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Author: Baker, P

An Exploratory Framework of the Role of Inventory and Warehousing in International Supply Chains

Peter Baker

Centre for Logistics and Supply Chain Management

Cranfield School of Management

Cranfield University

Bedford

United Kingdom

MK43 0AL

Tel +44 1234 751122

Fax +44 1234 752441

e-mail: peter.baker@cranfield.ac.uk

Biography

Peter Baker is a Lecturer at the Centre for Logistics and Supply Chain Management at Cranfield School of Management, where he lectures on warehousing and international transport. Following his original career in international freight forwarding, he gained a MSc degree in Distribution Technology and Management at Cranfield. Before returning to Cranfield to work in his current capacity, he undertook over 70 supply chain consultancy projects in a wide range of industries across many parts of the world. These projects ranged from supply chain strategy studies to distribution centre design and implementations. His current research interest is the interrelationship between supply chain strategies and distribution centre capabilities. He can be reached at the Centre for Logistics and Supply Chain Management, Cranfield School of Management, Cranfield University, Bedford, United Kingdom, MK43 0AL. Tel: +44 1234 751122; Fax: +44 1234 752441; E-mail: peter.baker@cranfield.ac.uk.

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Abstract

Purpose – The aim of this paper is to explore the role of inventory and warehousing within international supply chains and, from this, to develop an exploratory framework that assists understanding in the area.

Methodology / Approach – The research is based on case studies of 13 supply chains in 6 companies, using pipeline mapping techniques, questionnaires, quantitative measures of lead times, and Likert scales to measure the perceptions of supply chain managers to risk.

Findings – The results indicate that, for these case study supply chains, the supplier lead times were far in excess of the customer lead times and that, with the exception of new product lines, demand therefore needed to be supplied from inventory. In addition, inventory was a common risk mitigation strategy against the possibility of random demand variability and transportation delays. Based on these findings, an exploratory framework was developed to integrate such factors as inventory reduction strategies, risk management and inventory control theory.

Research limitations / implications – Further research is required to develop this exploratory framework in more detail so that it can help practitioners arrive at the most appropriate solutions. It is proposed that this is conducted initially in the fast moving consumer goods or retail sectors, so as to build on this research, and that this should include the upstream supply networks. Other types of industry sectors should then be explored.

Practical implications – It is intended that the exploratory framework put forward in this paper can form the basis for further research in the area and to develop useful tools for practitioners.

Originality / value – The literatures on inventory control theory and inventory reduction strategies have been largely separate to date. The findings of this paper lead to an exploratory framework to start to bring these areas together.

Keywords Inventory; Warehousing; International supply chains; Supply chain risk.

Classification Research paper

Introduction

Inventory holding and warehousing continue to play an important role in modern supply chains. A survey of logistics costs in Europe identified the cost of inventory as being 13% of total logistics costs, whilst warehousing accounted for a further 24% (European Logistics Association/AT Kearney, 2004). A similar study in the USA, found inventory costs significantly higher at 24%, with warehousing, at 22%, being close to the European figure (Establish/Davis, 2005). As well as being significant in cost terms, they are important in terms of customer service, with product availability being a key service metric and warehousing being critical to the success or failure of many supply chains (Frazelle, 2002a).

The role of inventory as a buffer against uncertainty has been established for a long time. However, more recently, the disadvantages of holding inventory have been increasingly recognised, particularly with regard to the adverse impact that this may have on supply chain responsiveness. This discussion can naturally be extended to the role of warehouses, as one of the prime *raisons d'être* of warehouses has traditionally been to hold inventory. The aim of this paper is to investigate the precise roles of inventories and warehouses by means of case studies in order to provide a deeper understanding of these roles and to develop an exploratory framework that may be used in this respect.

The role of inventories

Increasing globalisation has tended to lead to longer supply lead-times, which, by conventional inventory control theory, result in greater levels of inventory to provide the same service levels (Waters, 2002). The impact is normally recognised as occurring with regard to safety stock, with the amount of this stock increasing in a square root relationship to the lead-time. In addition, with more distant supply lines, there is also the possibility of an increasing variation in the supply lead-time and this would further increase the amount of safety stock. A further factor is the transport economics of long distance movements whereby there may be significant cost economies achievable by despatching in larger quantities (e.g. full container loads) and this would tend to increase cycle stocks. This relationship between the use of offshore sourcing strategies and the resultant increased inventory levels has been demonstrated by Lowson (2002).

However, there has been some concern about the true costs of inventory and whether companies do in fact recognise these fully. For example, Christopher (2005) highlights costs such as storage, obsolescence, damage, deterioration, shrinkage, insurance and management costs, as well as the more traditional cost of capital. With an incorrect assessment of inventory costs, there is the danger that companies may make inaccurate supply chain trade-offs in this respect and therefore hold too much inventory (Lee and Billington, 1992).

