The impact of an upstream buyer consolidation and downstream intermodal rail-based solution on logistics cost in the China-Europe container trades

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The Impact of an Upstream Buyer Consolidation and Downstream Intermodal Rail-Based Solution on Logistics Cost in the China-Europe Container Trade

Abstract

In the typical structure of the supply chains associated with the Asia-Europe container trade, containers are stuffed in China, and the cargo is subsequently cross-docked at a major European logistics hub or a distribution centre closer to the customer for further distribution to the final retailing points. However, this solution may not be optimal in the perspective of total logistics cost. Upstream buyer consolidation at the origin and a downstream rail-based intermodal system at the destination has been regarded as a potential solution for reducing the costs of supply chains. The purpose of this study is to identify the benefits of this potential solution. This research is based on a case study obtained from a Swedish retailer with a chain of retailing points in Scandinavia and Poland. A comparative analysis is used to reveal the cost advantage of the alternative solution. Our findings suggest that this alternative solution may reduce monetary logistics cost from two aspects: converting LCL shipments to FCL shipments and converting almost full 20-foot FCL shipments to 40-foot FCL shipments. In addition, certain non-monetary benefits of buyer consolidation, including reduced possibility of delay, reduced complexity, reduced carbon emissions and reduced activities in the destination countries, are illustrated in this paper. Based on our calculation, the cost-saving potential of the new alternative solution illustrated in this case study is considerable, which suggests that such solutions might be desirable as an alternative to the typical arrangements in this trade.

Keywords: upstream buyer consolidation, rail-based intermodal system, Asia-Europe container supply chains, monetary benefits, non-monetary benefits.

1. Introduction

The Asia-Europe container trade is one of the most important trades in the world in terms of volume transported. 17.4 million TEU was transported from East Asia to Northern Europe and Mediterranean in 2018, which is second only to the East Asia–North America trade (20.9 million TEU in 2018) (UNCTAD, 2019). In the typical structure of the supply chains associated with this trade, containers are stuffed in China, and the cargos are subsequently cross-docked at major European logistics hubs or distribution centres (DCs) in the destination countries for further transport to the final retailing points. However, this solution may contribute to higher logistics costs.

Fierce competition and world economic recession impel companies to pursue an increasingly improved supply chain solution with lower cost. Tompkins Supply Chain Consortium found that logistics costs as a percentage of sales for retail companies are around 10% based on a survey covering more than 100 companies in 2012 (Avila and Ferrell, 2012). This figure is around 10-12% for U.S. companies in 2015 (Keegan, 2018) and 14.2% for Norwegian companies in 2007 (Hovi and Hansen, 2010). Therefore, an efficient supply chain solution plays an important role in companies' profit generation. Certain early movers in the market have adopted an alternative solution that is characterized by upstream buyer consolidation and downstream intermodal rail-based solutions. Upstream buyer consolidation is an activity provided by logistics service providers (LSP) at a container freight station (CFS) in the origin country in order to consolidate cargo belonging to one buyer from multiple suppliers. This service actually turns multiple less than full container load (LCL) shipments into full container load (FCL) shipments in order to reduce downstream activities, e.g. de-/re-consolidation, thereby facilitating the use of intermodal transport downstream. De-/re-consolidation activities at the LSP's distribution center (DC) in the destination country are inevitable if one shipper transports cargo as LCL shipments because each container after commercial consolidation contains cargo belonging to multiple consignees. If intermodal transport is used in this situation, the reconsolidated cargo has to be delivered to an intermodal terminal. However, this pre-haulage dramatically reduce the competitiveness of the intermodal transport service.

Shifting cargos from road to other modes, such as rail or waterborne transport, is a potentially cost-saving approach to supply chains, and may also be attractive from an environmental point of view. Shifting cargos from road to rail/waterborne transport has become a key element of EU policy (EuropeanCommission, 2011).

Upstream buyer consolidation may help facilitate a modal shift from road to sea or rail in the downstream part of the supply chain. Such a solution would mean that containers will not be stripped when they arrive at the destination hub-port (e.g. in Europe), as they often would be under more traditional supply chain solutions. Avoiding this deconsolidation would make the use of trains and feeder vessels more likely and suitable for the downstream legs of the supply chains.

Upstream buyer consolidation has the potential to reduce the total logistics costs due to the following two aspects. Firstly, buyer consolidation in China may facilitate harvesting economies of scale as it may convert LCL shipments in the traditional solution to FCL shipments and increase container utilization. Effectively, would reduce the international freight rate per tonne or cubic metre (cbm). This effect may be further enhanced if 20-foot containers could be replaced by high-cube 40-foot containers. Secondly, warehouse activities are quite labour intensive. Therefore, relocating these activities to a place where HR costs are lower may reduce total supply chain costs (Lin and Hjelle, 2020).

In order to quantitatively identify the impact of upstream buyer consolidation on logistics cost, the authors compare logistics costs of the new and the traditional solutions. Previous research has provided general cost models and data in freight transport sector, e.g. the research conducted by the Institute of Transport Economics in Norway (Madslien et al., 2015) and Flodén (2007) in Sweden. However, the influence of buyer consolidation on total logistics cost has not yet been provided. Therefore, this research tries to answer the following research questions:

RQ 1: To what extent does upstream buyer consolidation influence supply chain performance in terms of cost?

RQ 2: Are there any less tangible benefits of upstream buyer consolidation? If any, what are they?

In this paper, we develop a model for analysing the cost-saving potential of the alternative supply chain solution characterized by upstream buyer consolidation and a downstream rail-based intermodal system. The model is applied to a case obtained from a Swedish retailer with a chain of retailing points in Scandinavia and Poland. The paper is structured as follows. Section 2 provides a review of the research literature relating to the rail-based intermodal transport and upstream buyer consolidation. Section 3 reviews the supply chain configuration of the focal company in this study. Section 4 describes two hypothetical supply chain solutions, which are used to illustrate the cost differences between the alternative solution and the traditional ones. Cost models are developed in Section 5 and 6. Monetary and non-monetary benefits are illustrated based on an in-depth analysis in Sections 7. Finally, conclusions are presented in Section 8, along with an assessment of research limitations and suggestions for further research.

2. Literature review

Upstream buyer consolidation facilitates the use of intermodal transport downstream. Therefore, in order to identify the benefits resulted from buyer consolidation, the authors review articles in the field of rail-based intermodal transport and buyer consolidation in this section and identify the research gaps.

2.1. The cost-saving potential of rail-based intermodal transport

The market share of rail transport within the EU-28 has been continuously decreasing during the period from 2000 to 2017, as shown in Table 1, whereas the market share of road transport has been steadily increasing over the same period (EuropeanCommission, 2019). These trends are contrary to the targets set by EU policy: “30% of road freight over 300 km should shift to other modes, such as rail or waterborne transport by 2030, and more than 50% by 2050” (EuropeanCommission, 2011). During the observed period, road is the dominant transport mode. The volume of cargo transported by road increased by 23.9%, from 1509 billion tonne-km in 2000 to 1870 billion tonne-km in 2017. Its market share also increased during the same period, from 48.4% to 51.7%. And road transportation is the only mode that keeps growing in terms of market share. (EuropeanCommission, 2019).

Table 1 Changes in volume and market share of freight transported in the EU-28, by mode, in billion tonne-km

Freight Transport in the EU	2000		2017	
	Volume (billion tkm)	Market Share (%)	Volume (billion tkm)	Market Share (%)
Total	3116	100	3614	100
Road	1509	48.4	1870	51.7
Rail	406	13.0	421	11.6
Inland waterways	134	4.3	147	4.1
Sea	1067	34.2	1176	32.5

Source: adapted from (EuropeanCommission, 2019)

de Miranda Pinto et al. (2018) identified four reasons why trucks are the most popular vehicles in the transport sector. They are: (1) reachability to most destinations; (b) flexibility; (c) shorter lead-time over short distance; (d) low maintenance cost and investment requirements. Compared with road-only solution, intermodal transport is complex due to more actors involved. Therefore, better cooperation and standardization among the actors is necessary for enhancing the competitiveness of intermodal transport. Based on the study of Gharehgozli et al. (2019), infrastructure, information and data exchange and equipment within the intermodal transportation chain have the most potential for standardization. In addition, the bundling of rail, road and feeder services may also increase the market share of intermodal transport. Panou et al., (2015) found that building on bundle value may be a solution to increase the competitiveness of a low share transportation service. Moreover, the development of dry ports is an important determinant of hinterland transport chain choice (Talley and Ng, 2018) and supports the growth of rail transport (Roso, 2009). The drivers of this development may include the growth of containerized traffic and the need for storage space (Rodrigue, 2011).

The research on intermodal transport can be traced backed to 1990s (Macharis and Bontekoning, 2004). The positive economic impact of rail transport may be one of the reasons that governments encourage the shift from road to rail. Troch et al., (2016) founds that almost 3 EUR on the national economy may be generated when the demand on rail freight transport increases by 1 EUR based on the situation in Belgium. In addition, the potential relief in social impact may constitute the other main reason. European commission estimated that external effects from road transport in the EU cost 250 billion EUR each year, half of which is resulted from congestions (Konings et al., 2008). If external cost is not considered, road transport may have a cost advantage over short distances, and this may be the main reason why many EU shippers seem to prefer truck to train. In total, 46% of transportation demand in the EU is transport over distances from 150 km to 500 km (Ye et al., 2014). Road transport may also be faster than rail over such distances (Danielis et al., 2005, Samimi et al., 2010). Rail-based intermodal transport seems to be more competitive in terms of cost and time over longer distances (Patterson et al., 2007). Mode choice is also a dependent on a number of other factors, e.g., carrier attributes, the type of cargo carried and past experiences of the decision maker (Francesco Dionori et al., 2015). In order to move the freight from road to rail, several researchers conclude that it is necessary to internalize the societal costs of road transport to make intermodal rail-road transport (IRT) more competitive over shorter distances, thereby contributing to the target of the EU policy mentioned above (MOVE, 2014, Jong et al., 2010).

The attractiveness of rail-based intermodal container transport is determined by its cost to a large extent. The cost-demand elasticity is close to 0.4 in average based on the findings from Marzano and Papola (2004) and by Rich et al. (2011). Jourquin et al., (2014) estimated that this elasticity varies from 0.29 to 0.98 according to the total length of transport and the distance of pre- and post-haulage (PPH).

