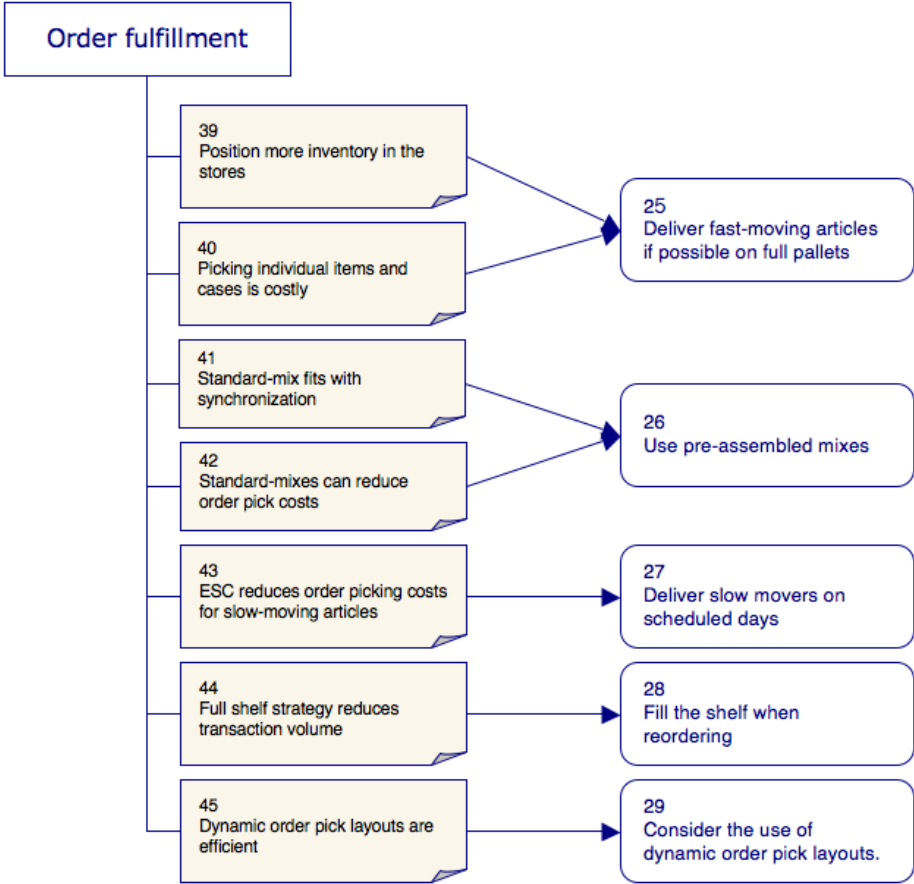


Figure 7.10: Shop replenishment design choices

7.3.3 Shop replenishment

Chapter 2 on inventory, has shown that in a properly tuned inventory distribution network safety stock should be positioned downstream. To reduce the costs of handling and inventory, also the cycle stock should be moved downstream the supply chain in large quantities directly upon availability. This means that all inventory, both safety stock and cycle stock

should be positioned downstream the supply chain close to the customer. The best place for inventory is in the stores and what does not fit in the store should be temporarily kept in a retail distribution center. See Figure 7.10.

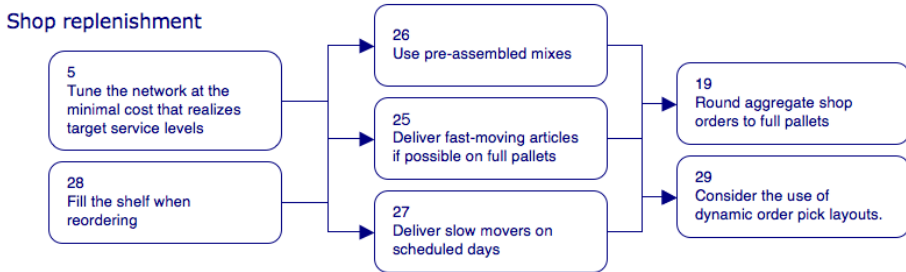


Figure 7.11: Shop replenishment design

To reduce the costs of order picking slower moving articles, one might consider the use of pre-assembled mixes, such as assortment boxes. Another option is the use of dynamic warehouse layouts. Especially when goods are pushed to the stores, the picking lanes can be adapted to the delivery pattern, or goods might be sorted with an automatic sorter.

Once an article with excess shelf space is due to be replenished to an outlet, a full shelf strategy should be followed: as many cases should be ordered as fill up the shelf space completely. That way the number of order lines is minimal and the pick efficiency is maximal.

Based on the excess shelf space the picking lanes in a slow mover warehouse can be redesigned and goods can be scheduled for replenishment to the stores in a scheme synchronized to the pick process in the warehouse.

7.3.4 The ‘Carrousel’

The Carroussel

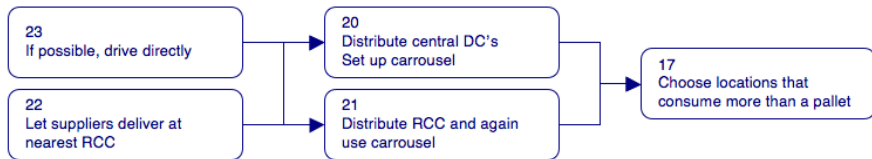


Figure 7.12: Carroussel design choices

An interesting supply chain structure, described in Section 4.6.2 on page 91, is what we called the ‘Carroussel’. Retailers often operate a network structure with more than one regional distribution center for fast-moving goods and one or more central distribution centers for slower moving items. The idea now is to distribute the central distribution centers over

the regional ones, such that each decentralized part still is central, but for part of the assortment only. Transport from central to regional now at the same time facilitates lateral transshipment between regional distribution centers.

By making each of the regional distribution centers also a retailer consolation center as described in Section 4.5 on page 79, suppliers can be allocated to the nearest consolidation center. Whenever a supplier has not enough volume to drive cost effectively to each of the regional retailers distribution centers, he can drop off all of the goods act to nearest distribution center, acting as consolidation point, part of the goods will be destined for the decentralized distribution center for slow-moving goods and part for the collocated regional distribution center for fast moving goods. The carrousel then takes care of the onward shipment to the other locations.

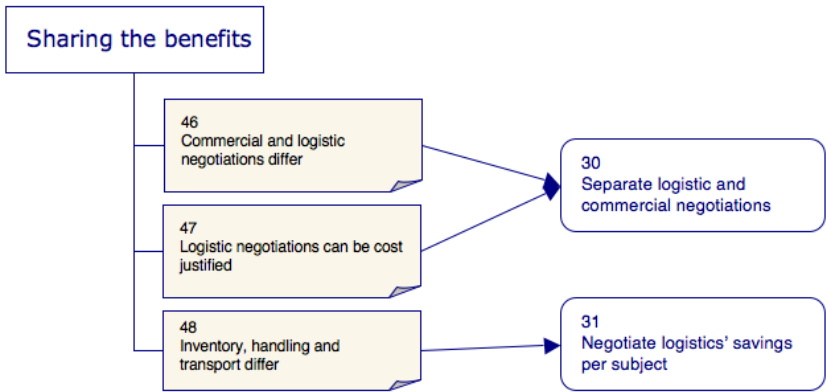


Figure 7.13: Negotiation design choices

7.3.5 Sharing the benefits

The commercial and the logistic negotiations should be kept separately, because they differ. The commercial ones result in a new price for some time to come using all sorts of arguments; they are held on a regular basis, e.g. annually. The logistic ones will be held whenever a logistic improvement has been realized. The savings achieved by this improvement can be calculated. This calculation forms the basis for the negotiations.

The three main subjects in distribution logistics (like the chapters in this thesis) are inventory, handling and transport. Because improvements in each of these three subjects workout differently in the way they realize savings, it is most natural to reward them differently as well. This means that the logistic negotiations should treat these three subjects differently.

7.4 Are all cost elements covered?

To see whether all cost elements have been covered, we return to the logistics cost breakdowns of both supplier and retailer.

We start with the supplier's cost breakdown shown in Figure 7.14

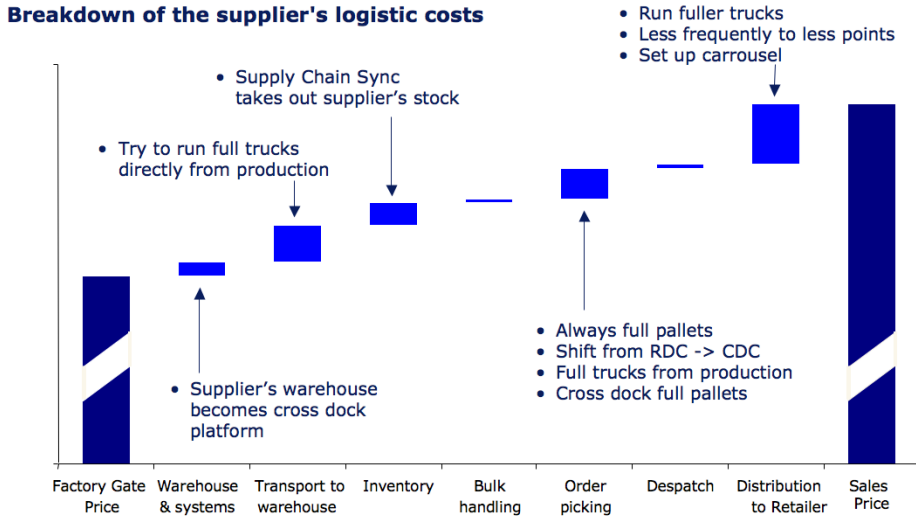


Figure 7.14: Attacking the supplier's logistics cost breakdown

Warehouse & Systems The supplier's warehousing costs will shrink because goods no longer will be stored, but cross docked upon arrival. If the warehouse is outsourced, savings will be immediate.

Transport to warehouse The costs of driving to the warehouse disappear for every full truckload that can be run directly from production to the retail client.

Inventory The costs of the supplier's inventory evaporate with the disappearance of the supplier's inventory.