In lean supply chain thinking, inventory is regarded as one of the seven ‘wastes’ and therefore it is considered as something to be reduced as much as possible (Womack and Jones, 1996). Similarly, in agile supply chains, inventory is held at few echelons, if at all (Van Hoek *et al.*, 2001), with goods passing through supply chains quickly so that companies can respond rapidly to exploit changes in market demand (Christopher and Towill, 2001). There have been various supply chain taxonomies based on these concepts and most stress the need for inventory reduction within each of the classifications. For example, Vonderembse *et al.,* (2006, p. 229) state that a lean supply chain "generates high (inventory) turns and minimises inventory throughout the chain", in an agile supply chain companies "make in response to customer demand", and in a hybrid supply chain companies "postpone product differentiation and mimimize functional components inventory". There is thus an emphasis on inventory reduction in each of these supply chain classifications.

Nevertheless, there is a recognition that inventory can play a key part in lean and agile thinking. The holding of 'strategic inventory' at decoupling points can act as a buffer, separating lean production activities from an agile response to volatile market places (Christopher and Towill, 2001). Customer orders can thus be satisfied from this inventory, enabling lean principles to be applied to the manufacturing process, based on a more level production schedule. The production and movement of goods is generally forecast-driven up to the decoupling point and then driven by actual demand orders downstream from the decoupling point (Christopher, 2000). This type of structure is necessary when the supply lead-time is greater than the demand lead-time (Harrison and van Hoek, 2005), as in such cases production cannot be based on actual customer orders.

Whilst inventories provide some security against fluctuations in the level of customer demand, there is concern that they may reduce the ability of supply chains to respond to changes in the nature of that demand. Inventories in international supply chains may therefore act as a buffer against one risk whilst increasing another type of risk. For example, Etienne (2005) lists factors such as speed to market for new products, responsiveness to new technology (leading to potential obsolescence of existing inventory), responsiveness to market niches, feedback time for quality issues, and "feed forward" time (e.g. speed of signal to the market, through actual use, that the product has been improved). One conclusion of this latter paper is that "inventory is a net destroyer of supply chain responsiveness" (p. 63).

The potential disadvantages of holding inventory are widely recognised and a number of inventory reducing strategies have been put forward. These include:

- A reduction in production lead-times, for example, by means of shorter set-up times and smaller manufacturing runs (Harrison and van Hoek, 2005).
- The use of production postponement, enabling inventory of common components to be held rather than a multitude of finished goods lines (van Hoek, 1998).
- The visibility of end consumer demand to all supply chain participants, to reduce excess inventories caused by demand amplification up the supply chain (Christopher, 2005).
- Total cycle time compression, in both information and material flow lead times (Mason-Jones and Towill, 1999).
- The centralisation of inventory. For example, the level of safety stocks can be reduced by centralising inventory in a single European Distribution Centre rather than holding inventory in several National Distribution Centres (Sussams, 1986).
- The virtual warehousing concept, whereby all inventory across many locations is regarded as one common inventory pool (Landers *et al.*, 2000). This may be

associated with the transhipment of goods between warehouses at the same echelon level in the supply chain (Herer *et al.,* 2002).

- Cross-docking goods to speed the flow of goods through the supply chain (Apte and Viswanathan, 2000). In this sense, cross-docking is defined as receiving goods at a warehouse and quickly transferring to despatch vehicles, without putting the goods away into stock.

Inventory has also been a subject in the debate on supply chain resilience, which has been of increasing interest in recent years, particularly as the "leaning-down" of companies and global sourcing have increased supply chain risks (Christopher and Peck, 2004). It is recognised that international supply chains may be particularly vulnerable owing to such factors as the geographic area covered, the transport modes used, political / border factors and environmental issues (Prater *et al.,* 2001). Whilst risk mitigation strategies may contain many elements, the use of inventory is generally recognised as one possible tool. For example, Chopra and Sodhi (2004, p.60) list "increase inventory" as a risk mitigation approach, whilst Christopher and Peck (2004, p.8) state that "the strategic disposition of additional capacity and/or inventory at potential 'pinch points' can be extremely beneficial in the creation of resilience within the supply chain". Lee (2002) particularly emphasizes the role of inventory in situations of supply uncertainty.

There are thus widely varying views about the role of inventory in the literature and some of these views appear to have conflicting goals. For example, the goal of traditional inventory control theory has been the optimisation of inventory levels, whereas the goal discussed in more recent thinking, such as that on lean and agile supply chains, has concentrated more on the minimisation of inventory levels. However, the latter has been counteracted to some extent by the understanding of the role of decoupling points and the part that inventory may play in some risk mitigation strategies. Whilst the minimisation of inventory is widely discussed, this needs to be defined and there is a recognition that resources can be reduced too much, leading to terms such as "corporate anorexia" (Radnor and Boaden, 2004). This suggests that there is in fact an optimum level of inventory. However, the identification of this level needs to involve wider concepts than those just associated with traditional inventory control theory.

