FLOATING STOCKS IN FMCG SUPPLY CHAINS:

Geerten Ochtman, Rommert Dekker, Eelco van Asperen
(School of Economics, Erasmus University Rotterdam)

Walter Kusters
(Vos Logistics)

ABSTRACT

In this paper we present a new distribution concept called ‘floating stocks’, which uses intermodal transport to deploy inventories in a supply chain in advance of retailer demand. Supplying part of the demand directly by road compensates the longer transit time of this transport. First an analytical comparison is made which shows that this concept has advantages in inventories over pure road and intermodal transport. Next a simulation study of a real case is made which quantifies the cost-differences in detail.

Keywords: Supply chain, Floating Stock, Intermodal Transport, Virtual Warehousing, Inventories.

INTRODUCTION

Intermodal transport can be defined (cf. European Conference of Ministers of Transport (1993) as the movement of goods in one and the same loading unit or vehicle by successive modes of transport without handling of the goods themselves during transfers between modes, e.g. container transport via rail and road. Nowadays this transport method is strongly advocated by governments in order to reduce road congestion and pollution. Intermodal transport is however, on short distances more costly than road transport as it requires more handling. Furthermore, its transit time is often longer than that of direct road transport and its reliability is not always high (cf Konings (1996)). Transport studies such as Bookbinder and Fox (1998), and Rutten (1995) typically make such comparisons between road transport and intermodal transport, but in these studies inventories are left out of consideration.

Inventory management is another important topic in supply chains (see Chopra and Meindl, 2004). The main emphasis here is on determining how much inventory should be kept at which stocking locations, while typically only one lead time (and hence transportation mode) is considered. A well-known result is that centralization or pooling can reduce inventories if demands are uncorrelated, at the expense of higher transportation costs and a longer response time. This has led to the creation of European Distribution Centers, from which goods are trucked to clients throughout Europe directly upon client’s calls. Different transport modes are considered primarily in the case of emergency shipments to take care of stockouts (cf Moinzadeh and Schmidt, 1991). Some studies also consider lateral transshipments in multi-echelon chains, but mostly again only in the case of stockouts (cf Minner (2003) and Diks et al., 1996). Herer et al. (2002) is an exception as they consider lateral transshipments to enhance postponement and hence leagility (i.e. a combination of lean and agility) in supply chains. There are a few studies that integrate transportation and inventory control (see e.g. Tyworth and Zeng (1998)), but they focus on the relation between either transport frequency or transit time reliability and inventory control. No studies seem to exist which integrate intermodal transport and inventory control, according to recent reviews on intermodal research, such as Bontekoning, Macharis and Trip (2003) and Macharis and Bontekoning (2004).

In this paper we will present a new distribution concept (floating stocks) that exploits the opportunities intermodal transport offers to deploy inventories in the supply chain. The idea is that by advanced deployment and carefully tuning demand with alternating transport modes we can reduce non-moving inventories, shorten lead times and increase reliability. We use the floating of stocks and the existence of intermodal terminals to postpone the selection of the destination so that a pooling effect can be obtained in comparison to direct road transport. In a sense we build on Herer et al. (2002) as we use intermodal transport with deferred final transport instead of transshipment to achieve postponement. In this way we create a kind of virtual warehouse at the intermodal terminals, yet one different than commonly referred to in literature (see e.g. Landers et al. (2000), as they stress real-time global visibility of logistic assets). Moreover, the floating stock concept described in this paper avoids the inefficient method of storing products that is characteristic of the just-in-time concept which nowadays is frequently used in Fast Moving Consumer Good (FMCG)-supply chains (Van der Vlist and Broekmeulen, 2002).

Hardly any literature is available on floating stocks. It is to some extent already applied in practice for the case of Asian – EU / US maritime – road transport. Exceptions are the Dutch Distrivaart project (Boerema, 2003), and Teulings and Van der Vlist (2001), neither of which explicitly deals with inventories.

METHODOLOGY

We use a conceptual model to allow a qualitative comparison between four distribution concepts that differ in the use of intermodal transport and inventory deployment. To avoid many complicating and potentially conflicting aspects, we confine ourselves to a part of a Fast Moving Consumer Goods (FMCG) supply chain: from the manufacturer to the retailer's distribution center (DC). Moreover, we aggregate all products to one standard mix. For this case we also make an analytical comparison. Next we numerically evaluate our concepts in a case study in Europe taking data from Vos Logistics, a logistic service provider. We use simulation as the main method and check its outcomes with the analytical calculations. The advantage of this approach is that we can get an estimate of the real savings, yet the disadvantage is that the calculations are only done for one specific case. To get some idea of generality we also perform a sensitivity analysis.

CONCEPTUAL MODEL

The conceptual model consists of a general network representation of the distribution process, together with assumptions. First, we explain the assumptions and the construction of the network model with the possible choices in this model. We then formulate four distribution strategies based on the general choices on the position of inventories in the chain. Next we define the performance criteria and evaluate the different strategies.

Model

We consider fast moving consumer products that are made in batches. A production cycle starts with the production of a new batch and ends when the next batch is produced. We assume this production cycle length to be fixed. The size of a production batch is based on the remaining number of products from the last production cycle and a demand forecast for the new cycle. The demand forecast relies on information provided by the retailers. The production time is neglected.

The distribution process starts right after the production of a new batch. The output of a production batch can be stored in a storage location near the factory (which we call the factory storage) or can be transported to a regional stocking point (or a terminal used as such). All costs caused by these products from this moment are taken into account, whether they are for the manufacturer or retailer in reality. In our model the distribution process ends when a product arrives at the retailer's distribution center. (We will refer to this distribution center as DC in the remainder of this article.) In the supply chain between the factory and the DC, there can be one or two transshipment or stocking points. These points are used if the transportation is intermodal or if the storage is decentralized. In this paper we will refer to these points as terminals, but they could be regional distribution centers as well. Figure 1 shows a graphical representation of a sample supply chain consisting of a factory with a storage location, three terminals and two distribution centers.