Order picking The costs of order picking at the supplier's warehouses mainly stemmed from case picking. By delivering always full pallets, there will be no further case picking. The retailer should decide which goods should be delivered to the shops from the regional distribution center's (RDC's) and which goods from a central distribution center (CDC), such that all goods can be delivered by the suppliers on full pallets.

Distribution to retailer The costs of distribution to the retailers sink by running full trucks less frequently to less points. In the special case of the retailer operating a carousel, goods can be delivered at even less points, but the retailer then needs to move part of them on to their destination.

An analysis of the retailer's cost breakdown shown in Figure 7.15 leads to comparable results.

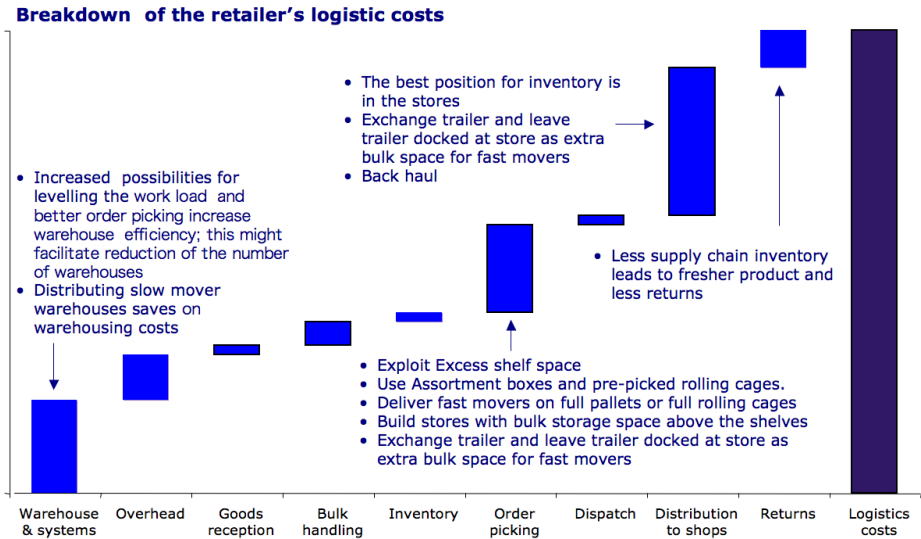


Figure 7.15: Attacking the retailer's logistics cost breakdown

Warehousing Increased possibilities for levelling the work load and better order picking increase warehouse efficiency; this might facilitate reduction of the number of warehouses. Distributing slow mover warehouses saves warehouse costs

Order picking By exploiting the Excess shelf space and grouping the delivery of product categories on certain days of the week, will increase the efficiency of the slow mover order pick process. The use of Assortment boxes for smaller items and pre-picked rolling cages with a standard mix of products lower the workload and the costs of the order picking process. With Supply Chain Synchronization goods move in larger quantities all the way down the supply chain preferably even down to the stores. Larger stores with a pallet lane for cheaper and voluminous fast moving goods, save on the cost of order pick at the warehouse. And at the same time such stores offer a better customer service, because more inventory is in the store. Another way to create extra 'back-room' storage space for fast-moving products can be created by exchanging the trailer, take the empty one away and leave the new trailer docked at the store.

Distribution to stores The best position for inventory is in the stores Exchanging trailers at the stores also reduces the costs of distribution. Trucks on their way back from replenishing a store might pass by a supplier plant or warehouse/consolidation center, pick up goods and deliver these at a retail distribution center or better a retail consolidation center (Back Haul).

Returns Most returns are being caused by products passing the 'best-before' date. Less supply chain inventory leads to a fresher product in the stores and subsequently to less returns.

7.5 Comparison with other supply chain improvement schemes

Now that all elements of Supply Chain Synchronization have been defined, it's time to compare our results with some other well known comprehensive supply chain improvement schemes such as ECR and the Bullwhip.

The ECR initiative.

Following the Quick Response (QR) initiative in the textile industry, the Efficient Consumer Response (ECR)² movement in the grocery industry began in the mid-nineties and introduced new principles of collaborative management in the retail supply chain. It was understood that companies can serve consumers better, faster and at less cost by working together with trading partners. For a critical overview of the ECR initiative see (Whiteoak, 1999).



Figure 7.16: ECR focus areas

Citing ECR: "ECR recognized a business environment with advanced information technology, growing competition, global business structures and with consumers focused on better choice, service, convenience, quality, freshness and safety and the increasing movements of goods across international borders aided by the internal European market. This new reality required a fundamental reconsideration of the most effective way of delivering the right products to consumers at the right price. Non-standardized operational practices and the rigid separation of the traditional roles of manufacturer and retailer threatened to block the supply chain unnecessarily and failed to exploit the synergies that came from powerful new information technologies".

ECR focuses on four areas: Demand Management and Supply Management and the supporting Enablers and Integrators. See Figure 7.16. ECR is in the process of developing an assessment scorecard, based on these four focus areas. This should become a tool to assess

²See the ECR- Europe website www.ecrnet.org

jointly with a supply chain partner the supply chain improvement potential.

VMI, Vendor Managed Inventory, is one of the techniques promoted by ECR. With VMI the Vendor (supplier) manages the stock levels and availability in his customer's warehouses, based on forecast demand. Currently ECR prefers to call it CMI, Co-Managed Inventory. With CMI retailers and suppliers work together to reduce the level of stock and to improve the availability of products in their supply chain. Sales forecasts and promotional plans are shared and discussed so that the precise amount of stock is available at the retailer's RDC's.

However ECR does not really promote to synchronize the supply chain. ECR at one time promoted synchronized production: instead of synchronizing distribution to production, ECR advocated to synchronize production to distribution, i.e. to the daily pull from the retailers. It is not realistic that the mostly batch oriented process type manufacturing industry can produce every article of the assortment every day (A pipe dream says Whiteoak.(Whiteoak, 1999)).

But as to the focus areas of ECR and their enablers and integrators, as presented in Figure 7.16: They are important supply chain improvement elements and for a great deal complementary to what we have described in this thesis. Supply Chain Synchronization comes on top of that and the ECR enablers might as well enable synchronization of the supply chain.

On the other hand, basically Supply Chain Synchronization is very simple and if necessary its main elements can be implemented rather easily, without most of the enablers listed by ECR. Take for example de-centralized management as described in Section 3.4.4. In its simplest form a supplier, based on his production schedule, publishes on the Web at which dates retailers should order which products plus an indication of the interval till the next synchronized ordering possibility. If retailers adhere to that synchronized ordering schedule, they get an extra discount. The retailer's then should order enough to cover their needs for the whole production interval. That basically is all there is to a simple implementation of Supply Chain Synchronization.

The Bullwhip-Effect

Due to information distortion and 'forward buying' on price promotions the multi-echelon retail supply chain suffers from exaggerated order swings, which Lee et al. have called the Bullwhip Effect. (Lee et al., 1997) As shown in Table 7.2, taken from that article, Lee et al. recognize four causes of the bullwhip effect, and several measures to attack these causes. Summarized: Share information among supply chain partners and align processes.

The elements of supply chain synchronization listed in this thesis, fairly well cover the measures proposed by Lee et al. But synchronizing distribution to production and shop replenishment the warehouse operation goes an important step further than Lee et al. do. In a synchronized supply chain, all of the inventory, as soon as it becomes available from production, is moved all the way down the supply chain and there is no frequent reordering and there will be no bullwhip at all

Table 7.2: The Bullwhip-Effect

Causes of Bullwhip	Information Sharing	Channel Alignment	Operational Efficiency
Demand Forecast Update	<ul style="list-style-type: none"> • Understanding system dynamics • Use point-of-sale (POS) data • Electronic data interchange (EDI) • Internet • Computer-assisted ordering (CAO) 	<ul style="list-style-type: none"> • Vendor-managed inventory (VMI) • Discount for information sharing • Consumer direct 	<ul style="list-style-type: none"> • Lead-time reduction • Echelon-based inventory control
Order Batching	<ul style="list-style-type: none"> • EDI • Internet ordering 	<ul style="list-style-type: none"> • Discount for truckload assortment • Delivery appointments • Consolidation • Logistics out-sourcing 	<ul style="list-style-type: none"> • Reduction in fixed cost of ordering by EDI or electronic commerce • CAO
Price Fluctuations		<ul style="list-style-type: none"> • Continuous replenishment program (CRP) • Everyday low-cost (EDLC) 	<ul style="list-style-type: none"> • Everyday low price (EDLP) • Activity based costing (ABC)
Shortage Gaming	<ul style="list-style-type: none"> • Sharing sales capacity and inventory data 	<ul style="list-style-type: none"> • Allocation based on past sales 	

VMI and CPFR

Supply Chain Synchronization does not contrast with Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting and Replenishment (CPFR). On the contrary, Supply Chain Synchronization with centralized planning is the ultimate form of VMI and CPFR, as is shown in Figure 7.17

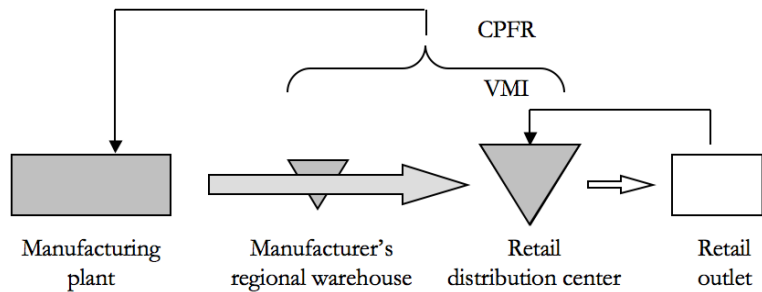


Figure 7.17: Supply Chain Synchronization

With Supply Chain Synchronization, when managed centrally by the supplier, retailers communicate their stock levels and their demand forecasts to the suppliers. These suppliers schedule their production based on overall supply chain stock levels and deliver the larger part of each production batch immediately after production to the retail distribution centers. As a result there will be hardly any inventory at the manufacturer, there will be more inventory at the retailer, closer to the customer. Because the production now is scheduled against the retail inventory levels and demand forecasts, instead of against the inventory levels in the manufacturer's regional warehouses, the production is more demand driven than before.