The role of warehouses

A questioning of the role of inventory naturally also tends to question the role of warehouses, as inventory holding and the servicing of customer orders from that inventory are key warehouse functions. This key role is recognised by most textbooks that cover warehousing (e.g. Ackerman and Brewer, 2001, Frazelle, 2002b, and Rushton *et al.*, 2006).

Other roles for warehouses are being seen as increasingly important as they change from "holding yards" to "switching yards" (Drucker, 1992). In this context, Higginson and Bookbinder (2005) list the roles of distribution centres as:

- Make-bulk / break-bulk consolidation centres, in order to consolidate customer orders together into one delivery and gain transport economies.
- Cross-dock centres, whereby customer orders are satisfied from another source (e.g. a manufacturing plant) and just pass through the distribution centre within a few hours (or a couple of days at the most).

- Transshipment facilities, which are used to change transport mode (e.g. from large line-haul vehicles to smaller delivery vehicles).
- Assembly facilities, where the final configuration of the product to individual customer requirements can take place.
- Product-fulfilment centres, responding directly to product orders from the final consumer (e.g. as Internet fulfilment operations).
- Returned goods depots, handling unwanted and damaged goods, as well as goods returning under environmental legislation such as for product recovery and packaging waste.
- Miscellaneous roles, such as customer support, installation and repair services.

A number of these roles may be associated with some of the concepts mentioned earlier, such as agility, production postponement, and time compression. These are generally recognised as increasing trends in warehousing (Maltz and DeHoratius, 2004). However, a survey of large warehouses in the United Kingdom indicated that over 50% of the floor area is generally taken up by storage, with most of the remaining area being used for the associated goods-in, order picking, packing and despatch activities (Baker, 2004). In that survey, although value-added activities took place in over 70% of the warehouses, they only accounted for about 5% of the floor area. These activities were thus relatively minor in nature and normally occurred as part of the pick and pack process. Similarly, cross-docking was rather limited in nature with 74% of the warehouses cross-docking 5% or less of their throughput. Inventory holding is thus still a key role of warehouses in modern supply chains.

The continuing importance of inventory holding, and associated warehousing, appears to warrant further research, particularly as the literature is somewhat equivocal on these subjects.

In spite of the steps taken to reduce inventories in many companies, inventory holding and warehousing continue to be very significant components of modern supply chains. The literature provides some very useful, but sometimes contradictory, insights into these components. In the light of this, a greater understanding is required as to how these elements link together, so that a framework can be developed of how to examine these components.

Research method

A case study approach was adopted for this research in order to gain a fuller understanding of the nature of any inventories held, as well as the precise functions of the warehouses used. In order to limit the scope of the research within this wide area, this exploratory research focuses on outbound distribution (i.e. post manufacturing) and covers a limited number of companies representing both manufacturers and retailers.

Six companies participated in the research and these were drawn from the following industry sectors. The number of supply chains examined for each company is shown in brackets:

- Agricultural supplies manufacturer (2 supply chains). A major global agri-business, with operations in over 90 countries worldwide.

- Automotive component manufacturer (1 supply chain). A Japanese headquartered multi-national company, with manufacturing centres in Japan, North America and Europe.
- Fast moving consumer goods (FMCG) manufacturer (2 supply chains). A division of a major multi-national food manufacturing company.
- Fast moving consumer goods manufacturer (2 supply chains). A manufacturer of non-food items, with sales to retailers and distributors in over 150 countries.
- Retail chain, departmental stores (2 supply chains). A leading retail chain with over 20 department stores in the UK.
- Retail chain, apparel and footwear stores (2 supply chains, each sub-divided into two). A leading fashion store chain with over 200 shops in the UK. For this company, a proportion of each fashion line is 'pushed' directly out to stores, whilst the remainder is held back at the UK distribution centre for subsequent replenishment to restock the stores when particular sizes or colours are sold. These two operations give distinctly different pipeline maps and are therefore regarded separately for the purposes of this analysis.

This gave a total of thirteen supply chains examined within this research.

These six companies were selected as giving a reasonable representation of sectors to include industrial manufacturing (two different industries), FMCG manufacturing (food and non-food), and retail companies (two different sectors). Although this number does not give a comprehensive cross-section of industry sectors, it does provide a balance between the desire to explore a variety of issues that may occur in different sectors whilst being a manageable number to be able to examine the supply chains in some detail. The number of supply chains to be examined was discussed with the companies and two supply chains each were regarded as being sufficient to gain a useful insight into the nature of their international outward supply chains.

The research was introduced to the participating companies in face-to-face meetings: one meeting with five of the companies in a group and one company individually. The representatives of these companies were senior supply chain managers or directors, holding the following positions: European Distribution & Warehouse Manager; General Manager (European Logistics); Logistics Director; Overseas Purchasing Manager; Project Manager (Supply Chain & Manufacturing Development); and Supply Excellence Director.