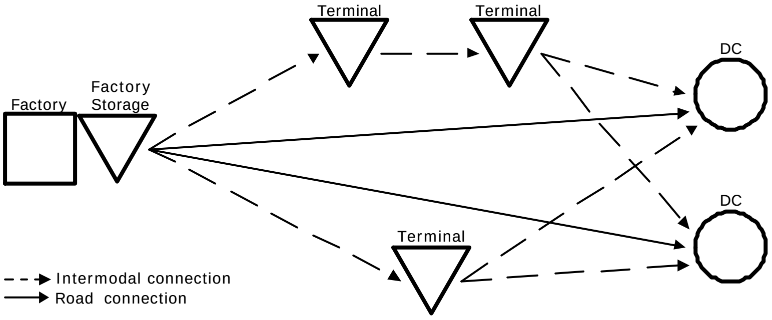

Figure 1: A supply chain

In order to make a good comparison between the distribution strategies, we assume that all orders and deliveries consist of full-truck-loads (FTL's). If, for example, a retailer is supplied using 40 ft. containers, then the order size of its DC must be exactly the number of products that fills a 40 ft. container (or a multiple of this number). The demand for fast moving consumer goods is high enough to make it possible to transport only FTL's of a single product. If the demand is too low for a single product, a standard product mix can be used to create FTL-transports (Teulings and Van der Vlist, 2001). The composition of this mix has to be fixed, because the products must remain in the load unit during the distribution process. In our model, every transport is a direct run from departure to destination. Vehicle route planning is not taken into account and we assume that a transportation vehicle is always available when needed.

All DCs can be reached both by a direct (road a.k.a. unimodal) connection and an indirect (intermodal) connection with one or two transshipment points (regional terminals). In these regional terminals the products can be stored for a short period. When a new production batch is ready, the manufacturer has to choose where to store the products. The products can either be stored on-site in the factory storage or transported to a regional terminal immediately after the production. For each order, the manufacturer has to choose from which stocking point it will be fulfilled and which transportation mode will be used. We assume that the transit time of a direct transport from both the factory and the regional terminals is short enough to be acceptable for the retailer as order lead time.

Distribution strategies

In this paper we examine four distribution strategies. For every full truck load unit, we have to decide whether it will be stored in a centralized or a decentralized location, and whether to use road or intermodal transport.

The first strategy is based on the just-in-time concept and applies direct road transport only. This is frequently used in FMCG-supply chains. The second strategy is completely based on floating stock: all transports are intermodal. This strategy is especially popular in supply chains where an intermodal connection has lower transport costs than a road connection. The third and fourth strategies are new, developed to try to take as much advantage of floating stock as possible.

Strategy CS: Centralized storage and unimodal transport

Using this just-in-time based strategy means that the whole production batch and the safety stock are stored on-site at the factory storage. When an order arrives, it is always fulfilled using road transport from the on-site inventory. In this strategy the emphasis is on fast transportations and easy coordination.

Strategy DS: Decentralized storage and intermodal transport

The complete production batch is shipped to regional terminals using intermodal transport. Orders are delivered by truck from these terminals to the DCs. The safety stock is also stored in these regional terminals. The emphasis is on using intermodal transportation and short order lead times (because the order lead time from the terminal will be shorter than from the factory). If the safety stocks are depleted at a terminal, lateral transshipments from other terminals are made.

Strategy DS/CSS: Decentralized storage, intermodal transport, and centralized safety stock

In this case the safety stock is stored at the factory storage, whereas the production batch is shipped to the terminal using intermodal transport and stored there. The regular deliveries to the retailers are fulfilled from the terminals, but in a period of excess demand, first lateral transshipments from other terminals and if these all terminals are without stock emergency deliveries are done from the factory storage. These emergency deliveries are transported by road, because the intermodal transit time is much longer.

The safety stock storage costs will probably be lower in the DS/CSS strategy when compared to the DS strategy. This is because long storage on-site is in general cheaper than long storage in a terminal. Furthermore, reliability increases if the safety stock is stored in a central location.

Strategy MS: Mixed storage

The mixed storage strategy stores part of the production batch in the factory storage (centralized) and part of the production batch is stored in decentralized terminals. The safety stock is stored at the factory. The part of the production batch that is centrally stored takes care of the expected demand during the intermodal transit time from the factory to the terminal. The remainder of the production batch is sent to the terminal using intermodal transport. All orders that are placed while the intermodal transport is in transit, are fulfilled from the on-site inventory at the factory using road transport. Once the products have arrived at the terminal, the orders are delivered from the terminal (with a shorter order lead time). Emergency orders in a period of excess demand are delivered using road transport from the safety stock stored at the factory. If the safety stock at the factory is depleted, lateral transshipments from other regional terminals are considered.

This last strategy is designed to benefit from costs advantages of floating stock storage without having to increase the total inventory level in the supply chain. The DS strategy ships the complete production batch using intermodal transport. This batch cannot be used to fulfill orders until it has arrived at the regional terminal. Any orders coming in during this transit time can only be fulfilled using products from a previous production cycle. This increases storage time and costs. If we split the batch into a part that is stored in the central factory storage and a part that will be stored in decentralized locations, then it is possible to benefit from the costs advantages of floating stock storage without suffering additional inventory costs. Orders received during the transit time of the intermodal transport can now be fulfilled using the on-site inventory from the current production cycle. In this way, the total stored inventory is low during the intermodal transport transit time and the reliability is high. Centralized storage of the safety stock and the expected orders during the intermodal transit time maximizes the savings. If more products were to be stored on-site, then the floating stock part (which generates the storage costs savings) would decrease. A lower level of centralized inventory will either lower reliability or increase storage costs (for products stored centralized from previous production cycles).

Performance criteria

The following criteria are relevant for evaluation of the strategies: expected costs, average order lead time, and reliability.