Chapter 8

Concluding remarks and suggestions for further research

8.1 Introduction

This thesis set out to design the retail supply chain with the overall lowest costs, whilst increasing customer service. The premise was that this can be achieved by "Synchronizing the Retail Supply Chain", as the title of this thesis states. More specifically this means synchronizing downstream client processes to upstream supplying processes.

We called this supply chain management control concept Supply Chain Synchronization.

This chapter concludes this research; it is structured as follows: We open the chapter in section 8.2 with a description of the line of reasoning behind the thesis. We then in the subsequent section 8.3 explore the field of application of Supply chain synchronization. In section 8.4 we indicate what this thesis adds to the existing body of knowledge. And in the final section 8.5 we list some suggestions for further research.

8.2 The line of reasoning

In this thesis we addressed the retail supply chain aspect by aspect and we made observations and design choices leading to a comprehensive description of Supply Chain Synchronization in Chapter 7. To conclude that design, in this section we will build the line of reasoning that was followed. That should prove that indeed we have developed the retail supply chain with the lowest costs.

The entire retail supply chain design in this thesis is based on three foundations:

- I. The logistics cost breakdown at both retailer and supplier in Chapter 1 shows that order picking and distribution are the most important cost elements.
- II. In the retail supply chain most of the product value is created upstream at the supplier. The extended Newsvendor-formula in Chapter 2 shows that from the point where most of the value is created, inventory should move all the way downstream.
- III. To produce efficiently suppliers have to produce in batches. By extending the EOQ-formula it was shown in Chapter 3 that goods should move in large quantities.

From thereon the line of reasoning went as follows:

1. To reduce the costs of order picking the order sizes per item should be rounded to full homogeneous pallets from the suppliers to the retail distribution centers and should be rounded to full boxes from the distribution centres to the stores.
2. From the retail distribution centers to the stores this means:
 - Full boxes might require more shelf space to be able to stock the contents of a box on the shelf. More shelf space means more facings per product or wider shelves.
 - Picking these full boxes efficiently might mean stores ordering slow movers less frequently, with ordering and delivery windows scheduled per product family on certain days of the week.
 - Full boxes for slow movers can also be achieved by using complementary mix boxes that contain either solely a fast mover or a fixed combination of that fast mover and a slow mover. The slow mover then cannot be ordered separately and always comes piggy-back on the fast mover.
 - More full boxes can also be attained by creating assortment boxes (average mixes) that might contain a complete basic assortment or all products involved in a price promotion.
3. Full pallets from supplier to retail distribution center implies
 - Full pallets means ordering less frequently per item. The maximum order size and the minimum number of transactions is reached when a retail distribution center orders or gets delivered only once per production interval with the order rounded to full pallets, which means that distribution is synchronized to the production schedule. Or only once per n production intervals if the "Best before" code date so allows.
 - If a regional retail distribution center from a certain product cannot accept a full pallet, because the average usage is less than a full pallet either per production interval or before passing the "Best before" code date, the item should not be stored in a regional distribution center, but should be stored in a more central slow mover distribution center covering a larger area and thus fulfilling a higher demand rate.
 - If even a central distribution center cannot accept a full pallet, either the manufacturer should produce lower pallets (and may stack two on top of each other at the production line) or the retailer should not sell the product at all.

4. To reduce the costs of distribution between supplier and retailer, the supplier should deliver full truckloads.
 - With very voluminous products one might be able to run a full truck with all the same product from a production line straight to a regional retail distribution center.
 - With less voluminous products the manufacturer might still be able to run a full truck with all the same product straight from a production plant to one of the retailer's regional distribution centers (preferably nearby and preferably requiring the larger part of that truckload) with this regional distribution center acting as a consolidation point and with the retailer moving on that part of the volume that is destined for his other distribution centers.
 - For his synchronized retail clients a manufacturer does not need to first store the goods in his warehouse and to later retrieve them on client order, but for these clients he can operate a cross docking process consolidating goods from various production lines and manufacturing plants into the same truck to a retail distribution center.
 - Supply Chain Synchronization takes away time pressure which means that a manufacturer might stage products for a short while to consolidate them into full truckloads.
 - If a manufacturer supplies not enough volume to run a full truckload to each of the regional warehouses, the volume should be shipped to one or more of the regional distribution centers acting as consolidation points, with the retailer moving on part of the volume.
5. By synchronizing delivery to the moments that goods become available from production, inventories are not lying idle upstream, but move downstream immediately to make them effective.
6. If the root node experiences a higher lead-time upstream similar amounts of inventory should still be shipped downstream, but on top of that extra safety stock should be kept at the root node. So, forcing manufacturers to be more flexible in their production scheduling increases the opportunities for shipping all inventory downstream.
 - If the most upstream node, the root node, adds most of the value, all inventory should be shipped all the way downstream.
 - In the retail supply chain the manufacturer adds most of the value. So all inventory should move all the way downstream.
 - This effect is so strong, that even with higher upstream lead-time at the root node in most practical cases all inventory should be downstream.
7. When the whole production batch is moved downstream, total supply chain inventory drops often below the level currently kept by the supplier alone. To the customer this means a fresher product on the shelf, because solely the amount of inventory in the supply chain determines the age of the products on the shelf ever since production.
8. Having done so, the bulk of the inventory is sitting downstream close to the customer, which improves the customer service because the excess cycle stock helps the safety stock to reduce the number of stock-outs.
9. Retailer and supplier need to negotiate conditions that support this way of working and share the benefits in a well-defined way.

In this line of reasoning we have taken the best design choice at each element of the supply chain design. Provided that these elements and our design choices are independent, the design as a whole is the best design. That should prove that our hypothesis was true and that indeed synchronization leads to the retail supply chain with the overall lowest costs whilst improving customer service, at least so in the field of application that we studied.

8.3 The applicability of Supply Chain Synchronization outside supermarket logistics

The applicability of Supply Chain Synchronization outside supermarket logistics can be determined from the following aspects:

- In supply chains where most of the product value is created in production and where upstream lead-times are not too high, inventory should be positioned downstream.
- Moving goods downstream at the moment they become available, saves on supply chain inventory.
- Manufacturers with high set-up cost have to produce in batches.
- Moving goods downstream in large volumes, saves on handling and transportation.

With these aspects as criteria Table 8.1 tries to give a first impression on the suitability for Supply Chain Synchronization of some quite different product categories.

Table 8.1: Suitability for Supply Chain Synchronization

	Most value added at production	Short upstream lead-time	High costs of inventory	Batch type production	High costs of distribution	Suitable
Dry grocery	✓	✓	-	✓	✓	✓
Fresh food	✓	✓	✓(decay)	✓	✓	✓
Appliances	✓	-	✓	✓	✓	✓
Cars	✓	-	✓	-	-	?
Tires	✓	-	✓	✓	✓	✓
Books	-	-	-	✓	✓	-
Jewelry	✓	✓	✓	✓	-	✓

This whole book concludes that Supply Chain Synchronization certainly should be able to improve upon the performance of the dry grocery supply chain.

The same is valid for fresh food, or even the more so, because synchronizing the supply chain will save on inventory and thus assure a fresher product and create a reduction in the costs of decay.

Household appliances have a long upstream lead-time, but the high value added at production compensates that. The manufacturer should try to push his inventory towards his distributors synchronous to production.

Also cars have a long upstream lead-time. They however come in many variants and their production process is not batch type. They better be produced on client order. But this might be quite different for cars produced overseas.

Tires are different from cars. They are produced in large batches and are expensive. The manufacturer indeed should try to get rid of his inventory and sell it to his distributors.

Printing books is cheap compared to the price paid in the bookstore. Not so much the printer, both the distribution channel adds to the price. Here it might be wise not to synchronize.

Synchronizing distribution to production seems a good concept for jewelry, because the added value at production is many times higher than downstream holding costs. This means that immediately after production of a fine piece of jewelry it should move downstream the supply chain and it should be stored in the shop; it would be waste of money in this supply chain to keep upstream inventory to balance store inventories. But it is unlikely that savings on the transportation budget through shipping in larger volumes and consolidation are relevant here

8.4 Contribution to the body of knowledge in supply chain management

In this section we reflect on what this research contributes to the existing body of knowledge. And it is by no means simple to state or claim what is new or original; one might be quite convinced to have invented or to have proven something new, but maybe one finally understood what others said or proved long before in slightly different words of which one thus-far just could not grasp neither their meaning nor their importance.

- First and foremost I have tried to make a practical and readable thesis that applies existing theory to a practical field of application and where necessary extends the existing theory in an integrated way.
- The logistics costs breakdown that we developed during this research shows to academia and logistics manager alike, what aspects should be given priority.
- The idea to synchronize or coordinate replenishments to realize economies of scale is known. See e.g. (Viswanathan and Piplani, 2001). Going as far as synchronizing distribution to production in retail to the best of our knowledge is original. At least so in literature, but it is so obvious that undoubtedly one has invented that before and maybe even has applied in practice.
- The theory on how to control a divergent multi-echelon distribution system existed and has been well described. See e.g. (Diks and De Kok, 1998). This thesis adds to that theory a proof via marginal analysis.

- This multi-echelon inventory theory is applicable in supply chains where goods accrue added value or cumulative holding costs. The partners in such supply chains buy upstream and sell downstream. In order to calculate the effects in a synchronized supply chain, we have juxtaposed to this the integrated supply chain point of view, where moving goods down the supply chain does not necessarily change their value. In that perspective total supply chain inventory adheres to the news-vendor-equation. All inventory is positioned downstream and the nodes upstream operate as stock-less depots. For the 2-echelon situation the theory on stock-less depots for the service level approach has been described by Eppen and Schrage already in 1981.
- In this thesis we have extended the single stage EOQ model to a multistage and even divergent modeling framework. We have been able to do so by explicitly modeling the delivery costs as a third cost component. The work is original and has been accepted for publication: (Van der Vlist et al., 2007)
- The concept of consolidating shipments is well known and described. See e.g. (Daganzo, 1996). Synchronizing distribution to production means larger volumes per item practically without time pressure. The use of consolidation in that environment is original and has been published: (Van der Vlist and Broekmeulen, 2006)
- The use of retail consolidation points and the decentralization of central warehouses are known concepts. Supply Chain Synchronization however creates a new and more favorable environment.
- In retail practice the use of pre-packs and mixed boxes is known and is in use. Broadening the field of application and modeling it was original and has been published: (Teulings and van der Vlist, 2001).
- Using Can-order and Must-order levels is known and in use for joint replenishment. Applying this to the retail shelf and using the space between these levels to rationalize the warehouse order picking processes is new.