The nature of the project and the research method was introduced to the participants, who were then asked to select supply chains for particular product groups that they regarded as being 'typical' of their own international logistics operations. The thirteen supply chains selected by the participants comprised six sea routes (by container) and seven road transport routes. The sea routes were primarily from Asia to Europe (with one being from the UK to USA), whilst the road transport routes were international supply chains across Europe. The supply chains were defined as being from the point of manufacture to the point of use (or to the store in the case of retail deliveries) and thus extended outside the companies themselves. However, the inward supply chain of materials to manufacture was not examined, as this would generally have required authorisation outside the remit of the individual participants and would have involved the mapping of numerous material supply networks (which would be worthy of a study in its own right). The impact of raw material sourcing as a potential source of risk and delay is thus not examined within this paper.

First of all, the participants were asked to complete a pipeline map for the supply chain of each product group selected, showing the number of days of inventory held at points along the chain, as well as in-transit inventory (e.g. whilst on ships or trucks). This was undertaken using a Powerpoint template that was sent out by email. This pipeline mapping method was selected as it is a well-established means of analysing long and complex supply chains (for example, see Scott and Westbrook, 1991).

A two-page questionnaire, for each of the selected supply chains, was also sent out to the participants attached to the same email. This comprised questions about the nature of the supply chain, including lead-times, transit times, inventory levels, and the purpose of inventory holdings and warehouses. In addition, questions were included on the sources of risk, extent of risk and avoidance actions taken (after Svensson, 2004). The severity of potential impact on the business and the likelihood of occurrence were measured on 5-point Likert scales. There was also an open ended question asking for views on whether inventory is primarily a source of risk or a means of risk mitigation.

Further information and clarification was then gained by face-to-face interviews, telephone conversations and e-mail, as appropriate, to gain a fuller understanding of the supply chains and the responses provided.

Results

The thirteen supply chains were mapped as per the example for the retail company shown in Figure 1. This particular chain involves road transport at each end, but also includes rail transport from the consolidation point in India to the Indian port, and then full-load seafreight container movements to the U.K. The pipeline map is drawn as per Scott and Westbrook (1991) with the movement of goods shown by horizontal lines and the holding of goods at any point in the supply chain shown by vertical lines. The total of the figures associated with the two sets of arrows represents the total pipeline inventory in the supply chain, including in-transit inventory and that at holding points *en route*. Two sets of total figures are given in this diagram. The first figure, of 36 days of pipeline inventory, represents the initial 'push' of products to the stores, with goods only being held an average of 2 days at the UK distribution centre. This just allowed time for sorting and for consolidating into the next load to the stores (as smaller stores were not served every day from the distribution centre). The second figure, totalling 51 days of pipeline inventory, includes an average inventory holding of 17 days at the UK distribution centre for replenishment purposes.

[Take in Figure 1]

The pipeline inventory levels for the thirteen supply chains are shown in Table I. For the purposes of this table, any goods held at a port for activities closely allied to transport (e.g. awaiting shipment or awaiting Customs clearance) are shown as inventory in transit. This enables the inventory held at warehouses to be analysed separately. In line with this definition, the transit times varied from 45 days for a Japan to France supply chain (i.e. including the time at ports, awaiting shipment and for Customs clearance) to 4 days for some European movements. The warehouse inventory ranged from 54 days to 2 days.

[Take in Table I]

The research is aimed at examining the nature of the inventory held at warehouses, and the purpose of each inventory holding point is shown in Table II. The table is arranged so that the inventory buffer is shown as Warehouse C, with activities in warehouses that occur prior to that shown as Warehouses A and B, and those after as Warehouse D. In general, the inventory buffer is just held at one point (except for the UK to S. Russia and UK to Italy supply chains, where safety stock is held by both the vendor and the buyer). In some supply chains, goods are shipped directly to the decoupling point, whilst in others goods are held for a number of reasons first (e.g. awaiting for other goods to consolidate to full load containers or trailers, co-packing activities to promotional / retailer packs, and palletising and feeding through to the main inventory holding point in a smooth flow). At the downstream side, some goods were shipped directly from the decoupling point to the point of use (or to the retail store), whilst others passed through a subsequent warehouse (e.g. for delivery consolidation, assembly line sequencing, and feeding on a quick response basis to individual stores).

Few value added services were noted by the participants, and that where these do occur they may be undertaken at external premises rather than at the main decoupling point (as in the example of co-packing in the UK to Italy supply chain). Other participants had limited examples of value added services that just applied to a small proportion of the throughput, such as the screen-printing of plain cotton tea-shirts or the hanging, and ironing, of garments. However, again, in both these examples, the activities were conducted by sub-contractors off-site. Although this particular research is not intended to be a wide representative sample, this is in line with the findings of the survey in Baker (2004), in which relatively little floor area is given over to value added services in large warehouses. Although this research was not designed as a full value chain analysis, no instances of added value activities were identified at the ports themselves, and this is an area that may warrant investigation in further research.