The cost of PPH may account for 25-40% of the total cost of a rail-based intermodal transport system (Ballis and Golias, 2002, Ballis and Golias, 2004) and in some cases even more than 70% over a total distance of approximately 300 km (Resor et al., 2004). Therefore, rail-based transport solutions are also dependent on efficient PPH in order to be competitive. This means that lowering the cost of road haulage could in some settings enhance the attractiveness of IRT systems, rather than representing a threat. In Europe, heavy goods vehicle with a maximum length of 18.75 m and a total weight of 40 or 44 tonnes are allowed to be used in many countries (ITF, 2015a, ITF, 2015b). The modular truck and trailer system, with maximum length limits of 25.25 metres and 60-tonne gross vehicle weight, has been in use for years in Sweden and Finland and to a limited degree in Norway. (De Ceuster et al., 2008) demonstrated that longer and heavier vehicles (LHVs) could reduce road transport cost by 33% and vehicle kilometres by 13%. In addition, (Bärthel and Woxenius, 2004) and (Bergqvist and Behrends, 2011) derived similar results showing that LHVs could significantly reduce the cost of PPH in an intermodal setting. Meers et al. (2018) also illustrated that a 25% cost reduction in pre- and post-haulage operations would lead to 25% increase in the intermodal terminal market areas based on the situation in Belgium. However, there are also some limitations to apply LHVs, like the weight of goods and the balance between 20 ft and 40 ft containers (Meers et al., 2018).

Ye, Shen et al. (Ye et al., 2014) analysed the cost structure of an IRT system from the Port of Gothenburg to a DC in Skara based on a real case of a Swedish retailer. They found that, by using 25.25-metre vehicles, an IRT system could be more cost competitive even over a travel distance of only 140 km when the annual transport volume is more than 11,000 twenty-foot equivalent units (TEUs). However, to the best of the author's knowledge, the influence of upstream buyer consolidation on logistics cost from Asia to Europe has not yet been examined. Based on the findings of Ye, Shen et al. (Ye et al., 2014) on the Swedish side, along with the case of this Swedish retailer, this current research will propose a set of cost models to examine the total cost savings resulted from upstream buyer consolidation and its effect downstream - the downstream IRT system. The case of the Swedish retailer will be described in detail in Section 3.

2.2. The benefits of buyer consolidation

Two main advantages of buyer consolidation can be found in the literature. Although some of the articles quoted here focus on freight consolidation in general, the advantages listed below can also be regarded as the advantages of buyer consolidation.

- Utilizing economies of scale. Freight consolidation would normally increase the utilization of containers or other cargo carrying units, effectively reducing the transportation cost (Zhou et al., 2011, Bygballe et al., 2012, Lin and Hjelle, 2020, Eidhammer and Andersen, 2014).
- Reducing the probability of dealing with single shipments in the downstream supply chain. After the buyer consolidation, the buyer receives one consolidated shipment every time, rather than a great number of individual shipments, thereby leading to savings in energy, equipment, labour and time (Lin and Hjelle, 2020).

Lin and Hjelle (2020) illustrated the potential of upstream buyer consolidation through 17 interviews in China and Europe. They found that the main customers of buyer consolidation are most likely to be found within mid- and small-sized retailers in Europe and Australia. Buyer consolidation services suit products with the following characteristics: (1) stable demand and easy forecasting, (2) high overall annual demand, (3) low annual average demand between a supplier and a store, (4) low value products, (5) low supplier dispersion, and (6) high labour cost differential between the supplier country and the customer country.

However, to the authors' knowledge, few studies have quantified the potential benefits from such a concept, including the higher utilization of containers, reduced use of 20-foot containers and reduced need for warehouse activities at the destination. The cost framework presented here is developed for analysing and quantifying such benefits.

3. The case description

The focal company of this study is a Swedish retailer who operates in the do-it-yourself (DIY) segment and focuses on offering its customers an attractive range of products at low prices. To achieve a cost advantage, this company purchases directly from manufacturers all over the world without intermediaries. The product range of the company has been expanded over the years to include tools, equipment, work clothing, garden products, paints and household items. This Swedish retailer has more than 90 stores in Sweden, Norway and Poland.

To lower the purchasing cost, the company mainly sources from China. In 2016, the purchasing volume in China was approximately 8000 TEUs from 618 different suppliers, while the total purchasing volume from all other countries was less than 1000 TEUs. In terms of cargo from China, most of the suppliers are located along the coast, and 90% of cargos are delivered as FCL shipments. Only 6-7% of cargos are buyer-consolidated in China. Other shipments are co-loaded with shipments of other Swedish buyers (i.e. traditional commercial consolidation services). The majority of shipments that are consolidated in China are smaller than 28 cbm. The average distance from suppliers to the nearby consolidation centres is approximately 100 km. Truck is the only mode for intra-China transportation in this case. All consolidation centres are quite close to the port of loading. Currently, this focal company uses 26 consolidation centres in China. The focal company has had close cooperation with its logistics service provider (LSP) for more than 10 years. Loading and unloading of trucks, buyer consolidation and temporary storage are the dominating activities conducted in these consolidation centres. After buyer consolidation, around 80% of cargo is transported in 40-foot containers. In this study, we mainly focus on shipments originating from suppliers around Shanghai, which are exported via a deep-sea shipping service to the Port of Gothenburg in Sweden.

After cargos arrive in Sweden, the focal company and its LSP use an intermodal rail-based solution to transport cargos from the Port of Gothenburg to the central warehouse in Skara, Sweden. More specifically, containers are transported 120 km from the Port of Gothenburg to an intermodal terminal in Falköping by rail and thereafter transported by truck further 27 km to the 150,000 m^2 central DC of the focal company in Skara. Based on the current regulation in Sweden, 25.25-metre vehicles are allowed for this leg. This type of truck can transport one 20-foot container and one 40-foot container simultaneously. All cargos from China along with other cargos from other regions are distributed from this DC to stores in Norway, Sweden and Poland. The main activities conducted in this DC are loading and unloading of trucks, stripping and stuffing of containers, storage and packaging based on the demand of each store. This supply chain is briefly illustrated in Figure 1.

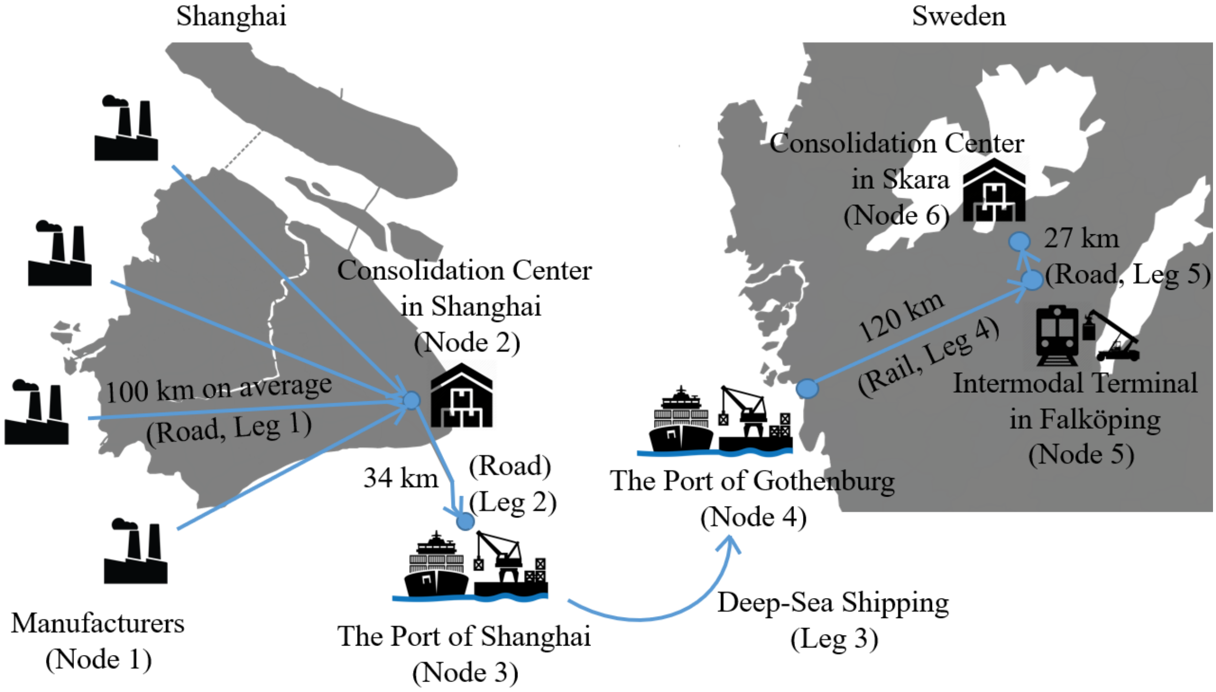

Figure 1 Supply chain solution of the focal company

In 2012, the purchasing volume of this focal company had increased to such a level that IRT service became potentially profitable and stable, and preparations for such a system commenced. In 2014, the first train departed from the container terminal in the Port of Gothenburg to the intermodal terminal in Falköping. This train had only 11 wagons, with a capacity of 44 TEUs in each direction 5 days/week. After October 2014, the train capacity was increased to 17 wagons, carrying 68 TEUs. After that, the capacity was increased again in 2015. From that moment, the service increased to 21 wagons carrying 84 TEUs in each direction 5 days/week.

4. Case analysis

The focal solution in this analysis, could be described as a case of upstream buyer consolidation in combination with a downstream intermodal rail-based solution. The main point of this case-analysis is to illustrate the cost-saving potential of such a solution, relative to the more typical solutions based on LCL or FCL services provided by the market.

In the focal case, the vast majority of shipments consolidated in China are less than 28 cbm. Therefore, we do not consider the situation of consolidation services for shipments larger than one TEU in this analysis. If there was no upstream buyer consolidation service taking place in China, cargos would typically be delivered by the suppliers either as LCL shipments or FCL shipments in 20-foot containers, subject to the prevailing cargo volume of each shipment. LCL shipment enables cargo owners to ship smaller amounts of cargo that is not of a large enough volume to make FCL a feasible option. A relatively large proportion of the cargo is typically delivered as FCL shipments. A 20-foot FCL shipment may not, however, necessarily fill the available 28-33 cbm of the container. When the freight rate is very low, shipping 15 cubic metres of cargo as an FCL shipment may still make sense on some occasions, even if half of the container is empty, to avoid the consolidation cost at the origin and the deconsolidation and sorting cost at the destination.

To illustrate the cost-saving potential of the focal supply chain design, we construct two hypothetical scenarios that will be compared to the alternative solution: One hypothetical scenario with the use of a traditional LCL service (HS-LCL) and one with the use of an equivalent FCL service (HS-FCL).