8.5 Further research

Branded versus Private-label

This research started with a project with eight international A-brand manufacturers. As a result of that this thesis mainly looks at branded products and not so much at private-label products. Private label is growing rapidly, both in volume and in turnover and thus in importance.

From a supply chain point of view private-label behaves quite different from A-branded products. A manufacturer can ship the products of his own brand to various retail-clients. A private label production run however has the name of the retail client printed on every package and can be shipped only to that retail client. Supply Chain Synchronization thus seems to be even more relevant for private-label products. This is for further research.

Network structure

Supply Chain Synchronization offers many opportunities to improve the distribution network structure. Even though there is a whole chapter on this subject (Chapter 4) many

questions remain for further research, like:

- what would be the effect of outsourcing some of the elements of the network's structure to a logistics service provider?
- how would the possibilities for running full truckloads increase if two or more manufacturers would combine their cross dock location (MCC)?

The "Carrousel"

In Section 4.6.2 on page 91 an specific retail distribution network structure has been introduced, that we called the "Carrousel". In that structure manufacturers with not enough volume to deliver directly to each of the RDC's might deliver to just one of the network locations (RCC) and the retailer moves the remainder of the goods on to their destination with a carousel of trucks. There is much research left on this subject:

- further mathematical modeling is required
- how to manage the carrousel in combination with Supply Chain Synchronization is undescribed yet
- does running a carrousel improve the possibilities for back hauling?
- what is the effect of running road-trains?
- what if the carrousel were outsourced to a third party logistics service provider?

Modeling

Fumero and Vercellis present a multi period multi product LP optimization model for the integrated development of production and distribution schedules in a single-supplier - multiple-retailer setting. (Fumero and Vercellis, 1999). They describe two model-variants: (1) a coordinated approach where transportation decisions may lead to changes in the production schedule and (2) a decoupled approach where transportation planning is not allowed to modify the production plan. They conclude that the integrated approach behaves slightly better. It would be interesting to modify and run their model to cover Supply Chain Synchronization and compare the results.

Warehouse operation

The Excess Shelf Coverage (ESC) principle from section 5.4 suggests the potential to improve order picking in retail distribution centers. This thesis only describes some speculative improvement possibilities. Further research is needed to find the true potential.

RFID

An important issue in supply chain management is the advent of radio frequency identification tags (RFID for short). As these RFID-tags are rapidly getting cheaper and smarter now, the retail supply chain will become more reliable. Shipments and receipts can be

checked automatically and depending upon whether pallets, boxes and/or individual items are tagged, at every checkpoint the corresponding information will be available in full detail.

To give an example: Already by tagging pallets and sending the corresponding information electronically in advance of the arrival of the goods, a pallet cross docking center can be completely automated.

Moreover, by tagging at production the boxes with items that go on a pallet goods receipt and storage at a retail distribution center can be greatly improved. At the retail distribution centers the order pick process can be better managed or might be replaced by an automatic goods sorting process.

In this thesis we did not study the considerable impact that these new technologies undoubtedly will have upon the choices made in retail network design. We leave it for further research.

Supply chain security

This thesis paid no attention to vulnerability and security of the supply chain. It is to be expected that a supply chain where large amounts of inventory are being positioned downstream, close to the client, as is the case in a synchronized supply chain, in many cases will be less vulnerable to disruptions in supply and distribution than a supply chain with all inventory upstream at the supplier. It is for further research to explore this aspect.

Making it happen

The concepts are there. An interesting topic for further research now is

- to better define the applicability,
- to detail the managerial and implementation aspects and
- to identify the enablers to make it happen on a large scale.

Or, to summarize it all:

Be Wise - Synchronize!

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Appendix A

Case studies

Introduction

To verify whether Supply Chain Synchronization actually works, case studies have been done, with eight large food manufacturers and two supermarket chains, a larger one and a smaller one, in the Netherlands. A year of historical product demand was simulated, with current order quantities and real costs.

The case studies were divided into two groups of manufacturer-retailer couples. Four manufacturers were linked to the larger supermarket chain and four manufacturers were linked to the smaller supermarket chain. Because the difference in size and assortment between the two supermarket chains has a significant effect on the results, these results will be summarized and presented per retailer.

Category	Prod. cycle (weekdays)	Cases / pallet	Avg. value / pallet
Baby food	10-60	90-210	€ 3100
Beverages	10-20	85-150	€ 860
Butter	2-5	60-100	€ 2100
Coffee/Tea	2-20	95-240	€ 3200
Cheese	2-5	40-65	€ 1800
Pet food	5-10	90-215	€ 950
Sauce	20-25	150-390	€ 1900
Snack food	2-20	40-150	€ 1450

Figure A.1: Product group characteristics

The small supermarket chain is growing fast, has a broad assortment and follows an Every

Day Low Price philosophy, which combines very well with Supply Chain Synchronization. The other supermarket chain is the second largest in the Netherlands, has a smaller assortment and uses a price promotion strategy.

The eight manufacturers encompass a great variety of product groups, from cosmetics to coffee, from paper to pet food. The largest product groups (i.e. those products groups containing most products analyzed in these case studies) are summarized in Figure A.1 with their main characteristics.

This table does not give a comprehensive overview of all product properties used in calculating the case studies though. Historical supermarket demand, service level requirements, lead times and order quantity are also taken into account.

Scope and approach.

The scope of the case studies encompassed all activities/costs from the order picking at the manufacturer up to replenishing bulk inventory at the retailer, except transport. Transport has been studied separately. Current production cycles and historical supermarket demand were used for each product group. The following cost components have been taken into account in these case studies:

- storage costs (both manufacturer and retailer)
- capital costs of inventory (both manufacturer and retailer)
- transaction costs (both manufacturer and retailer)
- handling at manufacturer (order pick, dispatch)
- handling at retailer (receipt, bulk storage)

From each of the product groups that were analyzed, a product sample has been taken encompassing fast-moving, medium-moving and slow-moving articles. The results from the calculations on these articles were then expanded to the whole product group. With such an approach, it is not possible to accurately simulate savings in transport costs. So transport costs have been excluded from these simulations and have been calculated separately at pallet level, using the method described in Appendix C.

Case study results at a large supermarket chain.

The case study results are presented by adding up the total supply chain costs for all four case studies for each retailer separately. In this way we can gain a better understanding of the impact of Supply Chain Synchronization on different size retailers.

Starting with the large retailer's four case studies, Figure A.2 shows that in the current situation the manufacturer's share of the supply chain costs is more than double the retailer's share. There are two main reasons for this, caused by the current practice. Firstly, because the deliveries to the retailer are not synchronized to production, inventory builds up at the manufacturer. Figure A.2 shows that stock levels at the manufacturer's warehouse are almost double the retail warehouses inventory levels. Secondly, retailers often do not order in full pallet quantities, because there is no direct incentive from the manufacturer to do so. This results in high order picking costs at the manufacturer.

By changing the minimum order quantity to a full pallet, supply chain costs can already be

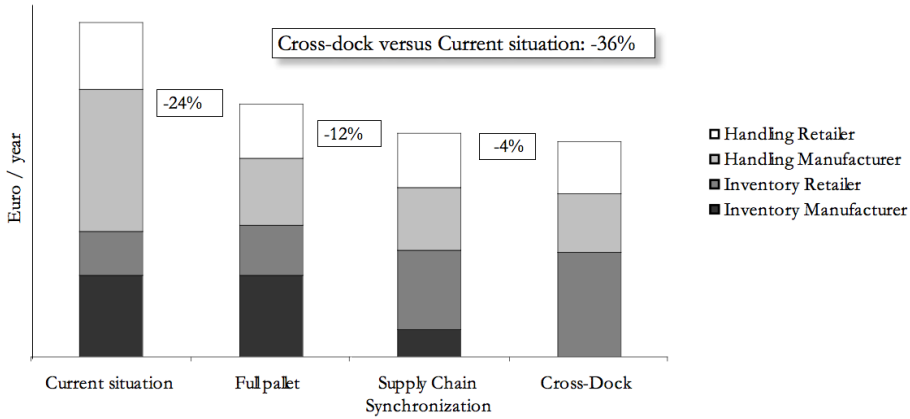


Figure A.2: Case studies with large retailer.

decreased by 24%. Because the decrease in costs is mainly due to reduction in order pick activities at the manufacturers, all of the savings are on their account. The retailer has an increase in inventory costs combined with a decrease in inbound handling, resulting in this case in a cost neutral alternative to the current situation. Total supply chain inventory goes up compared to the current situation.

The main drawback of working with full pallets for slower moving articles, is the increase in space used by an article in the order pick zone. The total order pick area at the retailer will increase in size and pick efficiency will drop. These extra costs are not considered in the case study, because there exist other possibilities to cope with this issue (e.g. changing the split over Slow-mover and Fast-mover warehouse and using the Shelf Coverage concept in Section 5.4).

The column Supply Chain Synchronization in Figure A.2 is the result of using a two-shipment strategy (See Section 2.4.6) whereby the first-shipment containing 70% of each production batch is shipped from manufacturer to retailer immediately after production. The other 30% is shipped after half the production cycle has passed. At the large retailer synchronizing the supply chain with this two-shipment strategy leads to another 12% reduction in supply chain costs. Because the minimum order quantity is still a full pallet, in- and outbound handling do not change. The main shift in supply chain costs is now caused by inventory. Because inventory has moved downstream immediately after production, most inventory shifts from manufacturer to retailer and as a result of this, the total supply chain inventory level drops by 20% compared to the full pallet option.