The expected costs are divided into transportation and handling costs, storage costs and holding costs. Transportation and handling costs differ per transportation route. They contain all costs that result from using the specific transportation route: these costs depend on the number of transported load units (FTL's in our model). Therefore, transportation costs can cause differences in the total costs of each strategy, but these are independent of the inventory levels during a production cycle. The storage costs are the direct costs for storing a certain number of products for a certain period. These costs depend on the storage tariff at the specific point, the storage time, and volume of the products (or load units) stored. The holding costs are the indirect costs for keeping inventory in the supply chain. Examples of holding costs are cost of capital and obsolescence cost. Storage costs are usually considered part of the total holding costs, but in this paper we list them separately to support our analysis.

The average order lead time is the average time between placement of an order by a DC and the supply moment of this DC. If intermodal transport is combined with decentralized storage its order lead time is shorter than a strategy with centralized storage and road transport, although intermodal is slower than road transport in general. Figure 2 shows an example of this with an order lead time of two days using centralized storage and one day using decentralized storage.

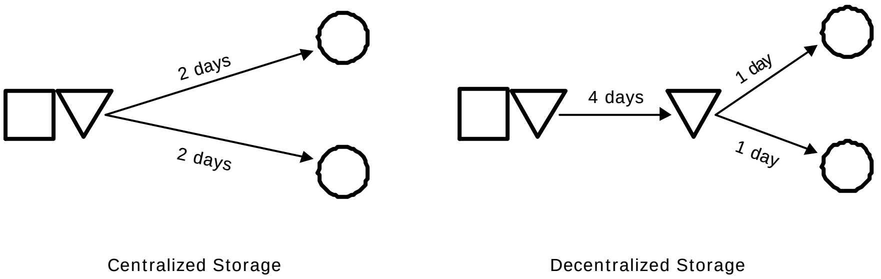

Figure 2: Centralized storage leads to longer order lead times

Orders can only be supplied from the inventory on hand, so inventory in transit (pipeline inventory) is not considered when an order arrives. If the available stock on hand is too low to fulfill the order, the order is rejected. There is no back-ordering. The reliability is the percentage of the orders that can be fulfilled. If a strategy's reliability is less than the required reliability, the safety stock must be increased. This causes additional holding and storage costs, so the increase should be the smallest possible increase that will lead to the required reliability.

Impact of distribution strategy on inventory

In this section we compare the four distribution strategies on their average storage levels. This gives insight into the storage and holding costs per strategy.

Consider the supply chain from factory to a single retailer's DC. The demand of the DC is assumed linear at rate r. The production cycle has length T, so on day T, $2T$, $3T$ etc. a new batch is produced of size $Q = T \cdot r$. Furthermore, the manufacturer uses a safety stock of size SS. The intermodal transport from the factory to the terminal has transit time $T^* < T$.

Using the CS-strategy, the manufacturer has $T \cdot r + SS$ in storage at the start of a production cycle, because in this strategy the whole new batch is stored at the factory storage immediately after the production. During the production cycle, this decreases linearly to the safety stock level SS at the end of the production cycle. A new batch is then produced and the process is repeated. The average storage level is $T \cdot r/2 + SS$. Figure 3 shows the inventory profile of this process.

Using the DS strategy, the new production batch is shipped to the terminal at the start of a production cycle using intermodal transport with transit time T^*. Therefore, a storage level of $T^* \cdot r$ from the previous production cycle is necessary at the terminal to be able to deliver the orders during T^*. The safety stock is stored at the terminal as well. The inventory level $T \cdot r + SS$ *is* reached at time T^*. The inventory profile (see Figure 3) is identical to the profile of the CS strategy with a delay of T^* days. Thus the average storage level of the DS-strategy is $T \cdot r/2 + SS$.

The DS/CSS-strategy differs only from the DS strategy in the location of the safety stock. This location makes no difference for the total average storage level, so the storage levels of these three strategies are all equal if they use the same level of safety stock. However, as the amount of pooling is different for the strategies, the safety stock level could differ.

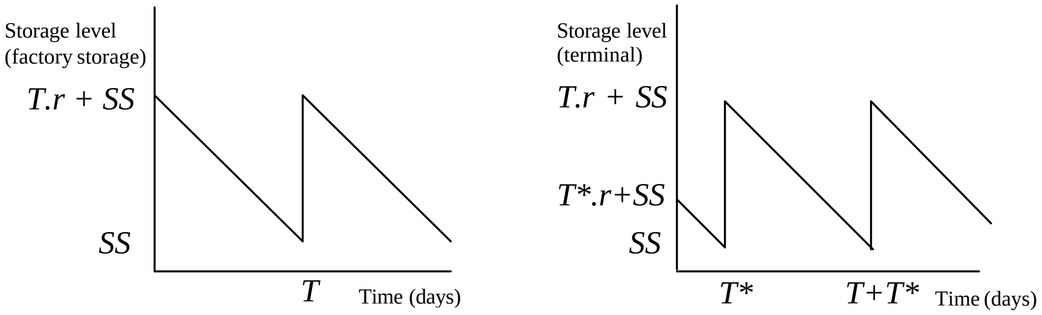

Figure 3: Storage at factory for CS-strategy (left) and at terminal for DS-strategy (right)

Using the MS-strategy, the new production batch is split into two parts. The first part is required to deliver the orders in the first T^* days of the production cycle: this part and the safety stock are stored at the factory. In total this amounts to $T^* \cdot r + SS$. The second part is used to deliver the orders in the last T-T^* days of the production cycle: $(T-T^*) \cdot r$ units are transported to the terminal using intermodal transport. In this strategy, the average storage level at the factory is $T^*/T \cdot T^* \cdot r/2 + SS$. The average storage level at the terminal is $(T - T^*)/T \cdot ((T - T^*) \cdot r)/2$. The total average storage level is the sum of the average storage level at the factory and the average storage level at the terminal: $\left(2T^{*2}/T - 2T^* + T\right) \cdot r/2 + SS$. So by this advanced positioning the MS strategy has a lower average storage level than the other three if $2T^{*2}/T - 2T^* < 0$ and because $T^* < T$, this is always true. This storage level difference is optimal in the case that $T^* = T/2$. Note that delivering T^*r directly is optimal, as a higher or lower amount does not reduce inventories.