[Take in Table II]

The need for inventory buffers in these supply chains is demonstrated by the wide difference between the supplier lead-time and the customer lead-time, known as the lead-time gap (as per Harrison and van Hoek, 2005). These lead-times are shown in Table III. Some of the supplier lead-times are shown as ranges, representing the manufacturing cycles. For example, in the UK to USA supply chain, the shortest supplier lead time is 42 days for an order placed just before the 5-day manufacturing cycle is finalised, whilst the longest is 47 days. Similarly, some customer lead-times are shown as ranges, representing the different service levels offered (e.g. larger stores may be on more frequent delivery schedules than smaller stores). Overall, the supplier lead-times for the replenishment supply chains are about 14 times greater than the customer lead-times. In these circumstances, it is very difficult for inventory reduction strategies to eliminate the need for safety stock.

[Take in Table III]

Conventional inventory control theory would suggest that the longer the supplier lead-times the greater would be the level of safety stock (subject to such conditions as similar service levels, lead-time variability, delivery frequency and customer demand variability). The graph in Figure 2 broadly shows this relationship for the thirteen supply chains that have been researched. The two low outlying points (at zero safety stock) are the two initial ‘pushes’ of new fashion lines into the stores. This shows the importance of designing supply chains to reduce or eliminate inventory where such business strategies are appropriate. The two high outlying points (at 30 and 35 days stock) are where there are two decoupling points in the supply chain, with both the vendor and buyer holding safety stock. This is in line with what may be expected where orders are passed from one level of the supply chain to another (for example, as modelled by Forrester, 1961).

[Take in Figure 2]

The respondents were asked to list the main supply chain risks that they perceived and to note the likely severity of the impact on the business, the likelihood of occurrence, and the risk mitigation strategies that they adopted. 5-point Likert scales were used to measure the impact on the business and the likelihood of occurrence, with mid-scores of 3 denoting a moderate impact on the business and being likely to occur about once per year, respectively (see Table IV for full description). The two main risk areas for the selected international supply chains were those associated with variability in demand and variability in lead-times.

[Take in Table IV]

Variability in demand was listed as forecast inaccuracy, and it was recognised that this may be either an over-estimation or under-estimation of demand. An over-estimation of demand led, in the words of the participants, to issues such as “excess stock”, “price mark-downs” and “inventory write-offs”, whilst an under-estimation of demand led to such issues as “lost sales” and “lost customers”. On average, this was regarded as having a moderate to high impact on the business and likely to occur, to a significant degree, almost once per year.

Variability in lead times was normally associated with shipping and road transport delays. The impact on the business was regarded as being between moderate and very high, whilst the likelihood of occurrence varied quite widely. Some delay risks were generic (e.g. weather and accidents), whilst others were particular to specific types of supply chain (e.g. the availability of hazard approved drivers, and regulatory delays in the USA caused by security regulations). Transport delays, in the words of one respondent, may lead to “poor availability, lost sales, loss of customer goodwill, and loss of customer confidence in the brand”. For industrial customers, it could lead to “production shut-downs”.

Multiple risk mitigation strategies were used, with the two most common strategies being the use of safety stock to buffer against these variations in demand or supply, and the use of collaboration with the various parties involved to work together to minimise the risks, or at least to be aware of them at an early stage. Actions such as the expediting of goods by airfreight may then be used to meet heavy demand or to overcome shipping delays. Multiple sourcing was also used in some supply chains to mitigate the risks (see Table V).

Interestingly, only one company mentioned the risk of substandard quality. For that particular company, it was regarded as having a high impact on the business, as it would be "likely to lead to the customer line being stopped".

[Take in Table V]

The participants were asked if inventory was regarded as reducing, or increasing, risk in international supply chains. It was generally viewed as acting in both ways, with a need to find a compromise between opposing influences. For example, one respondent noted that inventory acts as "risk avoidance from the fluctuations in demand, as well as between planning / production and customer lead times. There is a point where increased inventory leads to increased customer service failures. Too little and orders can exceed stock, too much and managing the volumes and stock locations leads to service failures".

Another participant noted the increased risks associated with inventory in international supply chains, as well as the reduced possibilities for risk mitigation strategies, commenting: "Undoubtedly, stock in an overseas supply chain involves more risk than if the same product is bought from a home supplier. It is not easy to react to changes in demand. If we bought the same product from a home supplier, we would expect them to be holding stocks, thus reducing our risks".

A third participant considered that inventory was a risk avoidance mechanism, but with the strong proviso that this is only the case when "you know that you are in touch with the market". As soon as that proviso does not hold, then inventory was regarded as being a source of risk (e.g. by inhibiting response to market changes).