Moving the complete production batch after production to the retailer (Supply Chain Synchronization with full Cross-Dock and zero-inventory at the manufacturer) results in another 4% reduction in costs compared to shipping inventory twice (Supply Chain Synchronization with the two-shipment strategy). In this case the manufacturer's warehouse does not keep any inventory anymore. The total reduction in costs compared to the current situation amounts to 36%. Note that this option still includes the outbound handling at the manufacturer's warehouse. Applying direct delivery would render this warehouse unnecessary, as

is discussed in Section 4.5 on consolidation.

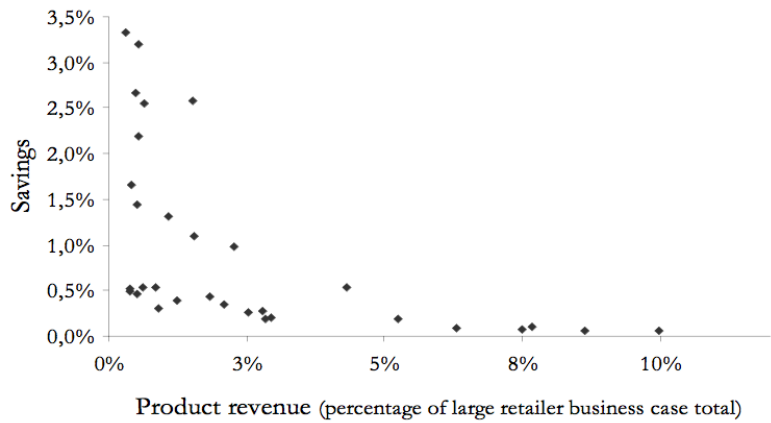


Figure A.3: Cost reduction as a percentage of turnover at large retailer

Figure A.3 shows the possible savings as a percentage of the retailer’s purchasing costs. Comparing the possible savings to current product revenue shows that the decrease in supply chain costs leads to a significant increase in profitability per product.

Case study results at a smaller supermarket chain.

The smaller retailer shows an even sharper drop in supply chain costs, mainly caused by the high number of slow moving products. Especially changing the minimum order quantity to a full pallet causes a dramatic reduction in handling costs at the manufacturers.

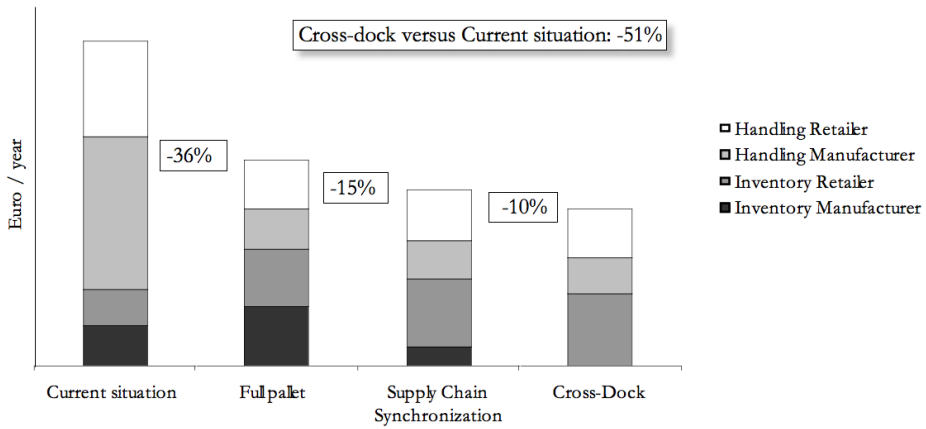


Figure A.4: Case studies with small retailer.

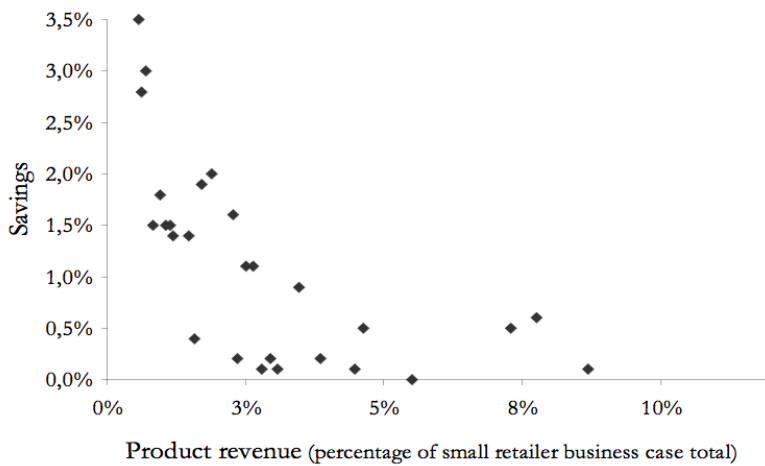


Figure A.5: Cost reduction as a percentage of turnover at small retailer

On the other hand, the increase in inventory is higher than observed at the large retailer. This is caused by the larger difference between the current order quantity and ordering full pallets. In the Cross-dock scenario as much as 51% can be saved on supply chain costs compared to the current situation.

Figure A.5 shows the possible savings to current product purchasing turnover at the smaller retailer. It can be seen that at the smaller retailer the decrease in supply chain costs leads to an even greater increase in profitability per product.

Appendix B

Logistics cost model

This Appendix gives a limited logistics cost model, to get an idea of the relative importance of the various cost elements.

1. Transaction costs		
Costs per bulk order-line	1.50	Euro
2. Costs of handling		
Item pick per order-line	0.05	Euro
Filling item pick location per box	0.30	Euro
Order picking per box	0.15	Euro
Filling box pick location per pallet	3.00	Euro
Pallet size	50 - 300	boxes
Retrieving a pallet from bulk storage	2.00	Euro
Goods dispatch per pallet	1.00	Euro
Goods receipt per pallet	1.00	Euro
Placing a pallet in bulk storage	2.00	Euro
Cross docking a pallet	1.00	Euro
3. Costs of storage		
Pallet location per day	0.25	Euro
Pallet wide box pick location per day	0.50	Euro
Costs of inventory (interest, insurance, aging, etc.)	10	% per year
Pallet value (grocery)	300 - 2000	Euro
4. Costs of transportation		
Trucking per kilometer	1.00	Euro
Full truckload pallets	26	pallets
Full truckload rolling cages	50	cages
Docking a truck at a warehouse to unload/load per stop	30.00	Euro
Truck unloading per pallet	1.00	Euro
Truck loading per pallet	1.00	Euro

Appendix C

Calculations

This Appendix contains the calculations for Table 4.2 and for the Carrousel in section 4.6.2

The notation and values used are:

W	Full truckload pallets	30	pallets
D	Docking a truck at a warehouse to unload/load per stop	30	Euro
d_{pw}	Distance from plant p to manufacturer's warehouse w	50	kilometers
d_{wi}	Average distance from w to any RDC	100	kilometers
d_{wh}	Distance from warehouse w to nearest RDC acting as hub RCC	50	kilometers
d_{pi}	Average distance from plant p to RDC	150	kilometers
d_{ph}	Distance from plant p to nearest RDC acting as hub RCC	100	kilometers
d_{hjk}	Average distance from RCC h to RDC	100	kilometers
d_n	Distance to nearest distribution center for next drop	30	kilometers
k	Scalefactor: geometry and trucking costs per kilometer	1	Euro
e	Empty kilometers after unloading	30	kilometers
L	Truck loading per pallet	1	Euro
I	In = Unloading, receipt and storage	4	Euro
O	Out = Retrieval, dispatch and loading	4	Euro
T	Transfer = Unloading, cross dock and loading	3	Euro
d_{wc}	Distance from w to CDC	100	kilometers
d_{pc}	Distance from p to CDC	150	kilometers
d_{cijk}	Average distance from c to RDC	60	kilometers
e_c	Empty kilometers after unloading	60	kilometers

C.1 Cost calculations for Table 4.2

This section gives the supporting calculations for the average costs per pallet fast movers, shown in Table 4.2 on page 88.

The network structures that are being modeled in this section are:

Table 4.2 Average costs per pallet fast movers

Euro per pallet		Delivery at RDC		Delivery via RCC
		A	B	C
		3 drops	FTL	66% transit
I	Traditional	28	24	27
II	SCS	23	19	22
III	SCS-direct	17	13	16

A

Retail network with 3 regional retail fast mover distribution centers, RDC's. Suppliers deliver goods separately at each of the RDC's in a multi stop trip with three drops (= 1/3rd truckload per drop), one at the warehouse of the retailer under study here; the other two at nearby DC's of other retailers.

B

Equal to scenario D, but suppliers deliver in full truckload at each of the RDC's

C

Suppliers deliver full truck loads, FTL, at the nearest RDC only, acting as a consolidation center RCC for that supplier. The retailer carries 2/3 of the goods supplied to the two other RDC'locations

The control structures that are modeled are:

I

The traditional current way of working, via a stock keeping warehouse at the supplier

II

Supply Chain Synchronization with cross dock at the supplier's warehouse

III

Supply Chain Synchronization with delivery in full truckload directly from the production plant, bypassing the supplier's warehouse

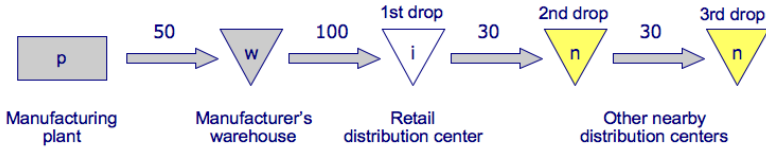


Figure C.1: Traditional structure with delivery at RDC

I-A

The calculations for the traditional control structure with delivery at an RDC and delivery in 3 drops, are based on the model shown in figure C.1

The transport related costs per pallet are

$$\frac{1}{W} \{ (D + kd_{pw} + D + ke) + (D + kd_{wi} + D + 2kd_n + 2D + ke) \} = \frac{1}{W} \{ 6D + k(d_{pw} + d_{wi} + 2d_n + 2e) \} = 15 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + I_w + O_w + I = 13 \text{ Euro}$$

So the total costs per pallet are $15 + 13 = 28$ Euro.