The storage levels at the factory storage and the terminal in this strategy are shown in Figure 4.

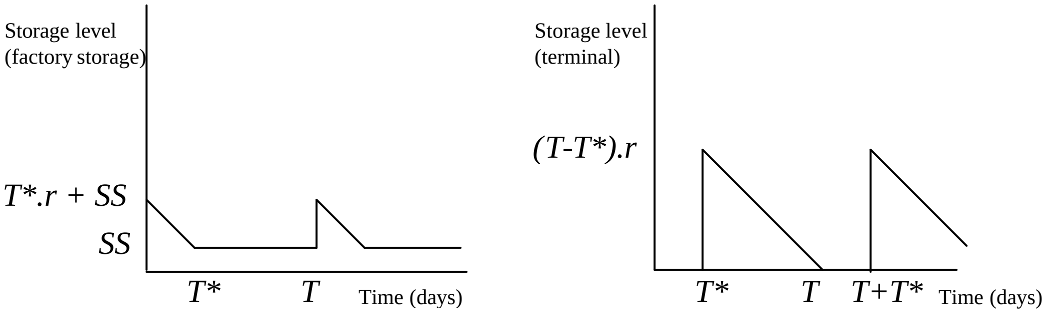

Figure 4: Storage at factory (left) and terminal (right) for MS-strategy

The average pipeline inventory level, i.e. the average number of products in transit, depends on the transportation mode. A strategy has a higher average pipeline inventory level if more intermodal transports are used because of the longer transit time of intermodal transport. Therefore, the DS and DS/CSS strategies always have a higher average pipeline inventory level than the other two. More pipeline inventory does not lead to higher storage costs, but it does lead to higher holding costs so this effect should be taken into account when the strategies are compared.

The amount of safety stock needed to reach a certain service reliability can also differ between the strategies. The CS, MS and DS/CSS all apply centralized safety stocks, which can therefore be lower than the total decentralized safety stock for the DS strategy. Moreover, the CS and, to a lesser extent, the MS strategy can also benefit from the safety aspect of a pooled cycle stock which may also lead to a lower safety stock (if demand at one location is low, cycle stock can be used for another location). Note however, that in our model the safety stock is held in an integer number of full truck units, hence a small effect may often remain unnoticeable.

In table 1 we summarize the performance differences between the various distribution strategies (IM indicates intermodal transport.)

	Strategy			
Aspect	CS	DS	DS/CSS	MS
Transportation	Road	IM	mainly IM	Road & IM
Centralized safety stock	Yes	No	Yes	Yes
Advanced deployment	No	Yes	Yes	Yes
Pooling effect of cycle stock	Yes	No	No	Partial
Pipeline stocks	Low	High	High	Moderate
Average order lead time	Long	Short	Short	Varying

Table 1: Comparison of the distribution strategies

To test how large these differences are and whether the storage advantage has any negative effect on the reliability of the MS-strategy, we performed a case simulation.

CASE DESCRIPTION

Below we present a real case and match it to the conceptual model that was presented in the previous section. The case uses realistic data from logistic service provider Vos Logistics[1]. In the next section we will describe a simulation model that was developed for the case study.

An FMCG-manufacturer runs a factory in Poznan (Poland) and distributes its products to four retail DCs in Germany, viz. in Dortmund, Köln, Rüsselsheim (near Frankfurt), and Appenweier (near Strasbourg). At this moment all orders are transported FTL by truck. The load unit is 40 ft. container. An alternative intermodal route is a rail connection from a station in Gadki (15 km from Poznan) to two train terminals in Duisburg and Mannheim. The conceptual network representation for this case is displayed in Figure 5.

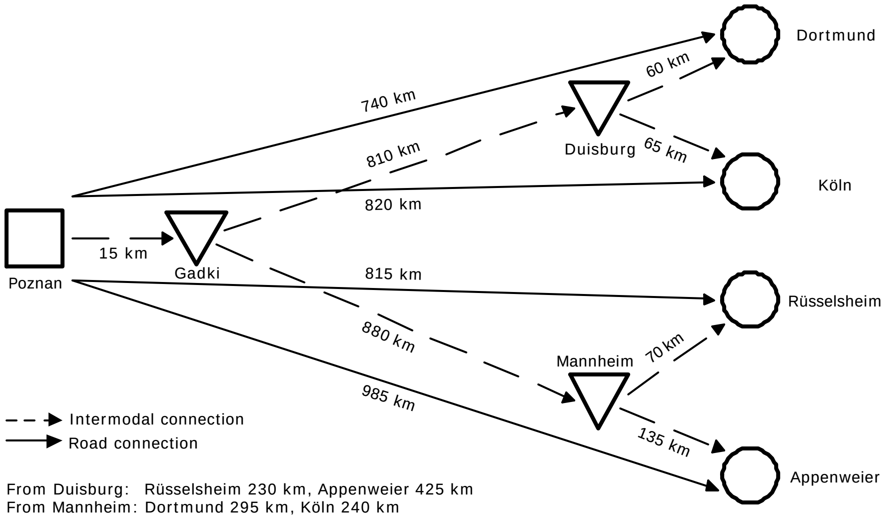

Figure 5: Conceptual network representation of the case

The transit time for all four direct truck routes is two days including handling time for in- and outbound in the on-site DC. The intermodal connection makes use of the rail connection. Due to the long time needed for shunting, the transit time of the train transport to both terminals is 2.5 days. The total transit time of the intermodal transport, including handling and waiting times, is five days (the individual steps are shown in Table 2). If a stock-out occurs at the regional terminal, the DC is supplied by the other terminal: in this case, the final truck transport takes a full day and the total transit time will be 5.5 days.