In addition, there were a number of comments that reflect the specific nature of individual supply chains. For example, in one supply chain lead times were reduced by despatching goods whilst quality control tests were still being run. This led to increased responsiveness - unless any tests proved negative, in which case there was then a high risk of customer service failures. In another instance, the Customs duty and tax implications of holding inventory in different countries had a direct impact on the nature of the supply chain, with implications for associated inventory levels and risks.

In any specific supply chain, there are thus likely to be a wide range of factors to take into account. In the case of international supply chains, lead times tend to be long and the need to hold inventory appears to be common, if not the norm. The question faced by the companies participating in this research is thus how to balance these different factors and determine the correct role and level of inventories, and, consequently, the appropriate role for warehouses at different stages in the supply chains.

Conclusions

The results indicate the importance of buffer inventory in international supply chains and suggest that it is very difficult to eliminate the need for such inventory completely. The lead-time gap tends to be very wide indeed. The question is thus not whether inventory is 'good' or 'bad', but how to determine the correct level. However, the complexity and wide range of issues involved is unlikely to render an optimisation approach *per se* as being feasible. This has been the traditional inventory control route in the past. On the other hand, there has been much written recently about the disadvantages of holding inventory (such as slow reaction to the market and slow quality feedback), and thus the need to reduce or eliminate inventory. Whilst very useful concepts have been put forward to achieve these ends, there has been little research into the recognition of the need for inventory in many situations and how companies should identify the 'world-class best-practice' levels of inventory. A wider framework is therefore required to integrate these concepts with inventory control theory.

Based on this research and on the literature, it appears that the first question is whether inventory is required at all. Some business models are suited to identifying consumer trends and rapidly pushing product directly to the market without holding any inventory. These may be particularly applicable in fashion and high technology markets, where product life tends to be short. This is thus the first step in the proposed framework shown in Figure 3. This differentiation may be regarded as a further refinement of the taxonomy for selecting global supply chain strategies set out by Christopher *et al.*, (2006), who differentiated between "standard" and "special" products, with the latter tending to require agile supply chains. Fashion goods may be regarded as "special" products in this taxonomy, with the initial 'push' of product just requiring sortation at distribution centres, but the follow-up replenishment items giving rise to inventory holding. In addition, any special requirements of the supply chain (e.g. holding goods in quarantine awaiting quality control testing) need to be identified during this initial step.

[Take in Figure 3]

The second step shown is to examine the inventory reduction strategies that may be appropriate. These may include for example the use of flexible manufacturing systems, production postponement, and the centralisation of inventory. A further example may be the use of final demand information throughout the supply chain (e.g. EPOS data) so that a single decoupling point can be established, rather than separate safety stocks held by the vendor and the buyer, and so that the 'bull-whip' effect may be minimised.

In parallel to this step, the risks associated with different supply chain strategies need to be examined, for example, the likelihood of disruption to supplies, or the possibility of inventory being rendered obsolete by new technology. This step should build on tools and techniques developed within supply chain risk literature (e.g. the supply network risk tool outlined by Harland *et al.*, 2003), taking into account qualitative as well as quantitative considerations (e.g. supply chain confidence, described by Christopher and Lee, 2004). Such qualitative factors may include the role of trust, social relationships and different cultures, which have not been examined within this particular research.

Once these strategies have been established, then it would be possible to identify the trade-offs between inventory and other supply chain elements, such a purchasing (e.g.

bulk discounts on goods at lower unit purchase prices), manufacturing (e.g. lower production costs through less frequent change-overs and hence larger batch sizes) and transport (e.g. full container load transport at lower unit transport costs). In this step, it is important to identify the full costs of inventory, as highlighted by Christopher (2005), so that these trade-offs are calculated correctly. Obviously, these decisions need to take account of the supply chain risks already identified.

Having explored these options and trade-offs, the appropriate level of inventory can be calculated utilizing established inventory control theory, in order to provide the desired service level to customers. Based on this, the need for, and role of, warehouses in the supply chain can then be identified. As noted in the case studies and the literature, these roles may include a mix of elements such as inventory holding, order consolidation, cross-docking, and postponement activities.

Inventory and warehousing strategies thus require co-ordination between various aspects of a business, including for example the logistics, marketing and manufacturing departments, as well as between supply chain partners. They are thus integral and important parts of overall supply chain strategies and need to be planned as such. The exploratory framework outlined provides a way of bringing the different elements that need to be considered together.