II-A

The calculations for the SCS structure with delivery at an RDC, are also based on the model shown in figure C.1, but with cross-docking at the supplier's warehouse.

The transport related costs per pallet are equal to I-A: 15 Euro.

The handling related costs per pallet are:

$$L_p + T_w + I = 8 \text{ Euro}$$

So the total costs per pallet are $15 + 8 = 23$ Euro.

III-A

The calculations for the SCS structure with direct delivery at an RDC, are based on the model shown in figure C.2 bypassing the supplier's warehouse.

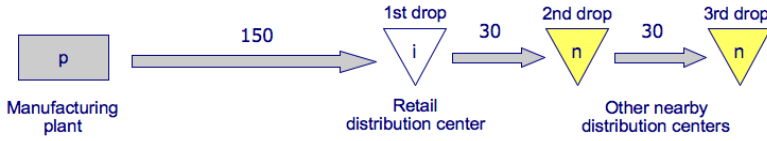


Figure C.2: Bypassing the manufacturer's warehouse

The transport related costs per pallet are:

$$\frac{1}{W} \{ (D + kd_{pi} + D + 2kd_n + 2D + ke) \} = \frac{1}{W} \{ 4D + k(d_{pi} + 2d_n + e) \} = 12 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + I = 5 \text{ Euro}$$

So the total costs per pallet are $12 + 5 = 17$ Euro.

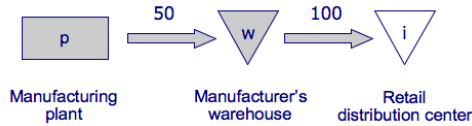


Figure C.3: Traditional with FTL delivery

I-B

The calculations for the traditional structure with FTL delivery at an RDC, are based on the model shown in figure C.3.

The transport related costs per pallet are:

$$\frac{1}{W} \{(D + kd_{pw} + D + ke) + (D + kd_{wi} + D + ke)\} = \frac{1}{W} \{4D + k(d_{pw} + d_{wi} + 2e)\} = 11 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + I_w + O_w + I_i = 13 \text{ Euro}$$

So the total costs per pallet are $11 + 5 = 24$ Euro.

II-B

The calculations for the SCS structure with delivery at an RDC, are also based on the model shown in figure C.3, but with cross-docking at the supplier's warehouse.

The transport related costs per pallet are equal to I-B: 11 Euro.

The handling related costs per pallet are:

$$L_p + T_w + I_i = 8 \text{ Euro}$$

So the total costs per pallet are $11 + 5 = 19$ Euro.

III-B

The calculations for the SCS structure with direct FTL-delivery at an RDC, are based on the model shown in figure C.4 bypassing the supplier's warehouse.

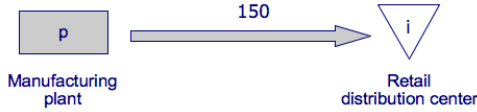


Figure C.4: Bypassing the manufacturer's warehouse with FTL

The transport related costs per pallet are:

$$\frac{1}{W} \{(D + kd_{pi} + D + ke)\} = \frac{1}{W} \{2D + k(d_{pi} + e)\} = 8 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + I_i = 5 \text{ Euro}$$

So the total costs per pallet are $10 + 5 = 13$ Euro.

I-C

The calculations for the traditional structure with FTL-delivery at an RCC and the retailer moving on 2/3 of the volume, are based on the model shown in figure C.5

The transport related costs per pallet are

$$\frac{1}{W} \{(D + kd_{pw} + D + ke) + (D + kd_{wh} + D + ke) + \frac{2}{3}(\frac{1}{2}D + d_{hjk} + \frac{1}{2}D)\} = \frac{1}{W} \{4D + k(d_{pw} + d_{wh} + 2e) + \frac{2}{3}(D + d_{hjk})\} = 12 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + I_w + O_w + \frac{2}{3}T_h + I = 15 \text{ Euro}$$

So the total costs per pallet are $12 + 15 = 27$ Euro.

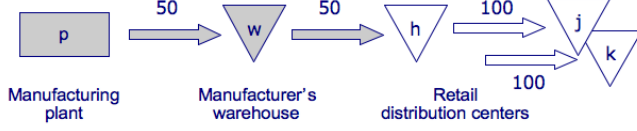


Figure C.5: Delivery at RCC and the retailer moving on 2/3 of the volume

II-C

The calculations for the SCS structure with FTL-delivery at an RCC, are also based on the model shown in figure C.5, but with cross-docking at the supplier's warehouse. The transport related costs per pallet are equal to I-C: 12 Euro.

The handling related costs per pallet are:

$$L_p + T_w + \frac{2}{3}T_h + I = 10 \text{ Euro}$$

So the total costs per pallet are $12 + 10 = 22$ Euro.

III-C

The calculations for the SCS structure with direct FTL-delivery at an RCC, are based on the model shown in figure C.6 bypassing the supplier's warehouse .

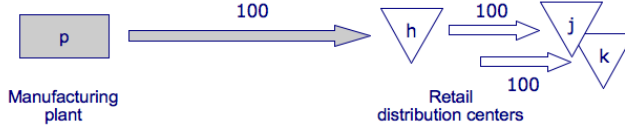


Figure C.6: Bypassing the manufacturer's warehouse

The transport related costs per pallet are:

$$\frac{1}{W} \{ (D + kd_{ph} + D + ke) + \frac{2}{3} (\frac{1}{2}D + d_{hjk} + \frac{1}{2}D) \} = \frac{1}{W} \{ 2D + k(d_{ph} + e) + \frac{2}{3}(D + d_{hjk}) \} = 9 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + \frac{2}{3}T_h + I = 7 \text{ Euro}$$

So the total costs per pallet are $9 + 7 = 16$ Euro.

C.2 Cost calculations for Table 4.4: The Carrousel

The former section only dealt with delivery at RDC's and neglected the existence of any central distribution center CDC. The pallet cost figures calculated therefore are the average costs for fast-moving items only. This section calculates average pallet cost figures for both fast-moving items hat currently are being distributed via 3 RDC's and slow-moving articles

Table 4.4 Average costs per pallet (3 RDC's, 1 CDC)

Euro per pallet		CDC		Carrousel	
		D	E	F	G
		3 drops	FTL	3 drops	FTL
I	Traditional	30	28	27	25
II	SCS	25	23	22	20
III	SCS-direct	(19)	-	19	13

that currently are being distributed via a central CDC. It is assumed that the RDC's and the CDC each get 1/4 of the volume.

The network structures that are being modeled in this section are:

- D** Central slow-mover CDC, that distributes store ready pallets via the regional fast mover RDC's, consolidated into the same trucks to the stores. Suppliers deliver goods separately at each of the RDC's and at the CDC in a multi stop trips with three drops (= 1/3rd truckload per drop), one at the warehouse of the retailer under study here; the other two at nearby DC's of other retailers.
- E** Equal to scenario D, but suppliers deliver in full truckload at each of the distribution centers (both RDC's and CDC).
- F** Suppliers deliver at the nearest RDC, acting as a conservation center RCC for that supplier. The slow mover distribution center CDC has been distributed over the RDC's. The retailer operates the Carrousel to carry-on fast-moving goods supplied at a consolidation center or slow-movers picked at any of the distributed CDC- locations. Suppliers deliver muti-drop, with average drop sizes of a third of a truckload.
- G** Equal to scenario F, but suppliers deliver in full truckload.

The control structures that are modeled are:

- I** The traditional current way of working, via a stock keeping supplier's warehouse
- II** Supply Chain Synchronization with cross dock at the supplier's warehouse
- III** Supply Chain Synchronization with delivery in full truckload directly from the production plant bypassing the supplier's warehouse

Figure C.7 shows the traditional structure for a retailer operating three regional fast mover distribution centers and one central slow mover distribution center

The calculations for delivery at an RCC and the Carrousel moving on 2/3 of the volume, are based on the model already shown in figure C.5, but this time also the transport of the former CDC volume is taken into account. The handling costs related to shop order

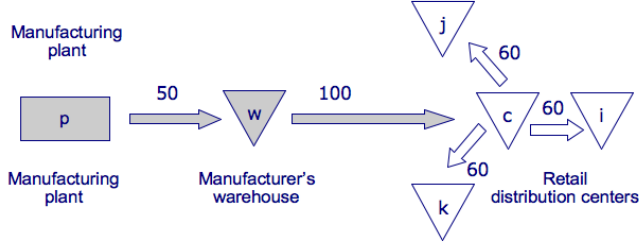


Figure C.7: Traditional structure with a central slow mover distribution center

collection and dispatch at the CDC are ignored in the calculations, because eventually the whole volume flows to the shops and goes through an order pick and dispatch process and whether this happens to be at the CDC or at one of the RDC's makes no difference in costs. In the calculations that follow, it is further assumed that equal volumes flow through each of the distribution centers (the 3 RDC's and the CDC each a quarter of the total volume).

I-D

Traditional, multi-drop delivery, with CDC, no carrousel.

The transport related costs per pallet for this traditional structure are:

$$\begin{aligned} & \frac{1}{W} \{ (D + kd_{pw} + D + ke) + (D + \frac{3}{4}kd_{wi} + \frac{1}{4}kd_{wc} + D + 2kd_n + 2D + ke) \\ & + \frac{1}{4}(D + kd_{cij} + D + ke_c) \} = \\ & \frac{1}{W} \{ 6.5D + k(d_{pw} + \frac{3}{4}d_{wi} + \frac{1}{4}d_{wc} + 2d_n + \frac{1}{4}d_{cij} + 2e + \frac{1}{4}e_c) \} = 17 \text{ Euro} \end{aligned}$$

The handling related costs per pallet are:

$$L_p + I_w + O_w + I = 13 \text{ Euro}$$

So the total costs per pallet are $17 + 13 = 30$ Euro.

II-D

SCS with multi-drop delivery, CDC, no carrousel

The transport related costs per pallet are equal to I-D: 17 Euro.