Step	Duration

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[1] www.voslogistics.com

Transport Poznan – Gadki and inbound Gadki	0.25 days
Expected waiting time Gadki	0.75 days
Loading time train	0.25 days
Transit time rail transport Gadki - Duisburg/Mannheim	2.50 days
Inbound regional terminal	0.25 days
Outbound regional terminal	0.25 days
Transit time final truck transport	0.50 days
Inbound retailer's DC	0.25 days

Table 2: Steps in Intermodal Transport

The cost components which are used to estimate the costs are linear per FTL container delivery and are detailed in Table 3.

Component:	Costs:
Transport and handling:	
For the direct road connection from factory to DC	€ 880 per container
For the intermodal connection from factory to DC	€ 900 per container
Extra costs for transport from terminal outside region of DC	€ 100 per container
Storage:	
Centralized at factory storage	€ 8 per container per day
Decentralized in terminal	€ 16 per container per day (no charge for first three days)
Holding:	
15% interest over € 41370 (value of products in 40 ft. container FTL)	€ 17 per container per day

Table 3: Cost Components

EXPERIMENTS

In this section we introduce the simulation program. Next we present the results of simulation of the case and explain them. Additionally a sensitivity analysis is performed to investigate the influence of a number of factors on the results. Finally, a cost analysis is done and the results of the experiments will be discussed.

The simulation program

The simulation program has been implemented in Arena 3.0 (Kelton et al, 1998). The core of the simulation program consists of three processes: the (stochastic) order generation process, the production process, and the distribution process.

Orders are generated by a random number generator using a probability distribution. The generated number is the interarrival time between two orders from one DC. Every DC uses its own random number generator so every time a retailer places an order, the time until the next order of that DC is drawn. This makes an order by a DC independent of the other DC's orders and of the orders from that DC in the past. The probability distribution used for the case is a triangular distribution with a variation coefficient of 0.5. All orders are per 40 ft. container FTL.

The production process takes place every time a new production cycle starts. The production batch size depends on the demand forecast in the new cycle and the remaining inventory from the last period. The exact algorithms used to determine the batch size differs per distribution strategy, but they always target to keep the cycle stock equal to the expected demand in one production cycle, taking into account the average order volume per day. (The algorithm is described in Appendix A.) Production time is neglected.

The distribution process models the distribution of the new production batch to the appropriate stocking points and the selection of the stocking point for order fulfillment. Only stored inventory can be used to deliver orders, so pipeline inventory cannot be used for this. The CS strategy delivers all orders from the factory storage. The DS strategy generally delivers an order from the terminal in the same region as the DC that placed the order. If this terminal does not have sufficient inventory, the order is delivered from the terminal in the other region (which causes higher transportation costs and a longer transit time). The DS/CSS strategy uses the same sequence as the DS strategy, but now the safety stock at the factory storage might deliver the order if both terminals are out of inventory. The MS strategy tries to deliver from the regional terminal first. If this terminal cannot deliver, the factory's inventory is checked. If this inventory is not sufficient either, the terminal in the other region may be able to fulfill the order. If the stocking points do not have enough inventory when an order arrives, the order is rejected. At the end of the simulation the reliability level of the distribution strategy is determined by dividing the total number of supplied orders (= total orders – rejected orders) by the total number of orders. If this reliability level is less than the required reliability level, then the simulation must re-run with a higher safety stock level, using a step of one full truck load.

Simulation Results

Table 4 lists the parameters used for the case simulation.

Parameter	Value
Transit time intermodal transport from factory to terminal (T*)	4 days
Production cycle length (T)	14 days
Variation coefficient of the order interarrival times	0.5
Demand forecast per DC per production cycle (T·r)	7 FTL's
Minimum reliability	99 %
Train departure frequency	daily
Demand ratio region 1 vs. region 2	50-50

Table 4: Parameters for the case

A simulation run consists of five independent replications. Every replication consists of a four day warm-up period and 500 production cycles (7,000 days). During the warm-up period, safety stock is produced and stored at the appropriate locations. The simulation output are the total average amount of inventory and transportation per production cycle. These are the averages of the five replications. The 95%-confidence intervals of these averages all have a very small half width so the results are very reliable. Table 5 shows the results of the simulation program for the four distribution strategies.

	Unit	CS	DS	DS/CSS	MS
Total average inventory	FTL	21.0	28.0	26.3	19.4
Total average pipeline inventory	FTL	4.0	10.0	9.8	8.1
Total average storage	FTL	17.0	18.0	16.5	11.2
Average storage in Poznan	FTL	17.0	-	2.3	4.0
Average storage in Duisburg	FTL	-	9.0	7.1	3.6
Average storage in Mannheim	FTL	-	9.0	7.1	3.6
Delivered from regional terminal	FTL/cycle	-	27.6	26.2	19.9
Delivered fromother terminal	FTL/cycle	-	0.33	0.75	0.10
Delivered from factory	FTL/cycle	27.9	-	0.90	8.0
Rejected orders	FTL/cycle	0.20	0.16	0.24	0.22
Required safety stock	FTL	3	4	3	3
Reliability	%	99.3	99.4	99.2	99.2
Average order lead time	days	2.0	1.01	1.05	1.28

Table 5: The results of the case simulation

Inventory

The average inventory levels of the four strategies are quite different. The DS and DS/CSS strategy need a lot more inventory than the other two strategies. This is because these strategies lead to a high pipeline inventory due to the use of the (slow) intermodal transport, whereas no savings on storage are obtained. Compared to the CS strategy, the MS strategy has a high pipeline inventory as well, but in this strategy the average storage level is low as explained in the conceptual model.