To simplify the analysis, the analytical unit is a typical consolidated container using the Port of Shanghai as the exporting port. In addition, we make the following simplifying presumptions: We assume that the alternative scenarios do not affect unit costs of trucking, warehousing, salaries or average utilization rates of consolidated containers. Since no pallets are used in the current solution of the focal company, we also assume that no pallets are applied in the hypothetical scenarios. The cargo in this value chain is light weight cargo, meaning that the limiting factor when stuffing containers are assumed to be volume rather than weight for all scenarios. In addition, after commercial or buyer consolidation, one container typically includes different types of cargo. Light and heavy cargo are mixed. The situation of only heavy cargo in one container is very rare. Consolidators need to avoid this situation when they make container load plan. Nevertheless, this situation of heavy-only cargo constitutes a limitation of the alternative solution studied in this article, which reduces the economics of scale brought from upstream buyer consolidation.

4.1. Description of the hypothetical LCL solution (HS-LCL)

This hypothetical solution is based on typical LCL solutions provided by LSPs or shipping companies. Under this solution, suppliers deliver cargos to the bonded warehouse in Shanghai by road for a commercial consolidation service. A bonded warehouse is regarded by customs authorities as an offshore zone, which means that suppliers may apply for a tax refund once their cargo is delivered into a bonded warehouse. This warehouse is operated by a third-party logistics (3PL) service provider who consolidates the shipments coming from the suppliers of the focal company along with shipments from other shippers. The LCL shipments are transported by road (36 km) from the bonded warehouse to the Port of Shanghai, where it is loaded on a deep sea service transporting the container to the Port of Gothenburg. After arriving at the port, the containers are stripped and the individual shipments sorted in a DC controlled by the LSP of the focal company, only 10 km by road from the port. The shipments destined for the focal company from various origins are then consolidated into containers, which are subsequently transported 124 km by road to the DC of the focal company in Skara. This hypothetical LCL transport chain is illustrated in Figure 2.

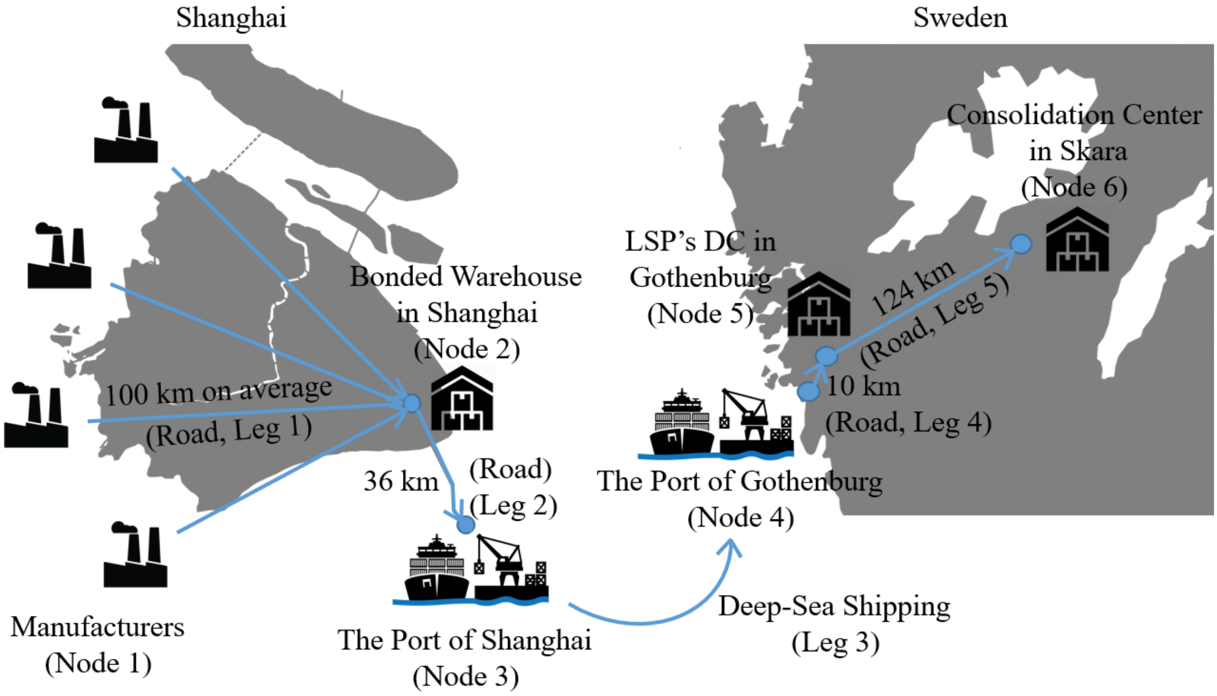

Figure 2 The hypothetical solution with commercial consolidation (HS-LCL)

4.2. Description of the hypothetical FCL solution (HS-FCL)

This hypothetical solution is based on a typical FCL solution. Suppliers deliver cargos as FCL shipments in 20-foot containers directly from the locations of the manufacturers to the Port of Shanghai by truck. These containers are thereafter transported to the Port of Gothenburg via an international deep-sea shipping service. After arrival at the destination country, without the need of deconsolidation and sorting for different consignees in this scenario, containers may be transported by an intermodal rail-based transport system to the consolidation centre of the focal company in Skara for final distribution. The supply chain design of this hypothetical FCL-solution is illustrated in Figure 3.

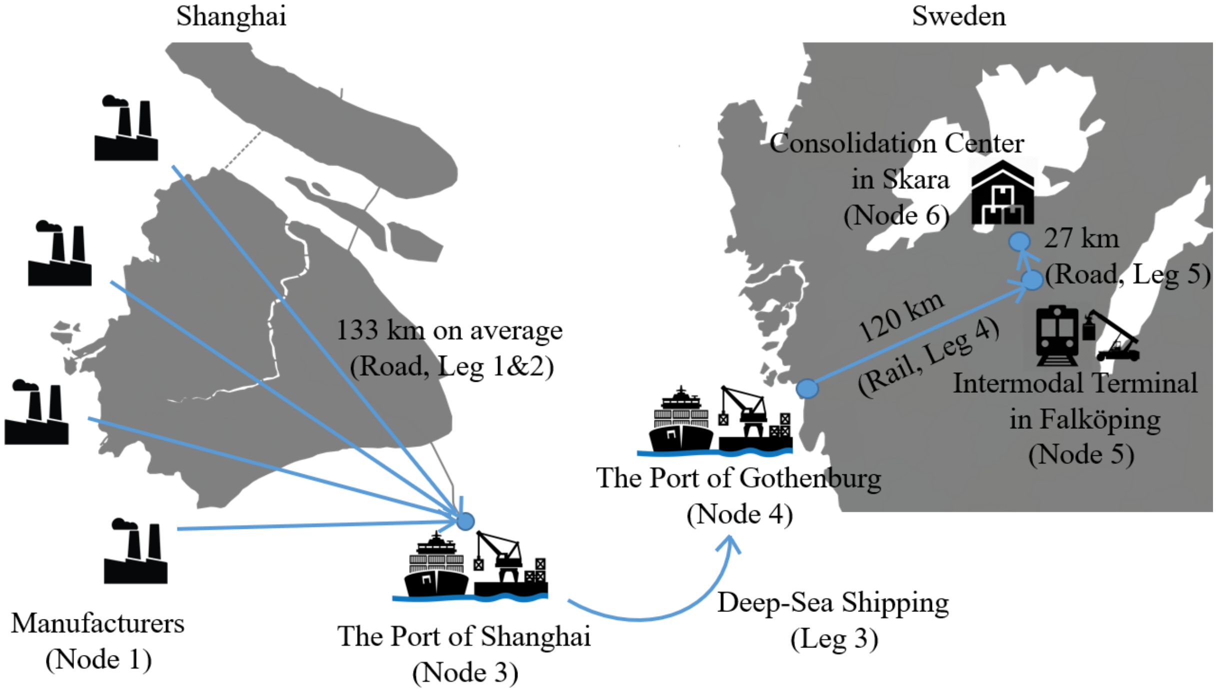

Figure 3 The hypothetical solution with FCL shipments (HS-FCL)

5. Cost calculation model

To calculate the cost differences between the alternative solution and the two hypothetical solutions, a set of cost models are developed, including the cost models for road transport, rail transport and warehousing activities. Formula (1) and (3) are adopted from Madslien et al. (2012). The other formulas are original works by the authors. Considering that the cost data are typically very sensitive and most of our interviewees are not willing to provide very detailed data, we use our results derived from these cost models to check with respondents during interviews in order to obtain more detailed cost information.

This research does not consider "total logistics cost" concept that include the costs generated in all stages in the order-to-collection cycle, including order process cost, logistics cost, outlet costs and inventory cost (Christopher, 2016). The reason is that this research considers the cost differences among solutions. Logistics settings do not influence the cost of order process and outlet. They are same in various solutions. In addition, inventory cost in this research equal to in-transit inventory cost and the cost of lead-time (the value of transport time). Compared with HS - FCL solution, the focal solution increases lead-time by a few days because of the buyer consolidation activity. In addition, the focal solution may also slightly influence the lead-time compared with HS - LCL solution. Although one or a few more days are reduced due to the removed warehousing activity at the LSPs' warehouse in Sweden, intermodal transport from the Port of Gothenburg to the consolidation centre in Skara prolongs the transport time. Therefore, the differences of the cost of transport time among solutions are too small to influence the results. Furthermore, the value of transport time variability is qualitatively discussed in Section 7.4 as a less tangible benefit.

5.1. Cost model for road transportation

The road transportation cost of a typical shipment by truck in a specific leg (C_{road}):

$$C_{road} = \left(\frac{\mathrm{f} \times Con_{fuel}}{100} + m_{truck} + \frac{c_{tire} \times n_{tire}}{l_{tire}} + \rho_{hw} \times \mathrm{t}\right) \times \mathrm{d} + \left(\frac{\mathrm{s}_{driver} \times 12}{n_{wd} \times n_{wh}} + \frac{c_{truck}}{l_{truck} \times n_{ud} \times n_{wh}} + \mathrm{i}_{truck}\right) \times \mathrm{h} + \mathrm{TC}_{back-road} \quad (1)$$

Trucking cost during a specific leg (C_{road}) can be classified into two categories: distance-related cost and time-related cost. Formula (1) is designed based on cost factors presented in a report conducted by the Institute of Transport Economics (TØI) (Madslien et al., 2012). The cost of the empty return trip ($\mathrm{TC}_{back-road}$) can be calculated according to the percentage of empty back-hauls, which is rarely considered in previous research on transport cost. The distance-related cost is the function of fuel cost per km, maintenance cost per km (m_{truck}), tire cost, tolls per km and travelling distance (d). Fuel cost per km can be calculated according to the fuel price per litre (f) and fuel consumption in litre per 100 km (Con_{fuel}). The cost of tires of a truck per km is determined by the cost of a tire (c_{tire}), the total number of tires on a truck (n_{tire}) and the lifespan in km of a tire (l_{tire}). Toll is calculated by the percentage of charged highway (ρ_{hw}) in a leg and the toll per km (t).

