A FRAMEWORK TO ACHIEVE LOW CARBON SUPPLY CHAINS FOR HI-TECH PRODUCTS

Ali Pazirandeh, Ph.D. student, NGIL, Dep. of Industrial Management and Logistics, Lund University

Sten Wandel, Professor, NGIL, Dep. of Industrial Management and Logistics, Lund University

ABSTRACT

Globalization, high customer service level and short life cycle have lead to an increase in the Green House Gas (GHG) emissions. At a global level, freight movement accounts for nearly one third of the entire transportation energy consumption, which in turn was 23% of the energy related Green House Gas (GHG) emissions in 2004 (Inter Governmental Panel on Climate Change, 2007). In 2007 the IPCC stated that in order to avoid dangerous climate change, developed economies must reduce GHG emissions by 80-95% by 2050 (Carbon Disclosure Project, 2008). Meanwhile CO_2 is considered to be one of the major contributors to GHG emissions by mankind (Hieb, 2003). Therefore companies and governments are increasingly paying attention to this challenge. The aim of this paper is to present a framework for designing and operating a supply chain for hi-tech products in order to achieve freight transport with low CO_2 emissions by 2050. The challenge within this research is that the hi-tech products have a high value per kilo, which means that the transportation cost is only a small percentage of their total cost. Besides, these products have a life cycle of only a few months, high customer service levels, and are most often produced in low wage countries and consumed globally.

Less carbon emissions can be achieved in many ways such as, combining transportation modes in sequence and/or in parallel and thereby use less unsustainable transport. For example, intermodal transportation in sequence could be shipments by sea from China to Dubai and by air from Dubai to Europe, and intermodal transportation in parallel could be sea for long lead time orders, Trans Siberian Rail for medium, and air as emergency last minute shipments. Long lead times and/or larger consolidated shipment sizes are other aspects that could improve the supply chain's transportation carbon footprint which can be achieved by innovative interfaces between suppliers and focal company and between focal company and retailers, such as vendor managed inventories, trans-lateral shipments, advanced consolidation schemes, central warehouse, regional customization centres close to the customer, where part of the manufacturing and all packaging are done, and where local suppliers of accessories and packaging material are being used.

Within this paper, these various supply chain designs for low carbon freight transportation are compared with one another according to their effects on weight and volume of the goods transported, the actual transportation distance, fill rate of load units and vehicles, mix of transport modes, energy efficiency, CO_2 intensity, total product cost, and customer services. For example in a make to stock supply chain with long lead time to replenish the inventory it is possible to consolidate shipments with others in order to fill the load units and use large and slow vehicles and thereby emit small amounts of GHG. However, high cost of holding inventory close to the customers, risk of obsolete products, and long time to introduce new products makes most strategies economically unsuitable for the hi-tech market. On the other hand, the make to order supply chain fits this market's requirements perfectly but requires unsustainable freight transportation to achieve the short lead time that the customers demand. Therefore companies have to adopt more innovative supply chain structures and operational processes to maintain competitiveness and simultaneously meet IPCC's goal for greenhouse gas (GHG) emission reductions by 2050.

The framework presented in this paper intends to help companies in the high tech industries; logistics service providers, vehicle and energy industries as well as government regulators to choose the right path towards low carbon supply chains in 2050. This framework is based on a literature review and a real case study at a hi-tech company with manufacturing in China.

Keywords: Sustainable, Supply Chains, Parallel Transport Modes, Carbon Emissions, Far East to Europe.

INTRODUCTION

Due to the ongoing globalization, transportation distances have increased within the supply chains. Sometimes raw materials are shipped from one continent to another, being processed, manufactured and turned into final products and eventually travel to a third continent to be consumed and later to be disposed of. This increase in transportation distances has increased the Green House Gas (GHG) emissions and hence the supply chain's carbon footprint. On a global level, freight movement accounts for nearly one third of the entire transportation energy consumption (Inter Governmental Panel on Climate Change, 2007). This means that with today's concern on environment and the expected radical increase in costs of CO_2, these supply chains have to change both their structures and operations. In other words, using slower means of transportation, larger consolidated shipments, shorter distances, less volume, and less weight of products and packages will lead to more sustainable supply chains.

In addition, hi-tech products' unpredictable demand, short life cycles, high variety, high obsolescence cost and high inventory cost (Lee, 2002) have resulted in shorter lead times to the customers. Hence, the make to order strategy with fast transportation to the market has recently become a highly effective solution for such markets. This means that the time saved on transportation is used to delay production until more information on the market is obtained. The problem with this design is that the combination of make to order and shorter lead times requires fast modes of transportation and small shipment sizes.

Meanwhile, according to the Council of Supply Chain Management Professionals (CSCMP) supply chain management is defined as:

> "… encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities." (Council of Supply Chain Management Professionals)

This concludes that storage and transportation of the products are major contributors to any supply chain. Therefore, the main purpose of this paper is to propose a framework for generating alternative supply chain designs, which will decrease its carbon footprint with regards to these two factors, without deteriorating the customer service level in the supply chains.

For this purpose the authors have employed McKinnon's (2003) framework for analyzing transportation carbon footprint. According to this framework, freight traffic within supply chains could be controlled by altering three critical ratios:

- Transport intensity: tonne.kilometers/output
- Vehicle utilization: vehicle.kilometers/tone.kilometers
- Transportation mode: CO_2 emissions/vehicle.kilometers

Where transport intensity itself is defined by the number of links within the chain and their average length (McKinnon, 2003). Hence, reducing the number of the links or their average length will reduce transport intensity while increasing vehicle utilization requires increased fill rates within the vehicle and/or larger vehicles. Another way of improving the environmental performance of transportation is a modal shift towards more sustainable and environmental friendly modes of transportation such as rail or sea freight (Kohn and Brodin, 2008).