The handling related costs per pallet are:

$$L_p + T_w + I = 8 \text{ Euro}$$

So the total costs per pallet are $17 + 8 = 25$ Euro

III-D

FTL from plant with multi-drop delivery, CDC, no carrousel

The transport related costs per pallet are:

$$\begin{aligned} & \frac{1}{W} \{ (D + \frac{3}{4}kd_{pi} + \frac{1}{4}kd_{pc} + D + 2kd_n + 2D + ke) + \frac{1}{4}(D + kd_{cij} + D + ke_c) \} = \\ & \frac{1}{W} \{ 4.5D + k(\frac{3}{4}d_{pi} + \frac{1}{4}d_{pc} + 2d_n + \frac{1}{4}d_{cij} + e + \frac{1}{4}e_c) \} = 13 \text{ Euro} \end{aligned}$$

The handling related costs per pallet are:

$$L_p + I = 5 \text{ Euro}$$

So the total costs per pallet are $13 + 5 = 19$ Euro.

The volumes per article at a slow mover CDC are so low, that running a full truck directly from production is not realistic.

I-E

Traditional with FTL delivery, without carrousel.

The transport related costs per pallet for this traditional structure are:

$$\frac{1}{W} \{(D + kd_{pw} + D + ke) + (D + \frac{3}{4}d_{wi} + \frac{1}{4}d_{wc} + D + ke) + \frac{1}{4}(D + kd_{cijk} + D + e_c)\} = \frac{1}{W} \{4.5D + k(d_{pw} + \frac{3}{4}d_{wi} + \frac{1}{4}d_{wc} + \frac{1}{4}d_{cijk} + 2e + \frac{1}{4}e_c)\} = 15 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + I_w + O_w + I = 13 \text{ Euro}$$

So the total costs per pallet are $15 + 13 = 28$ Euro.

II-E

SCS with FTL, no carrousel

The transport related costs per pallet are equal to I-E: 15 Euro.

The handling related costs per pallet are:

$$L_p + T_w + I = 8 \text{ Euro}$$

So the total costs per pallet are $15 + 8 = 23$ Euro

III-E

FTL from plant with CDC, no carrousel

The volumes per article at a slow mover CDC are so low, that running a full truck directly from production is not realistic.

I-F

Traditional with 3 drops and carrousel

The calculations for the traditional structure with delivery at an RCC and the Carrousel moving on 2/3 of the volume, are based on the model already shown in figure C.5, but this time the extra transport of the former CDC volume is taken into account.

The transport related costs per pallet for this traditional structure are:

$$\frac{1}{W} \{(D + kd_{pw} + D + ke) + (D + kd_{wh} + D + 2kd_n + 2D + ke) + kd_{cijk} + D + e_c\} = \frac{1}{W} \{6.5D + k(d_{pw} + \frac{3}{4}d_{wi} + \frac{1}{4}d_{wc} + \frac{1}{4}d_{cijk} + 2d_n + 2e + \frac{1}{4}e_c)\} = 14 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + I_w + O_w + I = 13 \text{ Euro}$$

So the total costs per pallet are $14 + 13 = 27$ Euro.

II-F

SCS with 3 drops and carrousel

The calculations for the SCS structure with delivery at an RCC with 3 drops and the Carrousel moving on 2/3 of the volume, are based on the model already shown in figure C.6, but this time the extra transport of the former CDC volume is taken into account.

The transport related costs per pallet are equal to those in situation I-F = 14 Euro.

The handling related costs per pallet are $L_p + T_w + I = 8$ Euro

So the total costs per pallet are $14 + 8 = 22$ Euro

III-F

SCS-direct with 3 drops and carrousel

The transport related costs per pallet for the SCS-direct structure with 3 drops and carrousel are:

$$\frac{1}{W} \left\{ (D + \frac{3}{4}d_{pi} + \frac{1}{4}d_{pc} + D + 2kd_n + 2D + ke) + \frac{1}{4}(D + kd_{cij k} + D + e_c) \right\} = \frac{1}{W} \{ 4.5D + k(\frac{3}{4}d_{pi} + \frac{1}{4}d_{pc} + \frac{1}{4}d_{cij k} + 2d_n + e + \frac{1}{4}e_c) \} = 14 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + I = 5 \text{ Euro}$$

So the total costs per pallet are $14+5 = 19$ Euro.

I-G

Traditional with FTL and carrousel

The transport related costs per pallet for this traditional structure with FTL and carrousel are equal to those in I-C.

$$\frac{1}{W} \left\{ (D + kd_{pw} + D + ke) + (D + kd_{wh} + D + ke) + \frac{2}{3}(\frac{1}{2}D + kd_{hjk} + \frac{1}{2}D) \right\} = \frac{1}{W} \{ 4.5D + k(d_{pw} + d_{wh} + 2e + \frac{2}{3}d_{hjk}) \} = 12 \text{ Euro}$$

The handling related costs per pallet are:

$$L_p + I_w + O_w + I = 13 \text{ Euro}$$

So the total costs per pallet are $12 + 13 = 25$ Euro.

II-G

SCS with FTL and carrousel

The transport related costs per pallet are equal to those in situation I-G = 12 Euro.

The handling related costs per pallet are: $L_p + T_w + I = 8$ Euro.

So the total costs per pallet are $12 + 8 = 20$ Euro

III-G

SCS-direct and carrousel

The transport related costs per pallet are:

$$\frac{1}{W} \left\{ (D + kd_{ph} + D + ke) + \frac{2}{3}(\frac{1}{2}D + kd_{hjk} + \frac{1}{2}D) \right\} = \frac{1}{W} \{ 2D + kd_{ph} + ke + \frac{2}{3}(D + kd_{hjk}) \} = 8 \text{ Euro}$$

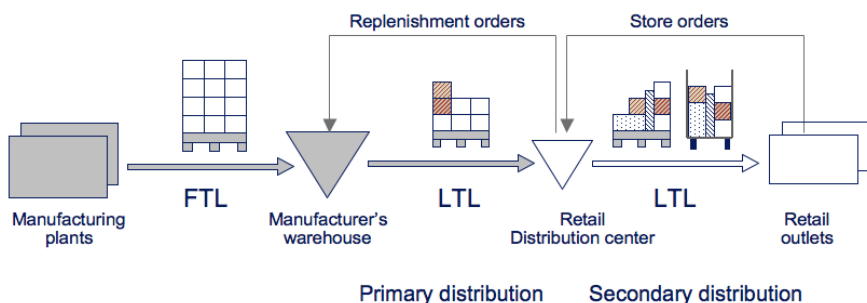
The handling related costs per pallet are equal to those in situation III-C = 5 Euro.

So the total costs per pallet are $8 + 5 = 13$ Euro

Appendix D

Samenvatting

Dit proefschrift is eigenlijk een ontwerp, een ontwerp van een betere en goedkopere logistieke keten voor supermarkten (Retail Supply Chain) dan de gebruikelijke. Dat wordt in dit proefschrift een gesynchroniseerde keten genoemd.



Figuur D.1: De gebruikelijke logistieke retail keten.

De gebruikelijke logistieke keten is weergegeven in Figuur D.1. Goederen gaan direct uit productie in volle homogene pallets in volle wagens (FTL) naar de magazijnen van de leveranciers. Om efficiënt te kunnen werken, produceren de leveranciers in grote series, met als gevolg relatief hoge seriegrootte-voorraden in hun magazijnen. De retailers bestellen frequent en in kleine hoeveelheden, om zodoende hun eigen voorraden laag te houden. Dientengevolge worden de retail distributie-centra (RDC's) beleverd in (met de hand samengestelde) bonte pallets in auto's die niet vol zijn (LTL). Ook de supermarkten bestellen frequent. Zij ontvangen de goederen op bonte pallets of rol-containers, die artikelen bevatten van meerdere leveranciers, gegroepeerd per product-familie, zodat de schappen in de winkel makkelijk zijn te vullen.

Maar het lijkt erop, dat de retail te ver is gegaan. Een specificatie van de logistieke kosten van leveranciers en retailers laat zien, dat de kosten van voorraad houden en order-verzamelen bij de leverancier meer dan 10 maal zo hoog zijn als de kosten van de voorraden

in de distributiecentra van de retailers. De focus van de retail op voorraadverlaging is dus op zijn minst discutabel. De meeste voorraad in de keten blijft nu liggen bij de leverancier, ver van de uiteindelijke klanten; terwijl in de distributiecentra van de retailers nog maar beperkte voorraad aanwezig is om in spoedgevallen winkels te kunnen bevoorraden. De voorraad is er dus wel, maar ligt op de verkeerde plaats in de keten.

Dit proefschrift gaat uit van de hypothese, dat in een goede retail supply chain de stroomafwaartse processen zijn gesynchroniseerd op de stroomopwaartse en niet andersom. Om de juistheid van deze hypothese te bewijzen verkent dit proefschrift in de hoofdstukken 2 t/m 6 de theorie van de verschillende aspecten van logistieke ketens en breidt die theorie waar nodig ook uit. De onderzochte aspecten zijn: *Voorraad*, *'Handling'*, *Netwerkstructuur* en het *Verdelen van de opbrengst*.

Hoofdstuk 2 over Voorraad breidt de in de logistiek bekende formule met het dilemma van de krantenverkoper¹ uit naar een distributie-netwerk met meerdere echelons en naar meerdere tijdperioden. In lijn met eerdere bevindingen van Diks en De Kok leidt dit tot de formule voor het optimaal inregelen van een logistiek netwerk, maar ditmaal afgeleid via 'marginale' analyse². Uit deze formule kan worden afgelezen dat stroomafwaarts gelegen distributie-knooppunten op hogere service-niveaus moeten worden ingesteld dan stroomopwaarts gelegen knooppunten. Dit betekent, dat de klanten op het meest stroomafwaarts gelegen knooppunt, de winkel, de service ervaren, waarop het meest stroomopwaarts gelegen knooppunt is ingesteld.