The time-related cost includes labour cost per hour, capital cost per hour, insurance cost per hour (i_{truck}) and the travelling hours of a specific leg (h). Labour cost per hour is the function of drivers' monthly cost (s_{driver}, including salary, social cost and holiday cost), the number of working days per year (n_{wd}) and the number of working hours in a day (n_{wh}). Capital cost can be calculated based on the investment cost of a truck (c_{truck}), depreciation period in years (l_{truck}), the number of days used (n_{ud}) in a year and the number of working hours in a day (n_{wh}). In addition, c_{truck} can be calculated according to the truck cost, depreciation period and interest rate.

Considering that cargos are transported by 20-foot and 40-foot container trucks in China based on the volume of each shipment, the transportation cost per TEU ($C_{road-TEU}$) is the weighted average of the transportation cost of these two types of trucks. ρ_{40ft} denotes the number of TEUs of 40-foot containers as the percentage of the total TEU in a specific leg/node.

$$C_{road-TEU} = \rho_{40ft} \times \frac{TC_{40ft}}{2} + (1 - \rho_{40ft}) \times TC_{20ft} \quad (2)$$

5.2. Cost model for rail transportation

Similarly, the cost of rail transport in a specific leg (C_{rail}) can be calculated by the sum of the distance-related cost, time-related cost and empty return trip ($\mathrm{TC}_{back-rail}$). Please see formula (3) that is also designed based on the aforementioned TØI's report (Madslien et al., 2012). The distance-related cost typically includes energy cost and maintenance cost (m_{train}). Energy cost is the product of electricity price per kWh (e) and energy consumption in kWh per km of train driving (Con_e). The time-related cost includes capital cost, labour cost and insurance cost per hour (i_{train}). Capital cost per hour is the quotient of annual capital cost ($C_{train-year}$) and travelling hours per year (h_{year}). The labour cost of a train driver can be calculated similarly to the cost of a truck driver.

$$C_{rail} = (e \times Con_e + m_{train}) \times d + \left(\frac{C_{train-year}}{h_{year}} + \frac{\mathrm{s}_{driver} \times 12}{h_{year}} + \mathrm{i}_{train}\right) \times \mathrm{h} + \mathrm{TC}_{back-rail} \quad (3)$$

Notably, the rail service between two nodes is quite often provided by a monopolist. The service from the Port of Gothenburg to the intermodal terminal in Falköping in this study is jointly provided by the focal company and its LSP. Under this situation, it is common that the service price for a leg is based on the price of an alternative service, rather than on the real cost of offering this service. C_{rail} in this leg based on formula 3 is approximately EUR 41 per 40-foot container when train's capacity utilization is 100%. Considering that the cargo flow in this leg is very unbalanced, the overall utilization of a round trip in this leg is approximately 60-70%. That is, the real logistics cost of transporting one 40-foot container in this leg is typically in the range from EUR 66 to EUR 74. However, unsurprisingly, we found that the market price for this leg is EUR 163 per 40-foot container, which is much higher than the real cost. In addition, the cost of trucking during this leg based on formula 1 is approximately EUR 235. In order to derive a more representative differential cost reflecting the influence of using the alternative solution on all cargo owners (rather than only the influence on the focal company in this case), we have chosen to apply the market price of EUR 163 per 40-foot container and EUR 122 per 20-foot container as inputs for our overall cost model, although EUR 66-74 per 40-foot container (2 TEU) may better tell the real cost of this focal company.

5.3. Cost model for warehouse activities

Activity-based costing is a method often applied for calculating the cost of warehouse activities. Typically, we can divide the total cost per TEU ($C_{warehouse}$) into the cost of unloading from trucks/containers and handling-in to the warehouse, the cost of handling-out and loading of containers and rent.

The cost of unloading and handling-in per cbm (C_{u-in}) is typically same as the cost of loading and handling-out per cbm (C_{l-out}). cbm_{TEU} denotes the volume of one TEU of cargo in cbm. Warehouse rent per TEU of cargo is the function of space usage by a TEU of cargo ($Space_{TEU}$), the percentage of space usage in a warehouse (ρ_{usage}), rent per square metre per day (R_{day}) and storage period (N_{day}).

$$C_{warehouse} = C_{u-in} \times cbm_{TEU} + C_{l-out} \times cbm_{TEU} + \frac{Space_{TEU}}{\rho_{usage}} \times R_{day} \times N_{day} \quad (4)$$

6. The breakeven shipment volume

Shippers often choose to ship non-FCL shipments as FCL shipments to avoid a higher freight rate and the extra cost in the destination country, including the deconsolidation, sorting and reconsolidation costs. To identify when shipping non-FCL shipments as FCL shipments is cost efficient, we need to know the breakeven shipment volume (BSV) where the LCL and FCL type of solutions arrive at the same logistics cost. All shipments larger than this BSV should be transported by FCL services to minimize costs. In our setting, this means that delta logistics cost between the current supply chain solution of the focal company and HS-LCL is the cost (dis)advantage of buyer consolidation and a rail-based intermodal transport system for shipments that are smaller than the BSV. Accordingly, the differential logistics cost between the current supply chain solution of the focal company and HS-FCL is the cost (dis)advantage of the alternative solution for shipments larger than the BSV.

To identify the BSV, we compare the costs of the two hypothetical solutions. The transportation costs in the leg from the Chinese suppliers to the Port of Shanghai must be different because the differences in vehicle choice, consolidation activity and the item to be charged (freight rate is charged based on cargo volume in cbm in HS-LCL and based on the number of containers in HS-FCL). Heavy box trucks are used in the first leg from the supplier to the bonded warehouse in HS-LCL. After commercial consolidation, only 40-foot container trucks are used in the second leg from the bonded warehouse to the Port of Shanghai. By contrast, only 20-foot container trucks are used in HS-FCL to transport cargo directly from suppliers to the Port of Shanghai without any stops in between. The costs in the Port of Shanghai are also different between these two solutions mainly due to the differences in terminal cost and customs clearance cost.

The differences in the number and type of containers and charged items also lead to cost differences in the following international deep-sea leg and the container handling service at the Port of Gothenburg. In addition, for the aforementioned reason, trucks are used in HS-LCL to transport cargos to the DC in Skara via a DC near the Port of Gothenburg, while HS-FCL adopts a rail-based intermodal solution in the destination country.

Therefore, the cost differences between these two hypothetical solutions (CS_h) are shown in the following legs and nodes illustrated in Table 2. If CS_h is smaller than zero, then HS-LCL has a higher cost, which means that the reduced transport cost due to reduced traffic flow is not enough to compensate the increased cost due to higher trucking/sea freight rate, de/reconsolidation, sorting and the costlier mode of transport (trucking) in the destination country. By contrast, if CS_h is greater than zero, transporting cargos as LCL shipments is a good option. In addition, the related variables are described in Table 3.

Table 2 The cost differences between the solutions

Legs & nodes	Cost differences between the solutions	
	HS - FCL	HS - LCL
Leg 1 & 2	• 20-foot container trucks are used in these legs . • Cost is based on service price for each container.	• Leg 1: Box trucks are used. Leg 2: 40-foot container trucks are used • Leg 1: Cost is based on service price for each shipment. • Leg 2: Cost is based on all-in price for each cbm of cargo.
Node 2	• There is no consolidation in this scenario.	• Commercial consolidation service is offered.
From Node 3 to Node 5	• Cost is based on each service offered in each leg and node, like cargo handling, consolidation, transport, etc. • Cargo is delivered as FCL shipments. • Intermodal rail-based solution is used in the destination country.	• Cost is based on all-in price for each cbm of cargo. • Cargo is delivered as LCL shipments. • Cargo is delivered on road in the destination country.
Leg 5	• From Falköping to Skara, 27 km.	• From Gothenburg to Skara, 124 km.

CS_h is the sum of the cost differentials in each leg and node between HS-LCL and HS-FCL. If $\Delta hc_{l1\&2}$ denotes the cost differences in Leg 1 and Leg 2, Δhc_{n2} denotes the cost difference in Node 2, Δhc_{n3} denotes the cost difference in Node 3, Δhc_{l3} denotes the cost difference in Leg 3, Δhc_{n4} denotes the cost difference in Node 4, Δhc_{l4} denotes the cost difference in Leg 4, Δhc_{n5} denotes the cost difference in Node 5, and Δhc_{l5} denotes the cost difference in Leg 5, we have: $CS_h = \Delta hc_{l1\&2} + \Delta hc_{n2} + \Delta hc_{n3} + \Delta hc_{l3} + \Delta hc_{n4} + \Delta hc_{l4} + \Delta hc_{n5} + \Delta hc_{l5}$
(5)

$h_2c_{l1\&2_{20ft}}$ denotes the cost of transporting one 20-foot container generated in the leg from suppliers to the Port of Shanghai under HS-FCL. However, 40-foot containers are used in HS-LCL after the commercial consolidation service. To make the cost information comparable between these two solutions, we introduce the concept of the breakeven conversion rate (BCR) that refers to the number of shipments with BSV that can stuff one 40-foot container.

$h_1c_{l1_{\mathrm{box}}}$ denotes the cost generated in the first leg under HS-LCL for transporting one shipment. Similarly, $h_1c_{l2_{40ft}}$ denotes the cost of transporting one 40-foot container under HS-LCL during the second leg. We assume that a large LSP always has enough LCL cargo to consolidate 40-foot containers in commercial consolidation service. Therefore, $\mathrm{BCR} \times h_1c_{l1_{box}} + h_1c_{l2_{40ft}}$ models the logistics cost of transporting one 40-foot container of cargo during leg 1 and leg 2 under HS-LCL, while $\mathrm{BCR} \times h_2c_{l1\&2_{20ft}}$ models the logistics cost of transporting the same amount of cargo during the same legs under HS-FCL. Considering that all costs have been calculated based on 40-foot containers until now, these costs need to be divided by 2 to derive the logistics cost for one TEU of cargo. Therefore, we have the formula for estimating the cost differences in Leg 1 and Leg 2 ($\Delta hc_{l1\&2}$) for transporting one TEU of cargo:

$$\Delta hc_{l1\&2} = (\mathrm{BCR} \times h_2c_{l1\&2_{20ft}} - \left(\mathrm{BCR} \times h_1c_{l1_{box}} + h_1c_{l2_{40ft}}\right)) \div 2 \qquad (6)$$