The framework presented in this paper is made up of concepts/modules that are combined into alternative designs. In the upcoming research the authors have used the abduction method combining an inductive theory based approach with a deductive empirically based approach. In other words, some theories found in literature review will be applied and tested on an illustrative and realistic consumer electronics example case. Here the focus is on the flow of goods in distribution from the factories via the focal company to the retail outlets while considering consequences of the changes on upstream activities as production and component sourcing. First the various concepts/modules of relevance to make supply chains more sustainable from theory are presented; these are then applied to the illustrative case study. Later, a framework for accessing carbon emissions, customer service, cost, flexibility and risk of designs combining these modules is presented, and finally some preliminary conclusions are proposed.

FRAME WORK OF COMPONENTS FOR REDUCING SUPPLY CHAINS' CARBON FOOTPRINT

Below several different components or concepts that may be used in isolation or in combination to reduce the carbon footprint of distributions from factories, through a focal company to the outlets of the retailers within a Hi-Tech industry supply chain are described. But first the hi-tech industry characteristics and challenges should be described. As Fisher (1997) described it, the hi-tech products are classified as innovative products with regards to their product life cycle, demand predictability, product variety and market standards for lead times and services (Fisher, 1997). In other words, these products have short life cycles, high demand unpredictability, high variety, and short lead time to the market. In addition, they also have high value, inventory and obsolescence cost (Lee, 2002) which makes them highly vulnerable to inventory and transportation. This means that the hi-tech industry strives to minimize its inventory of finished products and reduce its delivery time to the market as much as possible, hence reducing the risk of costs within the supply chain. Meanwhile, transportation cost is only considered a small percentage of the hi-tech industry's total cost within the supply chain and thus would not be considered as a major decision making factor within this paper. Therefore, this industry has special requirements when it comes to transportation as well as the design and control of the supply chain.

Within this paper, the authors start with the concepts that need the least change compared to a current generic system with make to order and air transport from factories to the hub and truck transport to the warehouses and further on to shops. Figure 1 depicts the current design and figure 2 an alternative where all concepts have been applied.

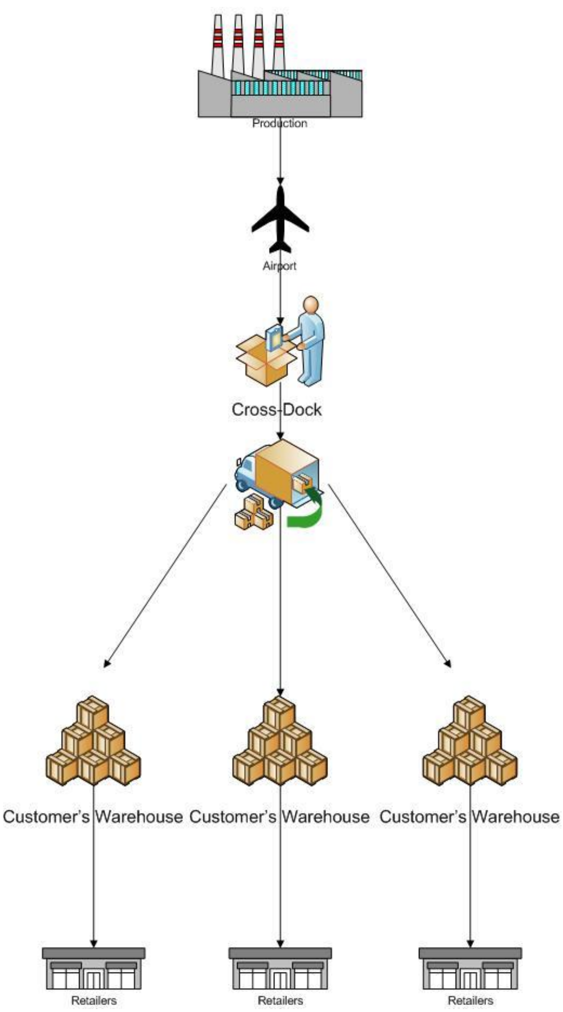

Figure 1 The Current Supply Chain

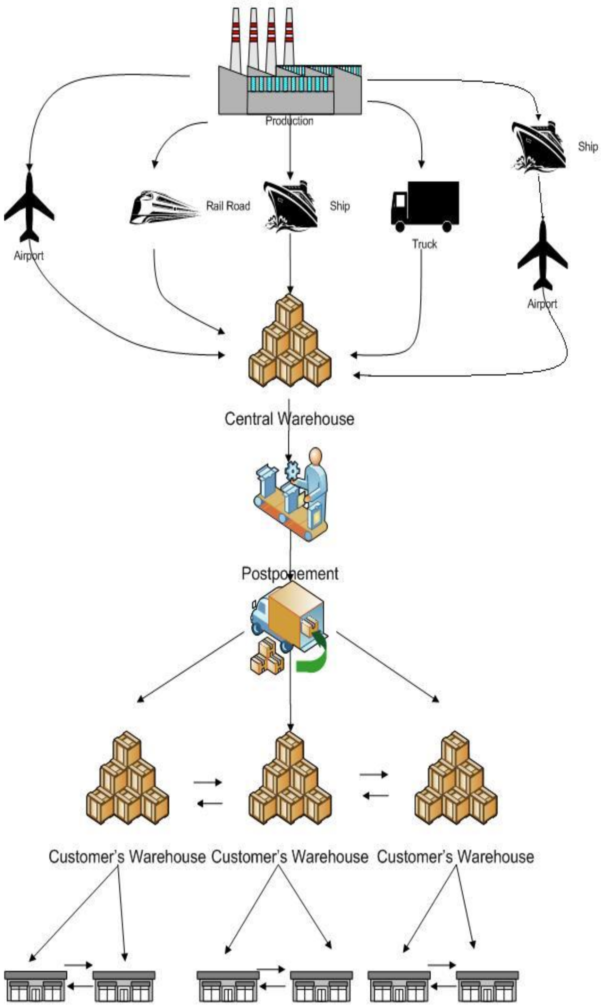

Figure 2 The Combination of all The Components Transportation

In these figures the network between the supplier and the customers' outlets is divided into a series of nodes and links. The nodes represent production units, hubs for trans-shipment and consolidation/deconsolidation and warehouses and the links represent transportation routes and modes. In this case, it should be noted that more nodes means more handling of the goods which in turn means higher risk of damage or theft of the goods. Thus it is advantageous to limit the number of nodes.