Further research is required to understand these elements more fully and to develop this framework as a useful tool for practitioners. It is proposed that this research should first of all concentrate on a particular industry sector so as to gain a rich understanding of the interrelationships involved, possibly commencing with the

FMCG or the retail sector so as to build on the exploratory research presented in this paper. In addition, the research should be extended further back up the supply chain to examine the supply networks prior to manufacturing. The number of supply chains explored should be extended until no new research findings of any significance are being found. These established findings can then be used as the basis for a more detailed framework that would be of benefit to practitioners in that sector. Additional sectors can then be looked at, based for example on Christopher *et al.*'s (2006) taxonomy of supply chain strategies, to explore to what extent the developed framework is generally applicable and how it would need to be changed to reflect different supply chain situations.

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Table I.
Supply chain inventory levels

Route	International transport mode	Inventory in transit (days)	Inventory held at warehouses (days)	Total pipeline inventory (days)
Japan to France	Sea	45	21	66
Indonesia to UK	Sea	36	22	58
China to UK	Sea	30	23	53
India to UK (initial)	Sea	29	7	36
India to UK (replenishment)	Sea	29	22	51
UK to USA	Sea	27	16	43
UK to S. Russia	Road	9	54	63
Poland to UK	Road	9	22	31
UK to Italy	Road	7	53	60
Spain to UK	Road	5	11	16
France to Czech Rep.	Road	4	15	19
Poland to UK (initial)	Road	4	2	6
Poland to UK (replenishment)	Road	4	7	11

Table II
Analysis of inventory held in warehouses

	Warehouse A		Warehouse B		Warehouse C (inventory buffer)		Warehouse D	
Route	**Purpose**	Inventory (days)	**Purpose**	Inventory (days)	**Purpose**	Inventory (days)	**Purpose**	Inventory (days)
Japan to France	-	-	-	-	Safety stock (France)	20	Assembly line sequencing (France)	1
Indonesia to UK	-	-	-	-	Safety stock (UK)	20	Delivery consolidation (UK)	2
China to UK	-	-	Consolidation (China)	5	Safety stock (UK)	14	Retailer DC: quick response (UK)	4
India to UK (initial)	Container consolidation (India)	2	Feed to DC (UK)	3	-	-	Sortation (UK)	2
India to UK (replenishment)	Container consolidation (India)	2	Feed to DC (UK)	3	Safety stock (UK)	17	-	-
UK to USA	-	-	Awaiting loading (UK)	3	Safety stock (USA)	13	-	-
UK to S. Russia	Factory stock [2 days] and awaiting export clearance at own warehouse [15 days] (UK)	17	Awaiting import clearance at 3PL warehouse (Central Russia)	2	Vendor safety stock (Central Russia)	20	Buyer safety stock (S. Russia)	15
Poland to UK	-	-	-	-	Safety stock (UK)	20	Delivery consolidation (UK)	2
UK to Italy	Factory stock (UK)	2	Co-packing (UK)	21	Vendor safety stock (UK)	10	Buyer safety stock (Italy)	20
Spain to UK	-	-	-	-	Safety stock (UK)	7	Retailer DC: quick response (UK)	4
France to Czech Rep.	-	-	Preparation for shipment (France)	1	Safety stock (Czech Rep.)	14	-	-
Poland to UK (initial)	-	-	-	-	-	-	Sortation (UK)	2
Poland to UK (replenishment)	-	-	-	-	Safety stock (UK)	7	-	-

Table III
Supplier and customer lead-times

Route	Supplier lead-time (in days)	Customer lead-time (in days)
Japan to France	112	14
Indonesia to UK	90	3 to 7
China to UK	28 to 42	1
India to UK (initial)	75	(Push)
India to UK (replenishment)	75	1 to 3
UK to USA	42 to 47	2
UK to S. Russia	26 to 52	4 to 5
Poland to UK	63	3 to 7
UK to Italy	28 to 54	2
Spain to UK	14	1
France to Czech Republic	26	2
Poland to UK (initial)	31	(Push)
Poland to UK (replenishment)	31	1 to 3

Table IV
Perceptions of supply chain risk

Area of risk	No. of supply chains	Severity of impact on business[(1)]	Likelihood of occurrence[(2)]
Forecast inaccuracy - higher demand - lower demand o shelf-life expiry	6	3.3	2.8
Road haulage delay - late collection - accidents - hazard approved drivers	7	3.1	3.4
Shipping delay - capacity - weather	5	4.0	2.6
3PL failure - error or omission	2	5.0	1.0
Regulatory delay - security regulations	1	4.0	4.0
Quality - manufacturing defect	1	4.0	2.0

(1) Likert scale 1 to 5: 1= very low impact; 2= low impact; 3= moderate impact; 4= high impact; 5= very high impact.
(2) Likert scale 1 to 5: 1= very unlikely to occur in a single year; 2= unlikely to occur in a single year; 3= on average, likely to occur about once in a single year; 4= likely to occur more than once in a single year; 5= very likely to occur multiple times in a single year.