Similarly, we have:

$$\Delta hc_{n2} = -h_1 c_{n2} \div 2 \tag{7}$$

$$\Delta hc_{n3} = \left(\mathrm{BCR} \times h_2 c_{n_{3-20ft}} - h_1 c_{n_{3-40ft}}\right) \div 2 + \mathrm{BCR} \times (c_{cc-nor} - hc_{cc-bonded}) \div 2 \tag{8}$$

$$\Delta hc_{l3} = (\mathrm{BCR} \times h_2 c_{sea_{20ft}} - h_1 c_{sea_{40ft}}) \div 2 \tag{9}$$

$$\Delta hc_{n4} = \left(\mathrm{BCR} \times h_2 c_{n_{4-20ft}} - h_1 c_{n_{4-40ft}}\right) \div 2 + \mathrm{BCR} \times (c_{cs-nor} - hc_{cs-HS1}) \div 2 \tag{10}$$

$$\Delta hc_{l4} = (\mathrm{BCR} \times h_2 c_{l4_{train-20ft-gf}} - h_1 c_{l4_{truck-40ft-gg}}) \div 2 \tag{11}$$

After de/reconsolidation at the DC in Gothenburg, we assume that the number and types of containers in HS-LCL are the same as those in the focal solution, with 40-foot containers representing 80% of cargo and 20-foot containers 20%. $h_1 c_{n_{5-TEU}}$ denotes the weighted average warehouse activity cost per TEU of cargo at node 5 under HS-LCL. $h_1 c_{l5_{truck-TEU-gs}}$ denotes the weighted average logistics cost per TEU of cargo during leg 5 under HS-LCL. Formula 18 shows the method for calculating weighted average cost.

$$\Delta hc_{n5} = (\mathrm{BCR} \times h_2 c_{n_{5-20ft}} - h_1 c_{n_{5-TEU}} \times 2) \div 2 \tag{12}$$

$$\Delta hc_{l5} = (\mathrm{BCR} \times h_2 c_{l5_{truck-20ft-fs}} - h_1 c_{l5_{truck-TEU-gs}} \times 2) \div 2 \tag{13}$$

To calculate the total logistics cost of a typical shipment, the values of all aforementioned variables are needed. In Table 3, all values of variables in the hypothetical solutions are illustrated.

Table 3 Description of variables and their values

<table>
<tr><th>Variables</th><th>Description</th><th>Values</th><th>Unit</th><th>References</th></tr>
<tr><td>$h_2 c_{l1\&2_{20ft}}$</td><td>The cost for transporting one 20-foot container in the leg from suppliers to the Port of Shanghai under HS-FCL</td><td>145.8</td><td>EUR /20-foot container</td><td>Face-to-face interview</td></tr>
<tr><td>$h_1 c_{l1_{box}}$</td><td>The cost for transporting one shipment in the first leg under HS-LCL</td><td>126.8</td><td>EUR /shipment</td><td>Face-to-face interview</td></tr>
<tr><td>$h_1 c_{l2_{40ft}}$</td><td>The cost of transporting one 40-foot container under HS-LCL during the second leg</td><td rowspan="3">646.7</td><td rowspan="3">EUR /40-foot container</td><td rowspan="3">Face-to-face interview</td></tr>
<tr><td>$h_1 c_{n2}$</td><td>The total consolidation cost in the bonded warehouse in Shanghai for one 40-foot container of cargo under HS-LCL</td></tr>
<tr><td>$\mathrm{BCR} \times hc_{cc-bonded}$</td><td>The customs clearance cost in China for cargos using bonded warehouse (Unit of $hc_{cc-bonded}$: EUR/shipment)</td></tr>
<tr><td>$h_2 c_{n_{3-20ft}}$</td><td>The terminal cost in the Port of Shanghai for one 20-foot container</td><td>139.5</td><td>EUR/20-foot container</td><td>Face-to-face interview</td></tr>
<tr><td>$h_1 c_{n_{3-40ft}}$</td><td>The terminal cost in the Port of Shanghai for one 40-foot container under HS-LCL</td><td rowspan="2">3915.4</td><td rowspan="2">EUR/40-foot container</td><td rowspan="2">Face-to-face interview</td></tr>
<tr><td>$h_1 c_{sea_{40ft}}$</td><td>The freight rate from the Port of Shanghai to the Port of Gothenburg for one 40-foot container under HS-LCL</td></tr>
</table>

$h_1c_{n_{4-40ft}}$	The terminal cost in the Port of Gothenburg for one 40-foot container under HS-LCL			
c_{cc-nor}	The customs clearance cost in China for cargos using normal warehouse, per shipment	8.9	EUR/shipment	Face-to-face interview
$h_2c_{sea_{20ft}}$	The freight rate from the Port of Shanghai to the Port of Gothenburg for one 20-foot container under HS-FCL	1142.0	EUR/20-foot container	Face-to-face interview
$h_2c_{n_{4-20ft}}$	The terminal cost in the Port of Gothenburg for one 20-foot container under HS-FCL	378.3	EUR20-foot /container	Face-to-face interview
c_{cs-nor}	The customs clearance cost in Sweden under the alternative solution and HS-FCL	25.4	EUR/shipment	Face-to-face interview
BCR × hc_{cs-HS1}	The customs clearance cost in Sweden under HS-LCL (Unit of hc_{cs-HS1}: EUR/shipment)			
$h_1c_{l4_{truck-40ft-gg}}$	The road transportation cost for one 40-foot container in the leg from the Port of Gothenburg to the DC in Gothenburg under HS-LCL	1713.0	EUR/40-foot container	Face-to-face interview
$h_1c_{n_{5-TEU}} \times 2$	The total cost generated in the DC in Gothenburg under HS-LCL (Unit of $h_1c_{n_{5-TEU}}$: EUR/TEU[1])			
$h_2c_{l4_{train-20ft-gf}}$	The rail transportation cost in the leg from the Port of Gothenburg to the inland terminal in Falköping for one 20-foot container under HS-FCL	122.0	EUR/20-foot container	Face-to-face interview
$h_2c_{n_{5-20ft}}$	The container handling cost in the inland terminal in Falköping for one 20-foot container under HS-FCL	19.3	EUR/20-foot container	Face-to-face interview
$h_2c_{l5_{truck-20ft-fs}}$	The road transportation cost in the leg from the inland terminal in Falköping to the DC in Skara for one 20-foot container under HS-FCL	35.1	EUR/20-foot container	Face-to-face interview
$h_1c_{l5_{truck-TEU-gs}}$	The road transportation cost in the leg from the DC in Gothenburg to the DC in Skara for one TEU of cargo under HS-LCL	102.6	EUR/TEU[2]	Face-to-face interview

As discussed above, the BSV can be identified when $CS_h = 0$. This is because the shipments with the BSV can be transported in both aforementioned hypothetical solutions if there is no buyer consolidation service at the origin. Based on the formula (5) – (13), when $CS_h = 0$, we have:

[1] The DC in Gothenburg reconsolidates cargo into 20-foot containers and 40-foot containers from 40-foot LCL containers. Because two types of containers are used, EUR/TEU here means the cost of reconsolidating one 20-foot container or half a 40-foot container.

[2] 20-foot containers and 40-foot containers are transported in this leg. Therefore, EUR/TEU here means the weighted average cost of transporting one TEU of cargo.

$$\mathrm{BCR} = (h_1 c_{l2_{40ft}} + h_1 c_{n2} + \mathrm{BCR} \times hc_{cc-bonded} + h_1 c_{n_{3-40ft}} + h_1 c_{sea_{40ft}} + h_1 c_{n_{4-40ft}} + h_1 c_{l4_{truck-4oft-gg}} + h_1 c_{n_{5-TEU}} \times 2 + \mathrm{BCR} \times hc_{cs-HS1} + h_1 c_{l5_{truck-TEU-gs}} \times 2) \div (h_2 c_{l1\&2_{20ft}} - h_1 c_{l1_{box}} + h_2 c_{n_{3-20ft}} + c_{cc-nor} + h_2 c_{sea_{20ft}} + h_2 c_{n_{4-20ft}} + c_{cs-nor} + h_2 c_{l4_{train-20ft-gf}} + h_2 c_{n_{5-20ft}} + h_2 c_{l5_{truck-20ft-fs}}) \quad (14)$$

According to Formula (14), the BCR is equal to 3.43 based on the current freight rate. If we assume that one consolidated 40-foot container contains 60 cbm of cargo, the BSV is 17.5 cubic metres (60 cbm/3.43). Notably, this BSV is not a constant. It changes from case to case based on all variables in formula (14) and is especially sensitive to the sea freight rate. Moreover, the freight rate and local charges at the origin and destination under HS-LCL are negotiable when total cargo volume is high, which will also influence the BSV to some extent. In addition, the BSV in this research is calculated only from the aspect of logistics cost. However, in practice, lead time and security reasons also must be taken into consideration. For instance, we found that one retailer transports all shipments larger than 14 cbm as FCL shipment to reduce lead time, even if the sea freight rate is relatively high (USD 1500 for 20-foot containers and USD 2700 for 40-foot containers from China to Norway in early February 2018).

7. Model application and analysis

This section applies the cost models to the case study and identifies calculated benefits of the alternative solution against traditional LCL and FCL solutions in terms of cost. In order to analyse the sensitivity of the calculations related to alternative sea freight rates and port charges, we present two sensitivity analyses in Section 7.3. Finally, some important, but less tangible benefits of the alternative solution are identified in Section 7.4.

7.1. Cost-saving potential of the alternative upstream buyer consolidation solution compared with a traditional LCL solution (HS-LCL)

Table 4 shows a comparison between HS-LCL and the alternative solution. We assume that the manufacturing costs are not affected by the alternative supply chain designs. After production, cargos are delivered to a consolidation centre or a bonded warehouse. In principle, a difference in distance would lead to a cost difference in this leg, But, in practice, this difference in transport distance is too small to make freight rates different. The difference in logistics cost occurs from the following node onwards. Buyer consolidation service in the focal solution converts LCL shipments into FCL shipments, which means the cargo owner pays the consolidation service at the origin and transports cargo under the FCL freight rate in the sea leg. By contrast, under HS-LCL, LSPs typically charge a freight rate based on cargo volume – approximately 80 USD per cbm during the sea leg including a terminal handling charge (THC) in the Port of Shanghai and the Port of Gothenburg based on the current freight rate in early February 2018. In addition, the consolidation service at the origin, the deconsolidation service at the destination and the related necessary trucking services are also charged by cargo volume under HS-LCL. We assume that 100% of containers in HS-LCL after commercial consolidation activity are 40-foot containers, since this would be the most cost efficient solution for light-weight cargos.

Further differences lie in the legs from the Port of Gothenburg to the DC in Skara. More specifically, in the alternative solution, the focal company uses an intermodal rail-based solution between the Port of Gothenburg and its central warehouse in Skara, which is a more cost-efficient mode of transport. In the hypothetical solution, the LSP would transport containers to a DC near the seaport, strip containers and reconsolidate cargos based on different consignees. When the cargo is ready, the focal company sends trucks to transport cargos to its own DC in Skara. The costs generated in the DC in Skara would be the same across these two solutions because this DC receives the same amount of cargo and conducts the same activities.