Inter-Modal

In inter-modal transportation, the links consists of two or more different transportation modes that are connected in a sequence. For example, the cargo travels from the manufacturer to the harbour with truck and to the second handling hub via boat, and then it is loaded on a plane and flown to the second hub, and finally transported by road to the retailer.
From an environmental perspective, instead of shipping the item all the way via a fast and less sustainable mean of transport, the item is shipped parts of its route by a slower but more sustainable means and the other parts by less sustainable means of transport. This will reduce the carbon footprint of the supply chain but on the other hand it will also increase the lead time between the supplier and the customer. But this also increases the amount of

handling required per shipment which in sequence means an increased risk of theft, damage and delay of the goods.
As an example for the case company, sea freight from Hong Kong in China to Hamburg in Germany takes approximately 30 days (Maersk Line, 2009) while a direct flight only takes about 12 hours. But if the cargo is shipped from Hong Kong to Dubai by sea freight and then flown to Frankfurt via air freight, it only takes about 15 days (Cederholm and Smajic, 2009). The origin and destination handling times have been omitted in this calculation but the handling time in Dubai has been included. According to these calculations, by sending the cargo via an inter-modal transport route, CO_2 emissions would be about 55% of a direct air freight case (Cederholm and Smajic, 2009). Currently companies such as Schenker offer this as part of their green strategy program. DB Schenker skybridge is the project that combines air and ocean freight. In this project containers arrive by ship to either Dubai or Vancouver, and then transhipped to Europe or US by plane. This has lead to a 30-50 percent transport time reduction compared to direct sea freight and also up to 50 percent CO_2 reduction compared to direct air freight (Schumacher, 2009).
Another example from the case company is using the truck from the factory to a train station for the Siberian railway to Frankfurt in Germany and then truck again from that point on, which takes about 20 days, including two days of handling on the way, compared with the 3 days for a direct flight including time for handling at both origin and destination. The total emission for the air freight is 1.97 kg CO_2/unit, and for the railroad 0.31 kg CO_2/unit, which implies a reduction of 84% (Cederholm and Smajic, 2009) . Siemens and IKEA have had a successful test run using the Siberian railway.

Parallel co-modal transportation

In the parallel co-modal transportation system, items are sent from the supplier to the customer via several transportation routes in parallel to one another. This means that an order which is placed well ahead of time is shipped via a slower and more sustainable mean of transport and later orders are shipped via faster and less sustainable means of transport. For example, sea transport for long lead time orders, Trans Siberian Rail for medium, and air for short lead time and as a backup if something goes wrong with the other transport options. Similarly for inventory replenishment, sea for the lowest end of the forecasted amount for next month, rail for the adjusted forecast for the next three weeks, and air for adjusting for forecast error the last week.
In comparison to inter-modal, the parallel co-modal transport has more flexibility for the customer in the way that they could place or change orders later in the process and it also has less handling per shipment since the cargo passes through less nodes which means less risk of theft, damage and delays. But on the other hand it involves more individual handling of the customer orders and for inventory replenishment, multiple reorder points and forecasts, one for each transport alternative, is required. To our knowledge, there is neither models in the scientific literature nor warehouse management software with the ability to handle more than two alternative means of transport for the same article.
From the CO_2 emission perspective, the amount of emission reduction is highly dependent on the percentage of cargo shipped by the more sustainable transportation modes. For example if a three ton shipment is to be shipped over a 10,000 km distance, if only air freight is used it will produce about 17,100 kg CO_2, while if one ton is shipped by sea freight, one ton by train and the remaining one ton by air, the total CO_2 emissions would be 6,200 kg

which is approximately 36% of the case with only air transport (Cederholm and Smajic, 2009, J. Nilson Cederholm; S. Smajic, 2009). Meanwhile it should be noted that multi-modal and co-modal can be combined as is shown in figure 2.

Order Fulfilment and Consolidation

As seen above, one of the main factors influencing the decision on the mode of transport within the hi-tech industry is the order lead time. This is true both for the transport from the factory to the hub and from the hub to the retailers' outlets. If the lead time is much greater than the shortest transportation time to the customer, then the shipper or its LSP (logistics service provider) have a wide variety of options to choose from to reduce the carbon footprint of their supply chain transportation, such as increasing the fill rate or the use of slower means of transportation. Consolidation of flows is a mean to increase the fill rate and refers to a situation where different shipments are grouped together to form a larger shipment in order to better utilize the transport vehicle's capacity and consequently lower the cost of transport per weight unit (Kohn and Brodin, 2008).

But the problem with this concept is that the customer has to place its order well ahead of time to permit the shipper or LSP the flexibility to use more sustainable modes of transportation or conduct a consolidation. In other words, either the customer has to give up some of its flexibility to the supplier which means that no late changes of orders are permitted and the customer/retailer takes a larger risk, or late orders or changes are accepted implying that the supplier has to carry an increased risk. This is particularly a problem when demand is volatile and the life cycle of the product is short. Lower customer service levels and longer lead times to the customer are hence the downsides of the consolidation process. On the other hand, consolidation has shown improvement of on time delivery and reduction in inventory levels while cutting down transport cost in some cases (Kohn and Brodin, 2008). Therefore, balancing and sharing costs and risks are essential when designing and operating consolidation process. There are many different ways of sharing risks, cost and revenues among the parties in the supply chain, e.g. choice of INCO-terms and incentive schemes in the contracts.