Table V
Risk mitigation strategies

Area of risk – of delays	Risk mitigation strategies	No. of supply chains
Forecast inaccuracy	Safety stock Collaboration with customer Airfreight	2 2 2
Road haulage delay	Safety stock Collaboration with haulier Extend order time	3 3 1
Shipping delay	Safety stock Multi-sourcing Airfreight or sea/air Extend order time	5 3 3 1
3PL failure	Collaboration with 3PL	1
Regulatory delay	Safety stock Collaboration with authorities	1 1
Quality	Total quality management	1

Figure 1.
Supply chain pipeline map of participating retail company

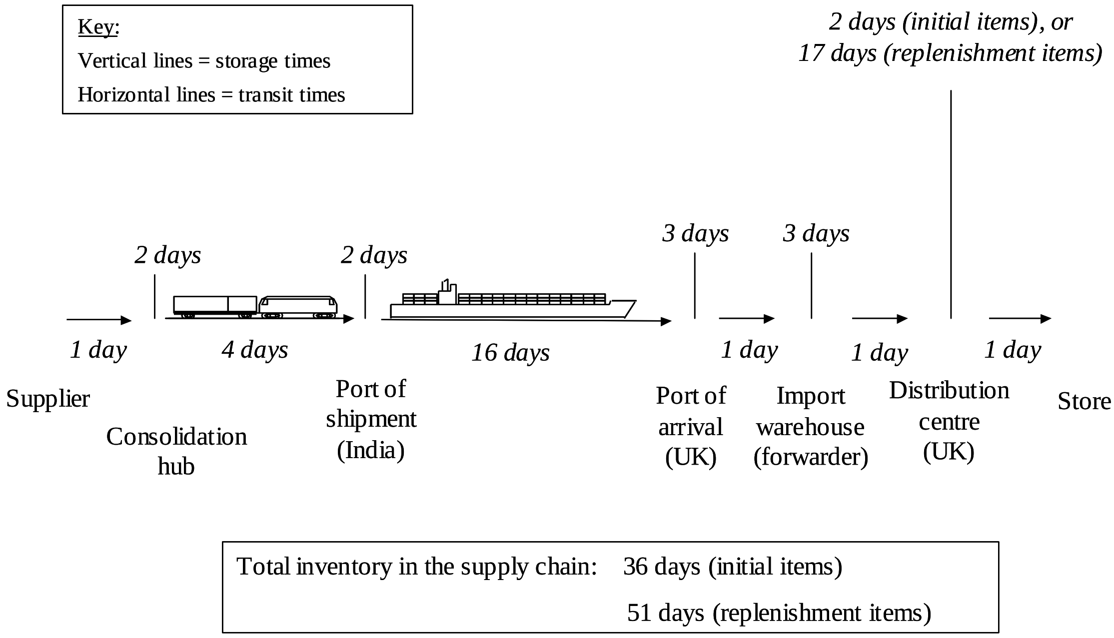

Figure 2
Supplier lead-times and inventory buffers

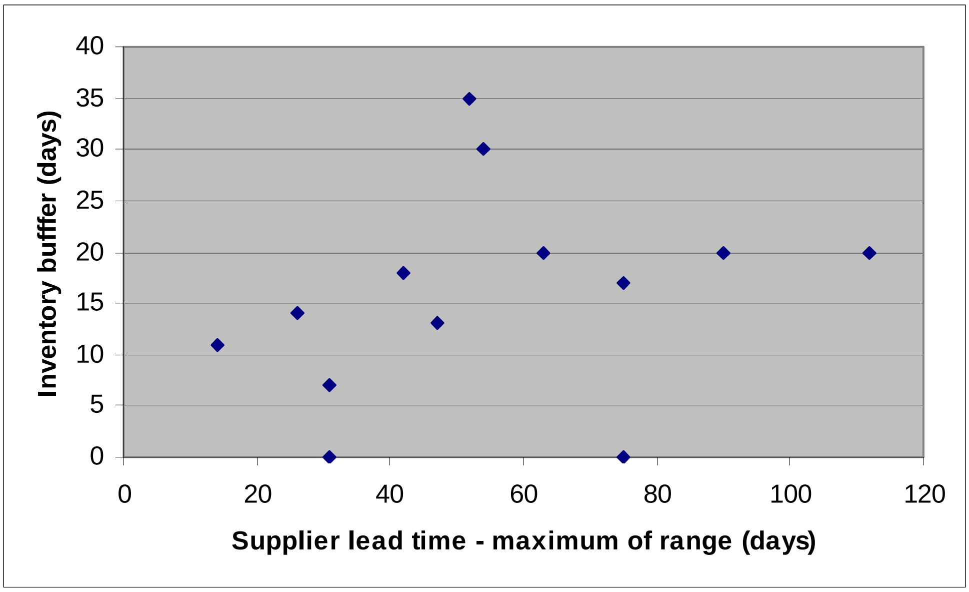

Figure 3
Inventory strategy framework