Table 4 The cost differences between the solutions

Legs & nodes	Cost differences between the solutions	
	HS - LCL	The alternative solution
From Node 2 to Node 5	• Cost is based on all-in price for each cbm of cargo. • Cargo is delivered as LCL shipments. • Cargo is delivered on road.	• Cost is based on each service offered in each leg and node, like cargo handling, consolidation, transport, etc. • Cargo is delivered as FCL shipments after Node 2. • Intermodal rail-based solution is used in the destination country.
Leg 5	• From Gothenburg to Skara, 124 km.	• From Falköping to Skara, 27 km.

The cost-saving potential of the alternative solution compared with the HS-LCL in terms of shipments smaller than 17.5 cbm is shown in the following formulas, and the related variables are described in Table 5.

If Δc_{n2} denotes the cost difference in Node 2, Δc_{l2} denotes the cost differences in Leg 2, Δc_{n3} denotes the cost difference in Node 3, Δc_{l3} denotes the cost difference in Leg 3, Δc_{n4} denotes the cost difference in Node 4, Δc_{l4} denotes the cost difference in Leg 4, Δc_{n5} denotes the cost difference in Node 5, and Δc_{l5} denotes the cost difference in Leg 5, the sum of the cost differentials in each leg and node between the alternative solution and HS-LCL (CS_{s1}) is: $CS_{s1} = \Delta c_{n2} + \Delta c_{l2} + \Delta c_{n3} + \Delta c_{l3} + \Delta c_{n4} + \Delta c_{l4} + \Delta c_{n5} + \Delta c_{l5}$ (15)

The cost differentials in Node 2 (Δc_{n2}) is the cost difference in this node between the HS-LCL ($h_1 c_{n_2}$) and the alternative solution (c_{n_2}). It is worth noting that after commercial consolidation, all cargo is delivered in 40-foot containers under HS-LCL. That is to say, the unit of $h_1 c_{n_2}$ is EUR/40-foot container. While, because both 20-foot containers and 40-foot containers are used in the alternative solution, the unit of c_{n_2} is EUR/TEU. Therefore, we divide $h_1 c_{n_2}$ by 2, in order to derive the consolidation cost per TEU of cargo.

$$\Delta c_{n2} = h_1 c_{n_2} \div 2 - c_{n_2} \tag{16}$$

The cost differentials in Leg 2 (Δc_{l2}) caused by transporting one TEU of cargo is the cost difference in this leg between the HS-LCL ($\frac{h_1 c_{l2_{40ft}}}{2}$) and the alternative solution ($c_{l2_{TEU}}$). Because only 40-foot containers are used in the HS-LCL, in order to derive the logistics cost per TEU of cargo, we divide $h_1 c_{l2_{40ft}}$ by 2. In addition, both 20-foot and 40-food containers are used under the alternative solution. In order to derive the cost per TEU of cargo, we calculate the weighted average of the costs generated by transporting one 20-foot container and one 40-foot container. ρ_{40-ft} is the percentage of cargo transported by 40-foot containers. All the following costs in TEU can be calculated in the similar way as shown in formula (18).

$$\Delta c_{l2} = \frac{h_1 c_{l2_{40ft}}}{2} - c_{l2_{TEU}} \tag{17}$$

$$c_{l2_{TEU}} = \frac{c_{l2_{40ft}}}{2} \times \rho_{40ft} + c_{l2_{20ft}} \times (1 - \rho_{40ft}) \tag{18}$$

Similarly, we have:

$$\Delta c_{n3} = \Delta c_{n3-customs} + \Delta c_{n3-port} \tag{19}$$

$$\Delta c_{n3-customs} = \frac{hc_{cc-bonded} * N_{shipment}}{2} - \frac{c_{cc-nor} * N_{shipment}}{2} \tag{20}$$

$$\Delta c_{n3-port} = \frac{h_1 c_{n_{3-40ft}}}{2} - c_{n_{3-TEU}} \tag{21}$$

$$\Delta c_{l3} = \frac{h_1 c_{sea_{40ft}}}{2} - c_{sea_{TEU}} \tag{22}$$

$$\Delta c_{n4} = \frac{h_1 c_{n_{4-40ft}}}{2} - c_{n_{4-TEU}} + \frac{hc_{cs-HS1} * N_{shipment}}{2} - \frac{c_{cs-nor} * N_{shipment}}{2} \tag{23}$$

$$\Delta c_{l4} = \frac{h_1 c_{l4_{truck-40ft-gg}}}{2} - c_{l4_{train-TEU-gf}} \tag{24}$$

$$\Delta c_{n5} = h_1 c_{n_{5-TEU}} - c_{n_{5-TEU}} \tag{25}$$

$$\Delta c_{l5} = h_1 c_{l5_{truck-TEU-gs}} - c_{l5_{truck-TEU-fs}} \tag{26}$$

Table 5 Variable Values in the alternative solution

Variables	Description	Values	Unit	References
c_{n_2}	The cost of warehouse activity in the CFS in Shanghai for consolidating one TEU of cargo under the alternative solution	245.9	EUR/TEU	Formula (4)
- C_{u-in}	Definition is given in Section 5.3	3.80	EUR/cbm	Face-to-face interview
- C_{l-out}	Definition is given in Section 5.3	3.17	EUR/cbm	Face-to-face interview
- $Space_{TEU}$	Definition is given in Section 5.3	13.87	m^2	Face-to-face interview
- ρ_{usage}	Definition is given in Section 5.3	70%	n/a	Face-to-face interview
- R_{day}	Definition is given in Section 5.3	0.19	EUR/m^2-day	Face-to-face interview
- N_{day}	Definition is given in Section 5.3	7	day	Face-to-face interview
$c_{l2_{TEU}}$	The road transportation cost per TEU from the consolidation center to the Port of Shanghai under the alternative solution	30.4	EUR/TEU	Formula (18)
- $c_{l2_{40ft}}$	The road transportation cost per 40-foot container from the consolidation center to the Port of Shanghai under the alternative solution	55.30	EUR/40-foot container	Face-to-face interview
- $c_{l2_{20ft}}$	The road transportation cost per 20-foot container from the consolidation center to the Port of Shanghai under the alternative solution	41.40	EUR/20-foot container	Face-to-face interview
- ρ_{40-ft}	The percentage of cargo delivered in 40-foot containers under the alternative solution	80%	n/a	Face-to-face interview
$N_{shipment}$	The average number of shipments that can staff one 40-foot container after buyer consolidation under the alternative solution	4 on average	shipment	Face-to-face interview
$c_{n_{3-TEU}}$	The terminal cost in the Port of Shanghai per TEU under the alternative solution	104.0	EUR/TEU	Based on the method shown in Formula (18)
- c_{n_3} for 20-foot containers	The terminal cost in the Port of Shanghai per 20-foot container under the alternative solution	139.5	EUR/20-foot container	Face-to-face interview
- c_{n_3} for 40-foot containers	The terminal cost in the Port of Shanghai per 40-foot container under the alternative solution	190.2	EUR/40-foot container	Face-to-face interview
$c_{sea_{TEU}}$	The freight rate from the Port of Shanghai to the Port of Gothenburg per TEU under the alternative solution	1044.1	EUR/TEU	Based on the method shown in Formula (18)

- $c_{n_{sea}}$ for 20-foot containers	The freight rate from the Port of Shanghai to the Port of Gothenburg per 20-foot container under the alternative solution	1142.0	EUR/20-foot container	Face-to-face interview
- $c_{n_{sea}}$ for 40-foot containers	The freight rate from the Port of Shanghai to the Port of Gothenburg per 40-foot container under the alternative solution	2039.3	EUR/40-foot container	Face-to-face interview
$c_{n_{4-TEU}}$	The terminal cost in the Port of Gothenburg per TEU under the alternative solution	272.4	EUR/TEU	Based on the method shown in Formula (18)
- c_{n_4} for 20-foot containers	The terminal cost in the Port of Gothenburg per 20-foot container under the alternative solution	378.3	EUR/20-foot container	Face-to-face interview
- c_{n_4} for 40-foot containers	The terminal cost in the Port of Gothenburg per 40-foot container under the alternative solution	491.8	EUR/40-foot container	Face-to-face interview
$c_{l4_{train-TEU-gf}}$	The rail transportation cost for transporting one TEU from the Port of Gothenburg to the intermodal terminal in Falköping under the alternative solution	89.5	EUR/TEU	Based on the method shown in Formula (18)
- $c_{l4_{train-gf}}$ for 20-foot containers	The rail transportation cost for transporting one 20-foot container from the Port of Gothenburg to the intermodal terminal in Falköping under the alternative solution	122.0	EUR/20-foot container	Face-to-face interview
- $c_{l4_{train-gf}}$ for 40-foot containers	The rail transportation cost for transporting one 40-foot container from the Port of Gothenburg to the intermodal terminal in Falköping under the alternative solution	162.7	EUR/40-foot container	Face-to-face interview
$c_{n_{5-TEU}}$	The container handling cost per TEU in the intermodal terminal in Falköping under the alternative solution	11.6	EUR/TEU	Based on the method shown in Formula (18)
- c_{n_5} for 20-foot containers	The container handling cost per 20-foot container in the intermodal terminal in Falköping under the alternative solution	19.3	EUR/20-foot container	Face-to-face interview
- c_{n_5} for 40-foot containers	The container handling cost per 40-foot container in the intermodal terminal in Falköping under the alternative solution	19.3	EUR/40-foot container	Face-to-face interview
$c_{l5_{truck-TEU-fs}}$	The road transportation cost for transporting one TEU from the intermodal terminal in Falköping to the DC in Skara under the alternative solution	35.1	EUR/TEU	Face-to-face interview

As can be seen in Table 6, the calculation result shows that the cost saving on the China side due to the buyer consolidation is estimated at EUR 44 per TEU in total. This saving is mainly caused by the more expensive cargo handling cost and trucking freight rate for LCL shipments. These modest benefits of the current solution on the China side, are accompanied by bigger savings in the downstream part of the value chain, i.e. in Sweden in our case. Cost savings in Sweden are estimated at EUR 803 per TEU. These savings are mainly due to the rail-based intermodal solution and the elimination of extra warehousing activities in Gothenburg. More specifically, consolidated shipments after buyer consolidation in China make the rail-based intermodal transport in the destination country possible. In addition, due to the upstream buyer consolidation service in China, the focal company does not need to have its cargos sorted and consolidated again in Gothenburg, which makes it possible to save 100% of the costs in the DC in Gothenburg.