As mentioned, with sufficient time, the shipper or its LSP would be able to consolidate the goods before shipping them. Consolidation can be made in several ways: over time with the same article to the same customer to create larger shipment quantities and thereby lower frequency, among several articles to the same customer, among customers, among other companies sending goods on the same route with the same forwarder, and finally among forwarder using the same origin-destination link. If orders with different times of delivery are combined into the same shipment, either by allowing larger time windows for deliveries or keeping some of the shipments for a couple of days at a central hub close to the market, further consolidation with higher fill rates and larger and more energy efficient vehicles can be obtained. This means that the shipper is able to increase the fill rate and by doing so minimize the amount of required transportation work (ton-kilometer) and hence the amount of CO_2 emissions.

Sustainable Packaging

When moving products over long distances, the packaging will play an important role in how large the environmental impact of that transport would be. The environmental impact from transportation related to packaging can be reduced by optimizing the size of the box and by reducing its weight, either of the things in the box, the box itself, the protective wrappings or all of them.
Optimizing the box means sizing it so that as many products as possible can fit on an e.g. a pallet. This will lead to:

- More units on the transportation pallet, leading to an increased fill rate and a reduced weight per unit, meaning that each product will drive less CO_2 when transported. It also brings greater possibility of consolidation of shipments.

- A smaller box requires less resources used in its production. It drives less material, requires less water, less chemicals, less dyes, less electricity etc. A smaller box also requires less insert materials, which enhances this effect even more.

- Less waste. This also means less transportation of waste and less energy needed in treatment plants etc.

Reducing the in-box weight is naturally tightly connected to reduced box size, but also includes potential reductions of in box materials, such as information leaflets and manuals. Reducing weight can also be achieved by reducing the protective wrappings surrounding master packs and pallets, for example by using protective cardboard only on the top and bottom of the pallet instead of around the full stack. However, this has to be balanced with the expected cost of increased damages and thefts.
Emissions of transport related CO_2 is usually calculated as kg of CO_2 per ton.km, meaning that lighter products drive less CO_2. In this case, less weight also means less materials used in production, as mentioned above.
It is in many times possible to reduce the distance or increase the time allowed for transport of the packaging material and/or the accessories by various forms of postponement as described below.

Vendor Managed Inventory

Supply chains regularly have to deal with a phenomenon called the “bullwhip effect”. In this phenomenon, the smallest change in the demand downstream will cause a huge fluctuation in the supply upstream. The only way supply chains could deal with such cases is through information sharing and collaboration(Lee, 2002). Vendor Managed Inventory (VMI) is one of these collaboration methods for controlling supply chains, which usually refers to cases where the supplier becomes responsible for replenishing the customer’s inventory. In this method order placing and handling is eliminated from the processes between the customer and the supplier and the required work is transferred from the customer to the supplier (Holmström et al., 2008). In other words the customer is not required to place an order anymore; in fact the supplier is in charge of handling the inventory directly. This allows the supplier or LSP, if they run the VMI, to choose a slower and more sustainable mean of transport when so appropriate, e.g. using a replenishing strategy involving several parallel transport alternatives, with different transport times and punctualities, as described in the order fulfilment section (Kaipia et al., 2002). Suppliers within the supply chain highly benefit from the more accurate and steady forecast generated by this control strategy (Hoover et al., 2001). This strategy has already been successfully implemented in the oil and gas distribution industry by the LSPs for a few decades.

On the other hand, there are some criteria which have to be fulfilled in order for a VMI relationship to be successful. First of all a significant material flow must exist between the supplier and the customer to be able to realize the benefits of VMI and the administrative savings. In other words, VMI would have higher benefits for a supplier that is replenishing a distribution centre rather than individual retailers, since stock lists are used rather than orders (Holmström et al., 2002). Second, the partners should be important for the focal company to be able to fully utilize the benefits of VMI (Nolan, 1997) . Third, the supplier benefits most when dealing with a small and limited number of retailers. The more the retailers are involved, the higher the variance in the demand and larger forecast error would be (Raghunathan and Yeh, 2001). Therefore only a few retailers with critical mass should be connected to the supplier to fully benefit from VMI. Forth, VMI systems do not handle campaigns and promotions well since the forecasted data were usually not included in the early VMI systems. Barrat (Barrat, 2004) also argues that VMI systems are a more interesting approach in more stable supply chains. Finally, the item itself plays an important role in this relationship. The life cycle of the item, the lead time from the supplier to the customer etc. highly influence the VMI relationship. For example, items with a steady and foreseeable production rate, low individual costs, and low importance to the customer, long life cycles, wide range of applications, and standardized are the best items for VMI systems.

On the other hand, the VMI relationship between the supplier and the customer could take many forms. Such as, the stage in the supply chain where the supplier transfers the ownership of the goods to the customer. For example in some cases the supplier owns the goods in the customer's warehouses until the point of sales and in other cases the supplier is the owner of the goods only until it arrives at the customer's warehouse or even only until it leaves the factory. Another aspect is who places the order, if the supplier is the sole responsible or if it is a collaborative act between the supplier and the customer. And finally the amount of the order placed, itself is an important factor. In some agreements the supplier has no limits; in others it has a maximum limit, in some a minimum and sometimes both a maximum and a minimum (Elvander, 2007).

With all these criteria in mind, it should be analyzed whether it would be a good idea to establish a VMI relationship between two partners in a supply chain or not. For example, in the case of an item with a low life cycle and a VMI where the supplier owns the goods until the customer's inventory, the supplier is accepting the risk of obsolete goods due to longer transportation times. But this issue could be solved by adding a central warehouse or a customization centre close to the retailer' inventories.