Met dezelfde formule kan ook de optimale positie van de veiligheidsvoorraden in de keten worden afgeleid. De formule geldt in ketens waar de betrokken partijen van elkaar kopen en aan elkaar verkopen. Goederen worden daardoor duurder naarmate ze meer stroomafwaarts in de keten en dichterbij de klant komen. Bij elk van de ketenpartners kunnen we het verschil tussen inkoopprijs en verkoopprijs zien als dekking van de gemaakte kosten en winstmarge, maar we zouden het ook de door die partij toegevoegde waarde kunnen noemen. Uit de formule volgt dan, dat wanneer alle partijen in een retail-keten evenveel waarde toevoegen (of: dezelfde kosten maken) en vergelijkbare levertijden hebben, het raadzaam is om vrijwel alle veiligheidsvoorraad stroomafwaarts in de keten te plaatsen, dus in de winkel. Als één partij relatief meer waarde toevoegt dan de andere partijen, dan is het raadzaam enige voorraad te positioneren op het laatste punt daarvoor. Als het meest stroomopwaarts aan het begin van de keten gelegen punt de meeste waarde toevoegt, dan hoort alle voorraad stroomafwaarts in de keten, in de winkel. Wanneer we de producent en dus ook de kosten van productie in onze beschouwing meenemen, dan wordt daar in de regel de meeste waarde toegevoegd. In dat geval voegt het meest stroomopwaarts gelegen knooppunt de meeste waarde toe en hoort alle voorraad stroomafwaarts: in de winkel. Simulaties bevestigen dit.

De kosten van 'Handling' hangen voornamelijk samen met ordergroottes. Hoofdstuk 3 breidt het bekende model voor de optimale ordergrootte (EOQ) uit naar een model voor een netwerk met meerdere echelons. Met dat model kan dan worden vastgesteld, dat in een gesynchroniseerde keten, ten opzichte van een keten waar iedere partij zijn eigen optimum kiest, de ordergroottes omhoog zullen gaan, de totale ketenvoorraad zal dalen en de totale kosten relatief nog meer zullen dalen.

Hoofdstuk 4 gaat over netwerk-structuren. Het hoofdstuk bestudeert het gebruik van

¹Hoeveel kranten moet de krantenverkoper kopen, wanneer een krant h kost en p oplevert.

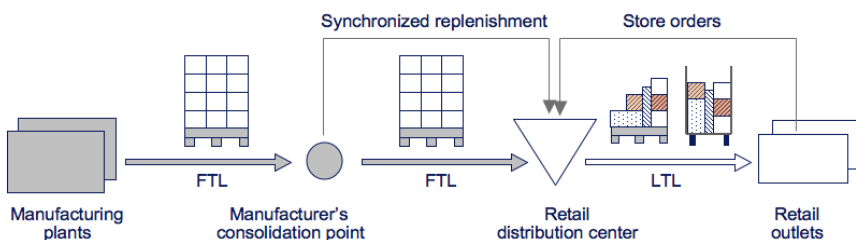
²De krantenverkoper koopt het juiste aantal kranten, wanneer de verwachte meerkosten van één extra krant gelijk zijn aan de verwachte opbrengst.

voorraad-loze consolidatie-punten en directe leveringen die een schakel in de keten overslaan. Toepassing van deze theorie op een voorbeeld-situatie laat zien dat directe leveringen al snel lonen (in het voorbeeld in een-derde van de gevallen. Het betreft dan leveringen rechtstreeks van productie naar een of meer RDC's. Het hoofdstuk bestudeert verder het gebruik van retail consolidatie-centra (RCC's), waar leveranciers al hun goederen kunnen aanleveren, waarna de retailer zelf voor het transport naar de overige RDC's zorgt. Gebruikmakend van het logistiek kostenmodel in Appendix B zijn als voorbeeld voor diverse situaties de gemiddelde kosten per pallet uitgerekend. Een interessante netwerkstructuur is die, waarbij de consolidatiepunten en eventuele centrale distributiecentra zijn opgesplitst en verdeeld over de locaties van de RDC's en waar een Carrousel van wagens de goederen tussen deze locaties verplaatst. Om een idee te geven: de gemiddelde distributiekosten per pallet bedragen in de gebruikelijke keten 27 Euro; dit getal daalt tot 13 Euro met de Carrousel. Tenslotte vergelijkt hoofdstuk 4 de netwerkstructuur met cross-dock bij de leverancier en voorraad bij de retailer met de structuur van Wal-Mart, met voorraad bij de leverancier en cross dock bij de retailer.

Hoofdstuk 5 over het uitleveren van winkelorders, speculeert op een aantal verbeteringen in het proces van beleveren van de winkel..Om wat voorbeelden te geven: Wanneer de integrale logistieke kosten worden meegenomen in de berekening, dan zal dit leiden tot grotere eenheden per product. Voor kleine langzaam lopende artikelen zou de winkelbelevering in assortimentsdozen kunnen plaatsvinden. En langzaam lopende artikelen, met voldoende schapruimte zouden op vaste dagen van de week beleverd kunnen worden.

De paradox van het synchroniseren van de keten is dat stroomafwaarts gelegen ketenpartners moeten investeren om kosten te besparen bij stroomopwaartse partners. Het zal duidelijk zijn, dat keten-synchronisatie alleen zal worden toegepast, wanneer er adequate contractuele overeenkomsten worden gemaakt om de opbrengsten te verdelen. Dat is het onderwerp van hoofdstuk 6. Er wordt in dit hoofdstuk vastgesteld, dat de reguliere commerciële onderhandelingen tussen retailer en leverancier gescheiden moeten worden gehouden van eventuele logistieke onderhandelingen. De logistieke onderhandelingen zijn gebaseerd op aantoonbare en volledig berekenbare kostenbesparingen. Tenslotte wordt uitgewerkt, dat logistieke verbeteringen in voorraad, handling en netwerk-structuur verschillend uitwerken en ook verschillend gecompenseerd zouden moeten worden.

Door heel het proefschrift heen zijn Observaties gemaakt en zijn op grond daarvan zijn ook telkens Ontwerp-keuzen gemaakt. Op grond hiervan laat Hoofdstuk 7 de puzzelstukjes op zijn plaats vallen tot een beschrijving van Ketensynchronisatie in al zijn aspecten.



Figuur D.2: De gesynchroniseerde logistieke retail keten

Een gesynchroniseerde keten is een keten waar stroomafwaartse processen zijn gesynchroniseerd op stroomopwaartse processen, in plaats van zoals gebruikelijk andersom. In een gesynchroniseerde keten is de distributie gesynchroniseerd op de productie en richt de winkelbelevering zich naar de operatie in de distributie-centra. Dat is de keten met de laagste kosten.

Vanuit keten-perspectief hoort de voorraad bij de retailer te liggen, zo dicht mogelijk bij de klant. Het moet naar de retailer worden gebracht in grote hoeveelheden en in volle wagens. Dat moet bovendien gebeuren zodra de goederen gereed komen van productie, ruim voordat ze echt nodig zijn: "Vervoeren als het kan en niet wachten tot het moet!" Met andere woorden de distributie moet gesynchroniseerd worden op het productieschema. Het magazijn van de leverancier reduceert dan tot een overslagpunt, waar de goederen van de verschillende fabrieken van een leverancier samenkomen om gezamenlijk in dezelfde auto naar de distributie-centra van de retailers te worden gebracht. Die structuur is weergegeven in Figuur D.2.

Appendix E

Curriculum vitae

Piet van der Vlist (1947) was born in Ouderkerk aan den IJssel. He received his high-school diploma from the Marnix Gymnasium in Rotterdam. Also in Rotterdam he graduated as Electronics Engineer at the University of Applied Sciences. He obtained a Master of Science in Electronics at the Delft University of Technology and one in Management Sciences at the University of Twente.

He worked 15 years with the Dutch Ministry of Defense on the design and realization of the first generation digital communications systems. Then he joined Bakkenist Management Consultants and later Deloitte Consultancy, together for over 20 years. As consultant he was involved in numerous projects on Data exchange and Supply Chain redesign. Besides that, he was for 11 years (part-time) professor in ICT and Logistics at the Eindhoven University of Technology. Piet wrote and edited several books on data exchange and published numerous articles in business and scientific journals. A fairly good overview of his scientific career can be found in the 'Liber Amicorum' that his friends wrote when he left Eindhoven University¹.

His current research interests lie in the design and management of retail supply chains, all the way from production down to the shelves. He found that the supply chain with the overall lowest costs requires synchronization of distribution to production and not the other way around as current practice seems to dictate.

When he had to quit his jobs for health reasons, he finally found the opportunity to devote his time to research and extend the theory that supports Supply Chain Synchronization. He programmed built to purpose simulation models to get a better insight in the dynamics of synchronized supply chains. He joined both the Rotterdam Erasmus University to work with Professor Jo van Nunen and the Eindhoven University of Technology to work with Professor Ton de Kok.

This PhD thesis is the result of that effort.

¹Monique Janssen-Vullers en Ton Valstar (ed.), Op het grensvlak van logistiek en ICT: Liber Amicorum voor Piet van der Vlist, Technische Universiteit Eindhoven, 2002, ISBN 90-386-1877-8.

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Synchronizing the Retail Supply Chain

This thesis is a design of a retail supply chain that is better and cheaper than the usual one. In the retail supply chain most of the product value is created upstream at the supplier. By extending the Newsvendor-formula it can be proven that from the point where most of the value is created, inventory should move all the way downstream. To produce efficiently suppliers have to produce in batches. By extending the EOQ-formula it can be proven that goods should move in large quantities. The cheapest retail supply chain is realized when distribution is synchronized to production. Right from production goods should move downstream the supply chain at low cost in full pallets and in full truckloads, in quantities large enough to cover the needs till the next production run. The supplier's warehouses then become stockless cross docking points, where goods from the supplier's various sourcing plants are brought together to consolidate them into full truckloads to the retail clients. Whenever suppliers deliver lower volumes, they better bring all of these goods to only the nearest retailer's facility; thereafter the retailer himself should move these goods onward to the proper destination within the retailer's network. And finally shop replenishment should be rationalized based on shelf coverage, so as to enhance the retailer's warehouse operations.

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