Table 6 Cost savings of the current solution vs. a hypothetical LCL-solution for shipments smaller than the break-even shipment volume (BSV), EUR/TEU

No.	Legs & Nodes	HS-LCL	The current Solution	Cost Savings
1	Leg 1	507	507	0
2	Node 2 + Leg 2 + Customs Clearance	323	312	11
3	Node 3 (terminal cost only)	137	104	33
4	Leg 3	1,467	1,044	423
5	Node 4 (terminal cost only)	354	272	82
6	Customs Clearance + Leg 4 + Node 5	856	203	654
7	Leg 5	103	35	67
8	Total	3,747	2,477	1,270

Overall, the total logistics cost saving due to the upstream buyer consolidation and the downstream intermodal rail transport solution is estimated at EUR 1270 per TEU on average for shipments smaller than 17.5 cbm. The logistics cost of the hypothetical LCL-solution is approximately EUR 3747 per TEU. The current solution therefore seems to reduce total logistics cost by some 33%.

7.2. Cost-saving potential of the alternative upstream buyer consolidation solution compared with a traditional FCL-solution (HS-FCL)

Table 7 shows a comparison between the hypothetical FCL-solution and the current solution. The costs generated in the leg from the manufacturers to the Port of Shanghai in these two solutions are different because suppliers deliver their cargos directly to the port and ship them as FCL shipments in the hypothetical solution, while cargos are consolidated in the current solution of the focal company. The cost difference in this leg from suppliers to the Port of Shanghai arises mainly because the buyer consolidation activity in the current solution generates extra costs. Minor changes also occur in road transport costs due to the use of different vehicles, and due to necessary repositioning of containers. On the other hand, fewer transported containers in the current solution after the consolidation activity leads to reduced logistics costs for all the subsequent legs and nodes, including the Port of Shanghai, the sea leg, the Port of Gothenburg, the rail leg, the intermodal terminal at Falköping and Leg 5 to the DC in Skara. In addition, considering that the cost difference between receiving cargo in one 40-foot container and receiving the same amount of cargo in a few 20-foot containers is very small, we presume that there is no difference in cargo receipt cost in Skara.

Table 7 The cost differences between the solutions

Legs & nodes	Cost differences between the solutions	
	HS - FCL	The alternative solution
From Leg 1 to Leg 2	• Cargo is delivered directly to the seaport. • Only 20-foot containers are used.	• Cargo is consolidated in the consolidation center. • Leg 1: Box trucks are used. Leg 2: Around 80% of cargo is delivered in 40-foot container trucks.
From Node 3 to Leg 5	• Only 20-foot containers are used, more containers delivered.	• Around 80% of cargo is delivered in 40-foot containers, less container delivered.

The cost-saving potential of the alternative solution compared with the HS-FCL in terms of shipments larger than 17.5 cbm is shown in the following formulas, and the related variables are described in Table 8.

If CS_{s2} denotes the cost differentials between the alternative solution and HS-FCL, we have:

$$CS_{s2} = \Delta c'_{l1\&2} + \Delta c'_{n2} + \Delta c'_{n3} + \Delta c'_{l3} + \Delta c'_{n4} + \Delta c'_{l4} + \Delta c'_{n5} + \Delta c_{l5}' \qquad (27)$$

in which, $\Delta c'_{l1\&2}$ denotes the cost differences in Leg 1 and Leg 2, $\Delta c'_{n2}$ denotes the cost difference in Node 2, $\Delta c'_{n3}$ denotes the cost difference in Node 3, $\Delta c'_{l3}$ denotes the cost difference in Leg 3, $\Delta c'_{n4}$ denotes the cost difference in Node 4, $\Delta c'_{l4}$ denotes the cost difference in Leg 4, $\Delta c'_{n5}$ denotes the cost difference in Node 5, and $\Delta c_{l5}'$ denotes the cost difference in Leg 5.

The logistics cost of transporting one FEU (Forty Feet Equivalent Unit) of cargo in the HS-FCL from the place of a manufacture to a POL (Port of Loading) in origin can be estimated by the product of CR (the number of shipments that constitute a full 40-foot container) and $h_2 c_{l1\&2_{20ft}}$. In addition, the logistics cost of transporting one FEU of cargo in the alternative solution can be calculated based on the cost in the first leg and the second leg. The logistics cost in the first leg can be estimated based on the product of CR and $c_{l1_{box}}$ (the logistics cost of transporting one shipment in leg one). While, the logistics cost in the second leg is two times of $c_{l2_{TEU}}$. Therefore, the cost difference per TEU of cargo between these two solutions during the leg from a Chinese supplier to a POL ($\Delta c_{l1\&2}{}'$) is half of $(\mathrm{CR} \times h_2 c_{l1\&2_{20ft}} - \mathrm{CR} \times c_{l1_{box}} - c_{l2_{TEU}} \times 2)$.

$$\Delta c_{l1\&2}{}' = (\mathrm{CR} \times h_2 c_{l1\&2_{20ft}} - \mathrm{CR} \times c_{l1_{box}} - c_{l2_{TEU}} \times 2) \div 2 \quad (28)$$

The cost differentials in Node 2 ($\Delta c_{n2}{}'$) is the cost difference in this node between the HS-FCL and the alternative solution (c_{n_2}). Because there is no consolidation activity in the HS-FCL, $\Delta c_{n2}{}' = 0 - c_{n2}$

$$\Delta c_{n2}{}' = -c_{n2} \quad (29)$$

The cost differentials in Node 3 ($\Delta c_{n3}{}'$) is the cost difference in the Port of Shanghai between the HS-FCL and the alternative solution. With the same thinking that we used in Formula (28), the cost in the HS-FCL is $\mathrm{CR} \times h_2 c_{n_{3-20ft}}$. In addition, $c_{n_{3-TEU}}$ is the terminal cost per TEU of cargo under the alternative solution. $c_{n_{3-TEU}} \times 2$ estimates the terminal cost of handling FEU of cargo. Therefore, $\Delta c_{n3}{}'$, the cost differentials per TEU of cargo between the HS-FCL and the alternative solution in the Port of Shanghai can be estimated by Formula (30).

$$\Delta c_{n3}{}' = \left(\mathrm{CR} \times h_2 c_{n_{3-20ft}} - c_{n_{3-TEU}} \times 2\right) \div 2 \quad (30)$$

Similarly, we have:

$$\Delta c_{l3}{}' = (\mathrm{CR} \times h_2 c_{sea_{20ft}} - c_{sea_{TEU}} \times 2) \div 2 \quad (31)$$

$$\Delta c_{n4}{}' = (\mathrm{CR} \times h_2 c_{n_{4-20ft}} - c_{n_{4-TEU}} \times 2) \div 2 \quad (32)$$

$$\Delta c_{l4}{}' = (\mathrm{CR} \times h_2 c_{l4_{train-20ft-gf}} - c_{l4_{train-TEU-gf}} \times 2) \div 2 \quad (33)$$

$$\Delta c_{n5}{}' = (\mathrm{CR} \times h_2 c_{n_{5-20ft}} - c_{n_{5-TEU}} \times 2) \div 2 \quad (34)$$

$$\Delta c_{l5}' = (\mathrm{CR} \times h_2 c_{l5_{truck-20ft-fs}} - c_{l5_{truck-TEU-fs}} \times 2) \div 2 \quad (35)$$

Table 8 Description of variables in the factual solution

Variables	Description	Values	Unit	References
$c_{l1_{box}}$	The road transportation cost per shipment from suppliers to the consolidation center under the alternative solution.	126.8	EUR/shipment	Face-to-face interview

Calculation results are illustrated in Table 9 and Figure 4. Due to the reduced traffic flows in the alternative solution, the consolidation cost in China can be easily compensated by the reduced cargo handling cost in the Port of Shanghai, the Port of Gothenburg and the intermodal terminal in Falköping. In addition, buyer consolidation increases container utilization and economics of scale in all the following legs after the consolidation activity. Therefore, the cost saving potential turns to be positive since the Node 3.

As shown in Figure 4, the larger the size of a shipment, the lower the cost-saving potential of the upstream buyer consolidation service will be. This is because, with shipment size increasing, the container utilization in the traditional FCL solution increases and the benefit of buyer consolidation decreases. According to the sea freight rate in early February 2018 (EUR 1400 for 20-foot containers and EUR 2500 for 40-foot containers), the cost-saving potential due to buyer consolidation for shipments greater than 17.5 cbm is estimated to be in the range from EUR 86 to EUR 1347 per TEU based on the size of each shipment. Accordingly, the total logistics cost of the HS-FCL is in the range from EUR 2086 to EUR 3457 per TEU during the leg from the points of manufacturers in China to the DC in Skara. Therefore, the alternative solution characterized by upstream buyer consolidation and downstream intermodal transport may reduce the total logistics cost by from 4% to 39% based on the case of the focal company. It is worth noting that all cost-saving potentials derived in this research are based on the assumption that container utilization after consolidation is 29 cbm per 20-foot container and 60 cbm per 40-foot container. That is, all cost-saving potentials are theoretically the maximum cost savings.

Table 9 Cost savings of the current solution vs a traditional FCL solution for shipments larger than the break-even shipment volume (BSV), EUR/TEU

No.	Legs and Nodes	Shipment Volume (cbm)						
		17.5	19	21	23	25	27	29
1	$\Delta c_{l1\&2}'$	2	0	-3	-6	-8	-9	-11
2	$\Delta c_{n2}'$	-246	-246	-246	-246	-246	-246	-246
3	$\Delta c_{n3}'$	135	116	95	78	63	51	40
4	$\Delta c_{l3}'$	914	759	587	445	326	225	137
5	$\Delta c_{n4}'$	375	325	268	221	182	148	119
6	$\Delta c_{l4}'$	120	103	85	70	57	46	37
7	$\Delta c_{n5}'$	22	19	16	14	12	10	8
8	$\Delta c_{l5}'$	25	20	15	11	7	4	1
9	Cost saving	1,347	1,096	817	587	393	228	86
10	Cost of FCL solution	3,457	3,184	2,881	2,630	2,420	2,240	2,086
11	Cost of the new alternative	2,110	2,088	2,064	2,043	2,027	2,012	2,000
12	The percentage of cost saving	39%	34%	28%	22%	16%	10%	4%

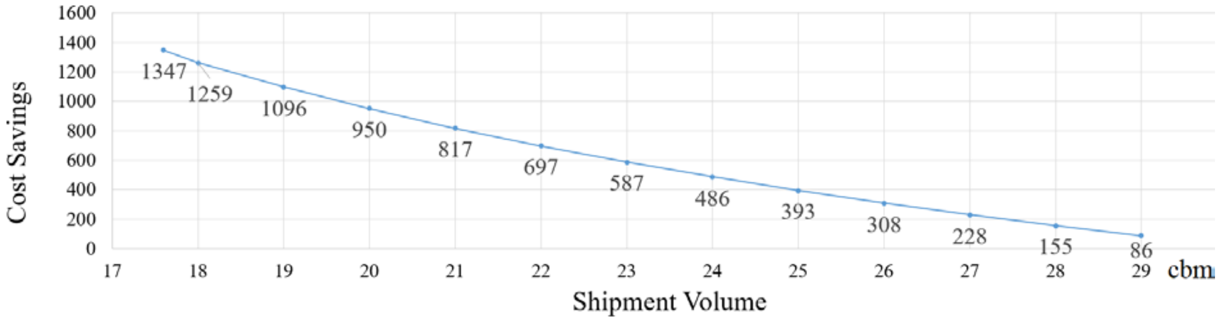

Figure 4 Estimated cost savings for shipments larger than BSV by shipment size, EUR/TEU

7.3. Sensitivity analysis

Before conducting the sensitivity analysis, the model results were validated with representatives of the case company and their associated freight forwarder to make sure the model presented results that was verified, in part and whole, by the involved actors. Two single-factor sensitivity analyses are conducted in this section. Sea freight rate and terminal cost of the unloading port (the Port of Gothenburg in this case) are selected as variables. Freight rate fluctuates dramatically and constantly and significantly influences the decision makers' selection of supply chain solutions. In addition, the terminal cost of the Port of Gothenburg is relatively high compared with the cost of other main container terminals in the same region. Therefore, the second sensitivity analysis tries to generalize the finding of this research to reveal the cost-saving potential of the alternative solution at different port charges.