In some cases the supplier could take the relationship one step further and assume the responsibility and the authority to transfer items between its retailers' central warehouses and/or retailers' outlets as seen in figure 2. In this case the supplier could easily and rapidly replenish one customer's urgent needs through another customer's inventory. In such cases the supplier needs much more access to its retailers' inventories but the concept requires less stored items in the supply chain. This is called trans-shipments and is common in spare

part distribution. In other words, trans-shipment enables sharing of stock among different retailers' warehouses (Yang et al., 2005).
According to this section, VMI is not a straight forward solution for the Hi-Tech industry due to the special characteristics of its products which do not match the VMI requirements. But on the other hand, when combining two or more customers, the focal company could benefit from a combined inventory structure which will lead to higher variety of available goods plus the option of trans-shipment between the customer warehouses. Also the LSP or the shipper could benefit from choosing the most suitable transport option and lead time since he decides when and how to replenish the inventory. Thus, the option of VMI should be evaluated for each supply chain to see if it is beneficial from both financial and environmental perspective.

Central Warehouse

Make to Stock (MTS) could be mentioned as a manufacturing strategy which highly influences the supply chain structure. In this method, the factory produces items based on speculation and the focal company or producer stores them in a central warehouse. Later in the supply chain, when the customer orders are received, their requirements could directly be fulfilled from these warehouses. From a supply chain perspective there are three levers that have to be considered when a manufacturing strategy is being chosen. These levers are, inventory, capacity and time. With the Make to Stock strategy, the inventory is the biggest issue, but since the production could be stored in the warehouses for future use, time and capacity are not such big problems. For example, if an order is placed for an item, the MTS strategy based supply chain could easily and rapidly fulfil the order from the warehouses, while on the other hand it also carries the risk of inventory cost, out of stock and obsolete goods (Vate, 2007).
Centralization creates new opportunities in changing the supply chain structure which are not feasible in a decentralized system. These changes are from both financial and environmental perspective. The financial benefit is evident since the centralized distribution network offers the low costs advantage (Feitzinger and Lee, 1997). But on the other hand, the environmental benefits might not be as obvious, since the overall amount of transportation required in terms of tone kilometres will increase in a centralized system. This is due to the longer distances that the goods have to be transported in comparison to a decentralized supply chain. However, in a centralized system, freight flows could be consolidated, more sustainable transportation modes could be selected and the required amount of emergency deliveries could be decreased. This in turn implies that although centralization leads to an increase in transportation work, it also provides opportunities in strategic changes in supply chain structure and transportation, which have favourable impact on outcomes in terms of cost, service and CO_2 emissions (Kohn and Brodin, 2008).
For example, the goods could be shipped to the central warehouse with a slower, less expensive and more sustainable mean of transport well ahead of the customer order, stored at the warehouse, and finally shipped out via truck or rail to the retailers, which means much more sustainable transportation processes. As an example, if instead of shipping one ton of goods directly by plane over a 10,000 km to a cross-docking hub in Europe, the goods are transported by sea for 9,000 km, stored in a central warehouse and then shipped out by truck the remaining 1,000 km when the customer orders are received, the CO_2 emissions would go

from 5,700 kg to 162 kg, which is a reduction by 97% (Cederholm and Smajic, 2009, J. Nilson Cederholm; S. Smajic, 2009). But this means that goods have to be transported well ahead of the orders and stored within the warehouses, which means high inventory costs for the focal company. Especially due to the hi-tech industry product categories, these costs would be at their highest level.

As evident above, the central warehouse system and the make to stock production strategy have high potential for reducing the carbon footprint in the supply chain, but this method is not considered as a suitable distribution method for highly volatile markets and for products with short life cycles due to high inventory costs and the risk of obsolete inventory rises to a high level. One way of circumventing this problem is to use make to stock only for the mid life of the products, and another manufacturing strategy for the ramp up and phase out parts of their life cycles.

Postponement

According to Pagh and Cooper (1998) there are three types of postponement. Logistics postponement, which is another name for the central warehouse strategy discussed earlier, manufacturing postponement and a combination of these two options (Pagh and Cooper, 1998). This speculation and postponement framework is presented in
Table 1.

Table 1 Pagh and Cooper (1998) Speculation and Postponement Framework

		Logistics	
		Speculation *Decentralized inventories*	Postponement *Centralized inventories and direct distribution*
Manufacturing	Speculation *Make to Inventory (Stock)*	The Full Speculation Strategy	The Logistics Postponement Strategy
	Postponement *Make to Order*	The Manufacturing Postponement Strategy	The Full Postponement Strategy

In other words, postponement in a broad term is considered to be “an organizational concept whereby some of the activities in the supply chain are not performed until customer orders are received” (van-Hoek, 2001). Make to Order (MTO) is an extreme version of manufacturing postponement which is also another manufacturing strategy as opposed to Make to Stock (MTS) where all the products are manufactured according to forecast. In this strategy, the production is not executed until the order is received from the customer. In other forms of manufacturing postponement, the final customization process could be postponed rather than the whole production. For the MTO strategy inventory would not be a problem as in the MTS strategy, since there is only in process inventory, but this puts much more pressure on time and capacity. In other words, the Make to Order strategy has a much longer lead time to fulfil the order since it has to produce the order and there is the risk of insufficient production capacity and insufficient time to fulfil the order and have a satisfactory customer service (Vate, 2007). Companies therefore often have contract were they share the risk of