In the analysis in the previous section, the average storage formula derived for the first three strategies was $T \cdot r/2 + SS$. For the case this is equal to 7*4/2 + 3 = 17 FTL's for the CS and DS/CSS strategies and 18 FTL's for the DS strategy (because of the higher safety stock required). The average storage level for the MS strategy is $\left(2T^{*2} / T - 2T^{*} + T \right) \cdot r / 2 + SS$. In this case, this is 11.3 FTL's. The simulation results agree with this with a little aberration because of the lost sales effect in the stochastic order process.

This analysis shows that the DS and DS/CSS strategy are inefficient. Although the total storage of these strategies is equal to the total storage of the CS strategy, they need much more pipeline inventory. This will cause more holding costs. On the contrary, the MS strategy has a slightly lower total inventory level than the CS strategy. Moreover this strategy makes efficient use of the floating-stock advantages, which leads to less storage and more pipeline inventory. In this way, the MS strategy could save on storage costs.

Other simulation results

The other simulation results are simply explained by the definition of the four strategies. The number of FTL's delivered from the terminal outside the region appears to be very small for every strategy. The extra transport costs, caused by this inefficient way of delivering is therefore marginal. The order lead time depends on whether the orders are delivered only from the factory (in two days for CS), mostly from the terminals (in a single day for DS and DS/CSS) or both (MS).

SENSITIVITY ANALYSIS

In the sensitivity analysis all seven parameters listed in Table 4 were varied individually to measure their influence on the simulation results of the four strategies. Only the intermodal transit time caused the differences between the strategies to change significantly. The simulation results with varying transit times are shown in Table 6 (the unit of measure is FTL 40 ft. container).

These results show that an intermodal transit time from the factory to the terminal that is closer to half of the production cycle length makes the MS advantage in storage bigger with respect to the other three as has been proven by the analysis in the conceptual model section.

	CS					DS				
Transit time factory-terminal	2	4	6	7	10	2	4	6	7	10
Total inventory	21.0	21.0	21.0	21.0	21.0	23.0	28.0	32.0	34.0	40.0
Total pipeline inventory	4.0	4.0	4.0	4.0	4.0	6.0	10.0	14.0	16.0	21.9
Total storage	17.0	17.0	17.0	17.0	17.0	17.0	18.0	18.0	18.0	18.1
Required safety stock	3	3	3	3	3	3	4	4	4	4
Reliability (%)	99.3	99.3	99.3	99.3	99.3	99.1	99.4	99.3	99.3	99.2

	DS/CSS					MS				
Transit time factory-terminal	2	4	6	7	10	2	4	6	7	10
Total inventory	22.2	26.3	30.3	32.4	38.4	19.2	19.4	19.6	19.7	19.9
Total pipeline inventory	5.9	9.8	13.6	15.6	21.3	5.6	8.1	9.5	9.7	8.6
Total storage	16.3	16.5	16.7	16.8	17.1	13.6	11.3	10.1	10.0	11.3
Required safety stock	3	3	3	3	3	3	3	3	3	3
Reliability (%)	99.4	99.2	99.1	99.1	99.1	99.3	99.2	99.2	99.2	99.1

Table 6: Results Sensitivity Analysis with Varying Intermodal Transit Time

COST ANALYSIS

In this paragraph we make a cost comparison between the strategies. The costs not only depend on used transport mode and average inventory levels, but also on the considered cost tariffs for calculating the transport, holding and storage costs. In practice cost calculations are rather intricate as they depend on many details and vary over time. That’s why this comparison can only give an impression on the possible differences of the strategies without guaranteeing that these differences will hold in another situation as well. The estimated costs by simulation of the case are shown in Table 7.

	Unit	CS	DS	DS/CSS	MS
Transport costs	€ per FTL	880	900	902	894
Storage costs	€ per FTL	68	98	80	46
Holding costs	€ per FTL	178	238	224	166
Total costs	€ per FTL	1126	1236	1206	1106
Required safety stock	FTL	3	4	3	3
Reliability	%	99.3	99.4	99.2	99.2
Average order lead time	days	2.0	1.0	1.1	1.3

Table 7: Cost Comparison for the Case Simulation

These results show that in the simulated case the MS strategy is cheaper than the other three strategies. Although intermodal transport is more expensive than road transport, the MS strategy has lower total costs than the CS strategy. By making efficient use of floating stock, the storage and holding costs advantages are big enough to compensate the higher transport costs. Furthermore, the average order lead time of MS is shorter than the lead time of CS, so in this case the MS strategy should be preferred over the CS strategy anyway. The DS and DS/CSS strategies always need more inventory than the other two strategies as shown in the conceptual model analysis. This is why the holding costs of these strategies are always higher than those of the other two. Because in this case the transportation costs and storage costs are higher as well, these two strategies are inefficient with respect to the other two.

DISCUSSION – GENERALIZATION

The results in the previous section show that under the assumed conditions, the MS strategy is the most efficient of the four strategies in the area of inventory management. Using this strategy leads to the lowest storage level without significantly effecting the reliability. Given the sensitivity analysis results it has been shown that the efficiency of this strategy does not depend on the used data. In every simulation experiment this storage level advantage existed and it even increased with a longer intermodal transit time.

The average order lead time when using the MS strategy is always shorter than when using the CS strategy so on this performance criterion, the MS strategy beats the CS strategy in any case. However, whether the storage level advantage actually leads to storage costs savings depends partly on the storage tariffs as well, so we cannot draw a general conclusion about this. In the case situation the MS strategy is slightly cheaper than the CS strategy, despite the higher transport costs for using the intermodal transport connection; however, this does not need to hold in general. It proves that it is possible to obtain cost advantages by switching partially from using road transport to intermodal transport even on a route where intermodal transport is more expensive.

The condition that the production takes place in batches is essential for these results to hold in general. This is because the costs advantages of the MS strategy are obtained by keeping the part of the inventory moving (without causing storage costs) that is not expected to be ordered on the short run. If on the contrary the production is continuous or order-based, this part does not exist and these advantages cannot be obtained. We would like to note that in the intermodal distribution strategies it is not essential to send the whole batch directly by intermodal transport. One may send the first containers and some days later the others. This prevents a long residence time at the terminal. As the differences will be small and the calculations more complex, we left this possibility out of consideration.