Table 10 illustrates the impact of freight rate changes on the cost-saving potential of the alternative solution. We assume that the freight rate for 40-foot containers is 78.6% higher than that for 20-foot containers based on the ratio of current 40-foot container and 20-foot container freight rates. The interval between the alternative 20-foot container rate is set to EUR 150. As could be expected, the breakeven shipment volume (BSV) increases with increasing freight rates. The analysis shows that the cost advantage of the current alternative solution compared with a traditional FCL type of solution is positive under most of the alternative freight rates. That is, if the total cargo volume is large enough, buyer consolidation may always be a better choice compared with the traditional solution and save more logistics cost except in certain extreme cases when the freight rate is lower than EUR 760 for 40-foot containers and EUR 425 for 20-foot containers. In these situations, the lower bound of the cost-saving potential of the alternative solution may go below zero. In other words, when freight rates are low and the volume of one shipment is very close to that of a 20-foot FCL shipment, delivering this shipment by the a FCL type of solution is a better choice. In addition, the last column shows the changes in the cost-saving potential of the new alternative solution when shipment volumes are lower than 17.5 cbm.

Table 10 Sensitivity analysis of cost-saving potential of the alternative solution under varying freight rates

Alternative 40 ft freight rate (EUR)	Alternative 20 ft freight rate (EUR)	Breakeven Shipment Volume (BSV, in cbm)	Cost-Saving Potential compared with HS-FCL		Cost-Saving Potential compared with HS-LCL
			Upper Bound	Lower Bound	
432	242	14.2	1,002	-22	114
700	392	15.0	1,061	-4	306
968	542	15.7	1,119	14	499
1236	692	16.2	1,177	32	692
1504	842	16.7	1,234	50	884
1771	992	17.1	1,291	68	1,077
2039	1142	17.5	1,348	86	1,270
2307	1292	17.8	1,405	104	1,463
2575	1442	18.1	1,461	122	1,655
2843	1592	18.4	1,518	140	1,848
3111	1742	18.6	1,574	158	2,041
3379	1892	18.8	1,630	176	2,233
3646	2042	19.0	1,686	194	2,426
3914	2192	19.2	1,742	212	2,619

Table 11 shows the impacts of changes in the terminal cost in the destination country on the BSV and cost-saving potentials of the alternative solution. Terminal cost is set 30% higher for a 40-foot container than for a 20-foot container. The interval between alternative terminal costs is set to EUR 30 for 20-foot containers. The breakeven shipment volume (BSV) is gradually reduced when the terminal cost at the port of destination (POD) decreases. In addition, due to reduced container handling activity at the POD because of buyer consolidation, the cost-saving potential of the alternative solution compared with the HS-FCL increases with the increasing terminal cost. The increase in the cost-saving potential of the alternative solution compared with the HS-LCL is mainly because of the elimination of de/reconsolidation activities at the destination and the IRT service under the new alternative solution.

Table 11 Sensitivity analysis of cost-saving potential of the alternative solution under varying port dues

Alternative port dues 40ft (EUR)	Alternative port dues 20ft (EUR)	Breakeven Shipment Volume (BSV, in cbm)	Cost-Saving Potential compared with HS-FCL		Cost-Saving Potential compared with HS-LCL
			Upper Bound	Lower Bound	
141	108	16.3	1,286	1	1,017
180	138	16.4	1,293	11	1,045

219	168	16.6	1,300	20	1,073
258	198	16.7	1,307	30	1,102
297	228	16.8	1,314	39	1,130
336	258	17.0	1,321	48	1,158
375	288	17.1	1,328	58	1,186
414	318	17.2	1,334	67	1,214
453	348	17.4	1,341	77	1,242
492	378	17.5	1,348	86	1,270
531	408	17.6	1,355	96	1,298
570	438	17.7	1,362	105	1,326
609	468	17.9	1,369	115	1,354

7.4. Other less tangible benefits of upstream buyer consolidation

In addition to the estimated benefits illustrated above and based on interviews with involved actors of the case company and its freight forwarder, we have identified some less tangible benefits of upstream buyer consolidation during the communications with practitioners.

Supplier management & reduced possibility of delay. Supplier management is typically an integrated service of upstream buyer consolidation. To consolidate cargos efficiently, LSPs have to work proactively to communicate with manufacturers and negotiate the cargo delivery date, rather than passively waiting for the arrival of cargos, which might lead to inefficient usage of warehouse space. That is, LSPs typically help their customers manage suppliers and control the cargo delivery date, thereby reducing the possibility of delay.

Offering know-how & reduced complexity. The internal transport in China often appears to be a “black box” to international buyers. Providers of upstream buyer consolidation services may also offer useful know-how related to this leg. Consolidated shipments may make cargo management work much better, effectively reducing the need for tracing and receiving a high number of shipments every time.

Environment-friendly approach & reduced carbon emissions. As discussed above, buyer consolidation may increase container utilization and reduce the use of vehicles, ship space, train services and container handling. The economies of scale harvested through upstream buyer consolidation not only have the potential to reduce transportation costs but are also very likely to reduce carbon emissions of the whole supply chain. Reduced container volumes may in turn lead to reduced traffic on congested networks at the origin and destination.

Store-level buyer consolidation & significantly reduced activity levels at the destination. In addition to the DC-level buyer consolidation discussed in this paper, we have identified the use of supply chain solutions characterized by store-level consolidation, which means that cargos are consolidated at the origin according to the demand of each store in the destination country, rather than according to the demand of the DC. As a consequence, buyers do not have to reconsolidate their cargos at the destination. Cargo/containers may be delivered directly to each final retailing point. Under this solution, one could add substantial additional savings related to the reduced need for DC functions.

8. Concluding remarks and implications

The article contributes to the two research questions relating to the alternative supply chain solution identified in Section 1. The main focus is on exploring the impacts of upstream buyer consolidation activity in the origin country on the overall performance of an international supply chain in terms of logistics cost. All contributions of this research are summarized in Section 8.1. While, limitations and suggestions to further research are presented in Section 8.2.

8.1. Conclusions

In this paper, we have developed a set of cost models to calculate the monetary benefits of a new alternative supply chain solution characterized by upstream buyer consolidation and downstream rail-based intermodal transport. The calculation is based on a real case from a Swedish retailer, operating in the DIY segment. To illustrate the benefits of buyer consolidation, we have contrasted the costs of the current solution of the focal company with two hypothetical solutions. Compared with HS-LCL, the alternative solution converts LCL shipments to FCL shipments, thereby removing the warehouse activities close to the POD, facilitating the integration of road and rail transport in the destination countries and reducing logistics unit price (convert the item to be charged from cbm to container). In addition, compared with HS-FCL, the alternative solution converts almost full 20-foot FCL shipments into 40-foot FCL shipments to increase container utilization and reduce the total number of containers to be transported. Because of the relatively low labour cost in China, the consolidation cost upstream in the alternative solution could be easily compensated by the reduced cargo handling cost in the following nodes and reduced traffic flows in the following legs. Although showing attractiveness, we also recognized that the cost saving potential of this alternative solution is reduced when handling heavy cargo.

We have introduced the concept of the BCR to identify which part of the shipments should be transported as FCL or LCL shipments in the traditional solutions. Based on this, the comparative analysis can be conducted and the benefits of the alternative solution can be identified. Two single-factor sensitivity analyses are also conducted in this paper to reveal the impact of changes in sea freight rate and terminal cost of POD on the cost-saving potential of new alternative solution. Based on our calculation, the cost-saving potential of the alternative solution illustrated in this paper is relatively considerable. And this new supply chain solution is worth further investigation. In addition, certain less tangible benefits of buyer consolidation, including reduced possibility of delay, reduced complexity, reduced carbon emission and reduced activities in the destination countries, have been identified.

This research provides a logistics cost framework and applies it to a case study. The result of the case study match to a great extent the findings from our interviews and the development of the supply chain solutions of the focal company, which means the models and method applied in this paper is trustworthy and applicable. Scattered suppliers restrict the application of the alternative solution. If all cargo from multiple suppliers of a region is not enough to stuff a container, the alternative solution may not be the best choice. Currently, the focal company imports 10000 TEU annually from China. In order to increase the percentage of buyer consolidated cargo, they reduce the number of suppliers and POLs used in the origin country. Due to the more congregated suppliers, 87% of buyer consolidated cargo is delivered in 40-foot containers after consolidation, which means the company benefits from the alternative solution and tries to apply it to other cargos.

All input cost data of this research is not case specific data. They reflect average market prices in early 2018. Through the sensitivity analyses the impact of changes in crucial inputs on total logistics cost is illustrated. These actions increase the applicability of this research. In addition, the model and methodology developed in this article allows analysts to apply their own data in order to identify the feasibility of the alternative solution to their cargo. The values of variables provided in this article are mainly to illustrate how the model could be applied.

8.2. Limitations and scope for further research

The main limitation of this research lies in the cost model. Only direct monetary costs are included in the model presented. Additional non-monetary elements are also likely to be important components of the performance of upstream buyer consolidation and downstream rail-based intermodal system. A more comprehensive model encompassing such elements would be an important area for further research. Another limitation is that we have not considered impacts on effective lead times in this study. Upstream consolidation activities will normally contribute to longer lead times, which come at a cost. Depending on cargo value, storage costs and the flexibility and punctuality of the suppliers in terms of the timing of their deliveries, this effect could be smaller or larger. Normally, buyer consolidation could also mean shorter downstream lead time that might compensate for this. A more thorough analysis should also encompass such effects.

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