having too little capacity with their partners upstream. Meanwhile, if assumed that the time to fulfil customer orders is to be constant, the time saved on transportation within the MTO strategy is used to produce the products; hence this strategy requires much faster and less sustainable transportation modes which could ship the products to the customer faster and maintain the same customer service levels. In addition, this also effects the vehicle utilization, since there is less time and information at hand to plan the shipments.
Again according to Pagh and Cooper (1998) , “product life cycle, monetary density, value profile, product design characteristics, delivery time, frequency of delivery, demand uncertainty, economies of scale, and special knowledge” are the important determinants that will help to choose the correct postponement strategy for the supply chain (Pagh and Cooper, 1998).Some companies, especially within the hi-tech industry, that work with volatile markets and face a high risk of obsolete inventories choose the Make to Order approach. This method does not have the inventory risk, but it has to deal with the capacity and lead time risks. If the capacity is too low or the lead time is too long, the customer service level is low, which would have a negative consequence on the business. On the other hand, the fast modes of transport used to keep the customer lead time at minimum will make these supply chains highly unsustainable (Lee et al., 1993). To be able to both maintain low carbon footprint and competitive advantages for such supply chains, the best strategy is the full postponement strategy which will increase the agility and responsiveness of the supply chain while helping it maintain an efficient production. In this strategy, both logistics postponement and manufacturing postponement are combined with each other to make it possible to benefit from both their advantages. In such cases, the supply chain operations up to the customer decoupling point (central inventory or order processing centre in this case) are considered to be lean and efficiency focused, while from there on they are agile. This situation in some cases is also referred to as leagility due to the fact that it combines the benefits of both lean and agile concepts (van-Hoek, 2000). Meanwhile, it should also be noted that the choice of the optimum postponement strategy is also highly affected by the transportation costs as well (Yang et al., 2005).
In some cases, the full postponement strategy could be a parallel combination of logistic and manufacturing postponement. In other words, in a supply chain, the standard items such as packaging material, manuals and accessories which are easy to forecast could be produced via logistic postponement strategy and be shipped to a central warehouse. When the final customer order is received, the customized items could be produced via manufacturing postponement strategy and shipped to be assembled with the standard products in the central warehouse to form the final product in accordance with the customer’s requirements (Skjoett-Larsen et al., 2007). As like in the sustainable packaging case, consider placing the packaging process closer to the customer. If the product was shipped in bulk to a regional packaging hub where it was placed in the right product box together with the correct information materials which were shipped there via a slower but more sustainable mode of transport well ahead of the customer order, a large level of transport related CO_2 would be taken out of the supply chain. Working with local suppliers of packaging material, boxes, and in box materials would magnify this effect even more.
For example, a company could ship the standard accessories for its final products, which in our illustrative case study is about 50% of the final product’s weight, to a local warehouse close to the customer by a slower mean of transport and then ship its customized core products, which would be the remaining 50%, via a fast mean of transportation to the same

warehouse to be packed with the accessories and shipped to the customer. If assumed that the focal company ships one ton of its products through this full postponement strategy to its customer over a distance of 10,000 km. The standard accessories, 50% of the final product, could be shipped well ahead of time by sea freight and the customized products later by air freight, while initially everything was shipped only via airfreight. The amount of CO_2 emissions in this case would be reduced from 5,700 kg to 2,900 kg which means about 49 % reduction from a pure MTO strategy (Cederholm and Smajic, 2009, J. Nilson Cederholm; S. Smajic, 2009).

Move production closer to the customers

A totally different option for CO_2 reduction is to use production sites and factories close to the customer and source the materials locally. In this case the focal company has its products produced close to the customer and thus has less distance to transport them. On the other hand, since there should be a economical incentive for the companies to perform carbon reduction actions, and also the fact that carbon audits of particular products' supply chains often reveal that transportation represents a very small portion of the total CO_2 emissions, companies should be very careful when deciding to move their production sites close to customers. In addition to moving the production sites close to the customer, companies should also have either vertical integration within their supply chains or local sourcing to make the effort count. In other words, if a company moves its production site close to its customers but still has its suppliers near its previous location and has to transport all its required material all the way to its new location, the attempt in CO_2 emission reduction would be effortless if not worse (McKinnon, 2008).

AN ILLUSTRATIVE CASE

The illustrative case referred to within this paper is a fast moving consumer goods company which today follows a make to order policy. The company has used different variants of this concept for a number of years. Ten years ago the products of the company were built as semi assembled products where they were shipped in bulk to a distribution centre in Europe via airfreight, to support the large European market. Similar setups existed for other markets. The assembly in Europe was an "assemble to order" concept where the products were customized for the market, combined with accessories and packaging material etc. The problem with this supply chain was that the semi-assembled products existed in too many variants that resulted in too low inventory turnover and low flexibility. The setup was also to a large extent dependent on good forecast accuracy due to the long lead-time from production to the customer order point.

Because of this, the company decided to change its approach by integrating the production from component to customer configuration within one and the same factory as far as possible. These factories were placed in low cost countries and were combined with direct shipments by airfreight to the customers. The customer order point was also placed earlier in the value chain and in combination with design changes the number of variants was minimized. The effect of this change was higher flexibility and a higher inventory turnover.

The downside was that the customer order lead-time remained long due to the transportation times.
This paper suggests a few solutions for further improvement of the company's supply chain. One suggestion for example is to combine a good product design for supply chain to minimize variants at the customer order point with a customer configuration point closer to the customers. This is expected to have a number of good effects both on the environment and for the customer:

- Shorter customer lead-times
- Space saving for the long distances transport and configure the customer unique orders close to end customer
- Fewer variants of material at the customer order point and higher flexibility

Further, the case study company has been working with sustainability issues since its foundation, and environmental consciousness has been important guidelines in the way they design and manufacture their products. They are committed to continuous improvement of their impact on sustainability and have implemented a life cycle approach to product development that takes into account materials, design, supply chain, manufacturing, product use, and end of life treatment of all products.
The case study company strongly believes that the concept of sustainable development entails "the integration of economic, social and environmental objectives, to produce development that is socially desirable, economically viable and ecologically sustainable" (Nath et al., 1996).
In 2007, the company created what they call "the sustainability programme" in which the full perspective of the product life cycle is embodied. The program consists of parallel projects, each with a specific focus, aiming at improving the sustainability performance in each step of the product life cycle, taking into account all three cornerstones of a sustainable development.
One of the projects within the Sustainability Program is the Greenhouse project, aiming at controlling, measuring and reducing the company's carbon footprint, with a particular focus on the supply chain. The company has committed to a reduction of its own CO_2 emissions with 20% in absolute value by 2015, using 2008 as a baseline.
Due to this, the company wants to further investigate the possibilities of cutting CO_2 in their supply chain while maintaining their competitive advantages. This paper has evaluated various concepts to improve the supply chain design and control for reducing the transportation carbon footprint within the hi-tech industry supply chain while maintaining its economical advantages. .