The case explanation proves that the MS strategy can be profitable on both one single transportation lane and a whole distribution network. So the presence of a network with a couple of terminals and DCs as in the case is not necessary. However, a greater number of terminals and DCs cause the demand forecast to be more accurate, because a joint demand distribution has less uncertainty. Moreover, the advantage of the MS strategy could even increase if more than two connections (and terminals) are available from which to supply the DC. The described MS strategy can then be extended in a strategy where the production batch is split up into more than two parts, which makes the storage savings even bigger.

Finally we would like to remark that in reality one can make use of Megatrailers for truck transport, which carry 100 m^3 containers. Although this changes most of the cost calculations, our conclusion that the use of the MS strategy has advantages over the other two intermodal strategies and that it improves the cost efficiency of intermodal transport compared to direct transport remains valid. Some calculations on this case were done in Ochtman et al. (2004).

CONCLUSIONS

Floating stock is a concept where a new production batch is (partly) pushed into the supply chain, without determining the exact destination for each product beforehand. Using this concept may lead to lower storage costs and a shorter order lead time, without a decrease in reliability. This is possible if immediately after the production a part of the batch is centrally stored at the factory to deliver the orders in the first part of the production cycle, while the other part of the batch is transported intermodal to a regional stocking point. Orders in the last part of the production cycle are then fulfilled from these regional stocking points. This strategy offers the best opportunities to benefit from low storage levels, which is the goal of the floating stock concept.

The popular just-in-time strategy often uses centralized storage and road transport. This case study shows that the floating stock strategy can reduce costs and lead times, and improve reliability, in spite of the possible higher transportation costs of an intermodal connection. So when considering a move from using road transport to intermodal transport, storage and holding costs as well as transportation costs should be taken into account.

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APPENDIX A: BATCH SIZES

Because of the different characters of the four distribution strategies, every strategy uses its own algorithm to determine the batch size of its new production batch. These algorithms are presented in this appendix. The storage locations 1 and 2 are the terminals; storage location 0 is the factory storage. The variables are:

$Batch_{0/1/2}$ = Part of the new batch size to be stored at location 0, 1 or 2 respectively.
T = Production cycle length
T^* = Intermodal transport transit time from factory to terminal
$r_{1/2}$ = Demand rate in region 1 or 2
SS = Required safety stock
$RS_{0/1/2}$ = Remaining stock at storage location 0, 1 or 2

1. CS strategy

```
$Batch_0 = T \cdot (r_1 + r_2) + SS - RS_0$
```

2. DS strategy

```
If $RS_1 + RS_2 = T^* \cdot (r_1 + r_2)$
    $Batch_1 = T \cdot r_1 + (r_1 / (r_1 + r_2)) \cdot SS$
    $Batch_2 = T \cdot r_2 + (r_2 / (r_1 + r_2)) \cdot SS$

Else
    If $RS_1 = T^* \cdot r_1$
        $Batch_1 = T \cdot r_1 + (r_1 / (r_1 + r_2)) \cdot SS$
        $Batch_2 = T \cdot r_2 + (r_2 / (r_1 + r_2)) \cdot SS - (RS_1 + RS_2 - T^* \cdot (r_1 + r_2))$
    If $RS_2 = T^* \cdot r_2$
        $Batch_2 = T \cdot r_2 + (r_2 / (r_1 + r_2)) \cdot SS$
        $Batch_1 = T \cdot r_1 + (r_1 / (r_1 + r_2)) \cdot SS - (RS_1 + RS_2 - T^* \cdot (r_1 + r_2))$
    Else
        $Batch_1 = T \cdot r_1 + (r_1 / (r_1 + r_2)) \cdot SS - (RS_1 - T^* \cdot r_1)$
        $Batch_2 = T \cdot r_2 + (r_2 / (r_1 + r_2)) \cdot SS - (RS_2 - T^* \cdot r_2)$
```

3. DS/CSS strategy

```
$Batch_0 = SS - RS_0$

If $RS_1 = T^* \cdot r_1$
    $Batch_1 = T \cdot r_1$
    If $RS_1 + RS_2 = T^* \cdot (r_1 + r_2)$
        $Batch_2 = T \cdot r_2$
    Else
        $Batch_2 = T \cdot r_2 - (RS_2 - T^* \cdot r_2) + (T^* \cdot r_1 - RS_1)$

Else if $RS_2 = T^* \cdot r_2$
    $Batch_2 = T \cdot r_2$
    If $RS_1 + RS_2 = T^* \cdot (r_1 + r_2)$
        $Batch_1 = T \cdot r_1$
    Else
        $Batch_1 = T \cdot r_1 - (RS_1 - T^* \cdot r_1) + (T^* \cdot r_2 - RS_2)$

Else
    $Batch_1 = T \cdot r_1 - (RS_1 - T^* \cdot r_1)$
```

```
    $Batch_2$          $= T \cdot r_2 - (RS_2 - T^* \cdot r_2)$
```

4. MS strategy

```
$Batch_0$          $= 0$

If $RS_1$          $= T^* \cdot r_1$
    $Batch_1$          $= (T - T^*) \cdot r_1$
    $Batch_0$          $= Batch_0 + (T^* \cdot r_1 - RS_1)$
Else
    $Batch_1$          $= (T - T^*) \cdot r_1 - (RS_1 - T^* \cdot r_1)$

If $RS_2$          $= T^* \cdot r_2$
    $Batch_2$          $= (T - T^*) \cdot r_2$
    $Batch_0$          $= Batch_0 + (T^* \cdot r_2 - RS_2)$
Else
    $Batch_2$          $= (T - T^*) \cdot r_2 - (RS_2 - T^* \cdot r_2)$

If $Batch_0 + SS = RS_0$
    $Batch_0$          $= 0$
Else
    $Batch_0$          $= Batch_0 + SS - RS_0$
```

APPENDIX B : RESULTS WITH CONFIDENCE INTERVALS

These results are measured in TEU (twenty-foot equivalent unit). These results match the results of the case described in the paper. The empty rows can be derived from other data.