FRAMEWORK FOR EVALUATING ALTERNATIVE SUPPLY CHAINS

Depending on the design of the supply chain, type of the product, retailers and suppliers (relations, lead times, flexibility, location, etc.), different combinations of these components affect the supply chain differently. To be able to evaluate these effects individually, each component would be conceptually analyzed using the time-geography framework. This framework aims at analyzing these strategies' with regards to temporal and spatial aspects. This facilitates to view the case in a new context as a remedy for an overly aggregated and generalized description (Lenntorp, 1999). In general, the time constitutes a limited resource (Ellegård et al., 1977), and the products have to travel a certain distance through various nodes and links to reach the customer within this limited resource. Meanwhile, the life cycle of these products as individuals is effected by internal and external effects during this path (Hägerstrand, 1985).

Furthermore, the customer service level is usually calculated as the time between the customer orders till the delivery of the products and since products are limited by speed of assembly, manufacturing and transportation, spatial constraints (could not exist in two or more locations simultaneously) and space available at each location and path for storage and transportation (Hägerstrand, 1985), their movements and its carbon footprint within this time period is highly effected by temporal and spatial factors. **Error! Reference source not found.**3 a presents the various transportation modes between the manufacturer and the customer on a geographical layout while Figure 13 b analyzes these modes within a time-geography context. Here, the time period to fulfil the customer orders is depicted as T1, which is from the customer order entry point (T=0) till the delivery of the products. As presented here, these modes have the option to start their transportation at various times and arrive simultaneously at the same destination, hence improving the supply chain's transportation carbon footprint. It should be kept in mind that these graphs only depict the time and distance location, and do not visualize the value constraints and vulnerability of the products to the transportation mode.

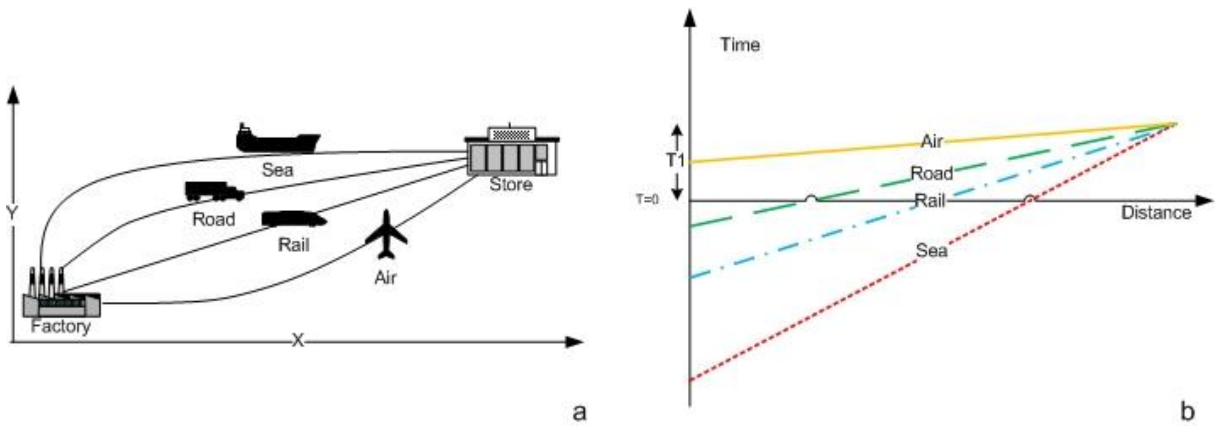

Figure 3 Comparison of various transportation modes a)Geographycal Layout b) Time-Distance

Figure 4 shows a comparison of these transportations mode with regards to their aggregated CO_2 emissions vs. distances they travel to reach the customer. Finally it should also be pointed out that these graphs are for presentation purposes and do not contain any real data. In other words, they are merely a framework for further analyses within various case studies.

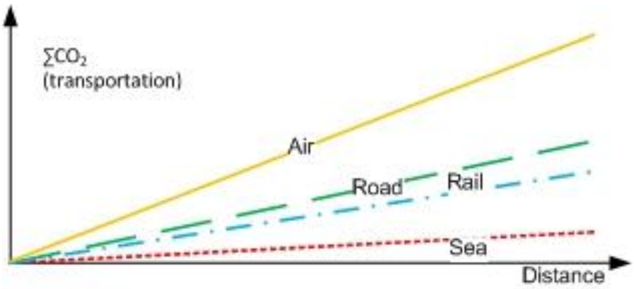

Figure 4 Comparison of various transportation modes on a CO_2 vs. Distance aspect

In addition, figure 5 illustrates a better example of the use of the time geography in assessing supply chains' performance and carbon footprint. Here, **Error! Reference source not found.**5 a presents the various postponement strategies within a time-geography context, as the full speculation strategy (FS), logistic postponement (LP), manufacturing postponement (MP) and full postponement strategy (FP). As depicted, some of the postponement strategies have the option to start their production and transportation before customer order decoupling point and hence increasing their required lead time to the customer which in turn will affect their transportation and its carbon footprint. This effect is illustrated in figure 5 b where the aggregated transportation CO_2 emission of these various postponement strategies are analyzed according to the distance they have to transport their products to arrive at the customer. Again it should be noted that these graphs are for presentation purposes only and do not contain any real data and the framework presented here is highly case sensitive.

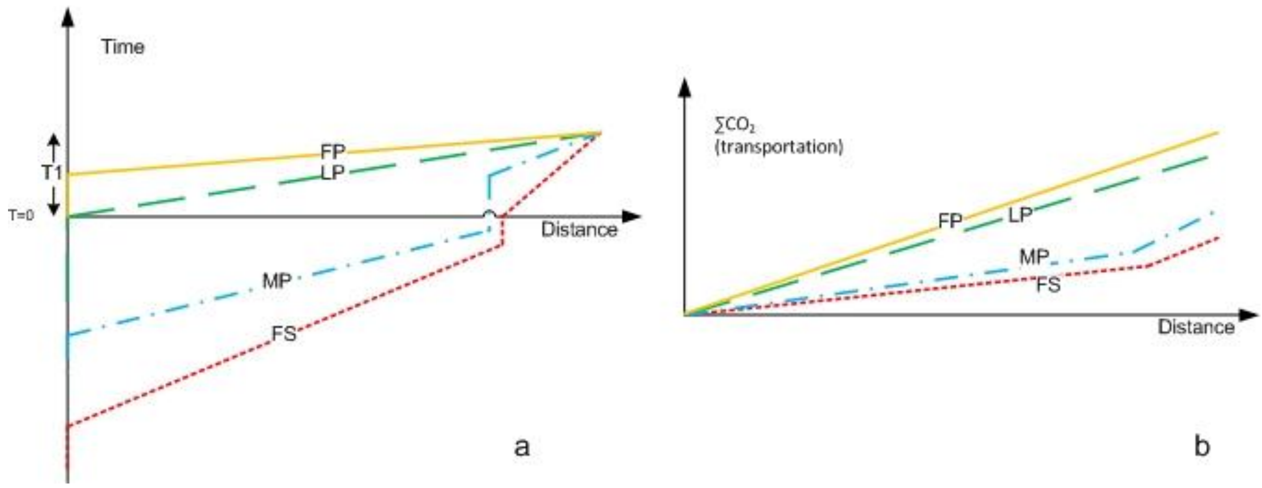

Figure 5 Comparison of various postponement strategies a)Time-Distance b)CO_2-Distance

As an example, Figure 4 a depicts a full speculation (FS) strategy which has much more time at hand to transport its products between the manufacturer and the customer and a full postponement (FP) strategy which has the least time for this purpose. Hence, the FP strategy has to use faster and more unsustainable modes of transportation to be able to maintain the same customer service level as the FS strategy, which highly effects the transportation CO_2 emissions within this supply chains. Figure 4 b compares the aggregated transportation CO_2 emissions vs. distances for these two postponement strategies plus others.

Table is a framework which will help companies to evaluate and find the best combination of the presented components for their supply chain at a certain point in time. However, the impact of the components do not just sum up, since they interact in a very complex way. In

other words, a combination which might be the optimal solution for one supply chain might be a bad solution for another. Thus for each supply chain, according to its specific criteria, alternative implementation schedules for individual as well as combinations of these components should be evaluated to obtain the most cost efficient and sustainable development path for that specific supply chain (Collin et al., 2009).
It should be noted that at this stage, these models are still being developed and other supply chain strategies or performance indicators might be added to the presented list here and a dynamic version will be developed to compare paths in the future, and finally a multi criteria analyze method can be applied to access the rank of the studied alternatives. But as it is presented here, the focal company evaluates and calculates its supply chain performance via simulation or other calculations of alternative design options by using a common standard method such as CEN's framework for assessment of the environmental impact of transport links (European Committee for Standardization, 2008) and fills out the table.

In the same way the performance indicators for each stakeholder in the supply chain can be calculated and also the grand total can be estimated by summing it up. However, some will be winners and others losers compared to the current system and hence what seems best for the whole chain may not be feasible to implement. It should also be noted that the weighting totally depends on the particular companies' individual preferences. For example, some retailers might want to give higher score to the cheapest alternative, while the focal company may choose the one with the lowest over all CO_2 emissions, and the factories the one with the least fluctuation in production volumes. The actual choice is then a result of negotiations among the stakeholder in the supply chain.

Table 2 framework for evaluating alternative supply chains

Performance Indicator	Alt. 1 (current)	Alt. 2	Alt. 3	Alt. 4	Alt. X
Total Cost					
Total CO_2					
Lead Time to Customer					
Flexibility					
Risk Level					
Total Score					

CONCLUSIONS

Less carbon emissions within the hi-tech industries' supply chain can be achieved by combining transportation modes in sequence and/or in parallel and thereby use less air and road transport, either in sequence, e.g. sea to Dubai and air to Europe, or in parallel, e.g. sea for long lead time orders, Trans Siberian Rail for medium, and air as a backup. Long lead times can be achieved, by e.g. innovative interfaces between suppliers and focal company and between focal company and retailers, vendor managed inventories, trans-lateral shipments, advanced consolidation schemes, regional customization, central warehouse, and suppliers closer to the market. Two frameworks for combining these carbon reduction concepts with focus on transportation were presented within this paper and evaluated according to carbon emissions, customer service, cost, flexibility and risk. These frameworks were both /descriptive and quantitative and hence support each other in the understanding and analysis of the supply chain's transportation carbon footprint.

Early results from a case company indicate that by encouraging retailers to place orders earlier, a substantial part of the transport from the factories can be done with less carbon emission, and with only minor changes of the order fulfilment process. This means that some reduction of CO_2 emission from transportation within the supply chain could be achieved in a short period of time. But for more drastic changes and further improvements, a longer time plan is required. Taking a 2050 perspective, the changes in technology or human behaviour will most definitely change the way the business is conducted and thus will change the supply chain structural designs and control methods. Eventually, it could be concluded that this framework is not only applicable to the hi-tech industry, it could be atapted to any other type of products.

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