CS

	Unit	Avg	Half	Min	Max
Total average inventory	TEU				
Total average pipeline inventory	TEU	7.956	0.017	7.934	7.980
Total average storage	TEU				
Average storage in Poznan	TEU	33.920	0.058	33.814	33.968
Average storage in Duisburg	TEU	-	-	-	-
Average storage in Mannheim	TEU	-	-	-	-
Delivered from regional terminal	TEU/cycle	-	-	-	-
Delivered from other terminal	TEU/cycle	-	-	-	-
Delivered from factory	TEU/cycle	55.696	0.350	55.260	56.200
Rejected orders	TEU/cycle	0.407	0.071	0.300	0.484
Required safety stock	TEU	6			
Reliability	%				
Average Order lead time	days	2.0	0	2.0	2.0

DS

	Unit	Avg	Half	Min	Max
Total average inventory	TEU				
Total average pipeline inventory	TEU	19.945	0.044	19.887	20.001
Total average storage	TEU				
Average storage in Poznan	TEU				
Average storage in Duisburg	TEU	17.977	0.018	17.959	18.008
Average storage in Mannheim	TEU	18.035	0.090	17.878	18.126
Delivered from regional terminal	TEU/cycle	55.129	0.327	54.744	55.576
Delivered from other terminal	TEU/cycle	0.654	0.076	0.560	0.748
Delivered from factory	TEU/cycle	-	-	-	-
Rejected orders	TEU/cycle	0.320	0.072	0.216	0.412
Required safety stock	TEU	8			
Reliability	%				
Average Order lead time	days	1.006	0.001	1.005	1.007

DS/CSS

	Unit	Avg	Half	Min	Max
Total average inventory	TEU				
Total average pipeline inventory	TEU	19.511	0.042	19.458	19.559
Total average storage	TEU				
Average storage in Poznan	TEU	4.628	0.032	4.582	4.669
Average storage in Duisburg	TEU	14.141	0.051	14.058	14.183
Average storage in Mannheim	TEU	14.217	0.106	14.059	14.356
Delivered from regional terminal	TEU/cycle	52.366	0.337	51.904	52.784
Delivered from other terminal	TEU/cycle	1.509	0.165	1.316	1.744
Delivered from factory	TEU/cycle	1.763	0.184	1.460	1.952
Rejected orders	TEU/cycle				
Required safety stock	TEU	6			
Reliability	%				
Average Order lead time	days	1.045	0.003	1.040	1.049

MS

	Unit	Avg	Half	Min	Max
Total average inventory	TEU				
Total average pipeline inventory	TEU	16.238	0.016	16.214	16.261
Total average storage	TEU				
Average storage in Poznan	TEU	7.914	0.043	7.857	7.965
Average storage in Duisburg	TEU	7.278	0.024	7.237	7.306
Average storage in Mannheim	TEU	7.337	0.044	7.279	7.397
Delivered from regional terminal	TEU/cycle	39.782	0.305	39.352	40.164
Delivered from other terminal	TEU/cycle	0.206	0.052	0.148	0.284
Delivered from factory	TEU/cycle	15.948	0.239	15.606	16.232
Rejected orders	TEU/cycle	0.438	0.074	0.328	0.524
Required safety stock	TEU	6			
Reliability	%				
Average Order lead time	days	1.283	0.004	1.278	1.288

APPENDIX C: COSTS COMPARISON WITH MEGATRAILERS

In this appendix we compare the strategies when megatrailers are used for the road transport instead of a normal container truck transport. This transport mode is very popular for high volume road transports, because its capacity is bigger than the capacity of a 40 ft. container whereas its extra costs are relatively low. The difference between these modes are shown in Table 8 where the presented costs are the costs for making use of the direct road connection (Poland -> Germany) of the case description.

Transport Mode	Capacity	Costs
40 ft. container truck transport	66 m^3	€ 880
Megatrailer transport	100 m^3	€ 1000

Table 8: Capacity and costs comparison of container and megatrailer transport

To test the consequences of this change for the investigated case, the simulation program has to be changed slightly. To deal with the different capacities, the order and transport volumes are now given in Twenty-Equivalent-Units (TEU). A 40 ft. container has a capacity of two TEU, a megatrailer of three TEU. Because the main transport in the CS strategy is road transport, the orders and deliveries in this strategy now are all per 3 TEU. In the other strategies the orders are still per 2 TEU (1 FTL Container), because these strategies focus more on intermodal container transport. However, if in the MS or DS/CSS strategy an order is delivered by road from the inventory at the factory storage, the transport takes place by megatrailer as well. Because in that case the retail-DC is 'over-supplied' with factor 1.5, the next order of this DC is delayed with the same factor to take this effect into account. The total demand forecast per cycle remains 56 TEU in any situation. The results of this simulation are shown in Table 9.

	Unit	CS	DS	DS/CSS	MS
Transport costs	€ per TEU	333	450	447	417
Storage costs	€ per TEU	37	49	41	23
Holding costs	€ per TEU	96	119	113	83
Total costs	€ per TEU	467	618	601	523
Required safety stock	TEU	9	8	6	6
Reliability	%	99.0	99.4	99.0	99.1
Average order lead time in days	days	2.0	1.0	1.1	1.3

Table 9: Results of the simulation where the road transport mode is the Megatrailer

Now the CS strategy is the cheapest solution, because the transport costs are much lower. Although the MS strategy compensates somewhat for this difference by saving storage and holding costs, it is not enough to have the lowest total costs overall. Of course the average order lead time of MS remains shorter, so it could still be preferred over the CS strategy in some situations. With respect to the other two intermodal strategies, the MS strategy is still the most efficient, as is shown by the enormous difference in costs per TEU.