CONSOLIDATION IMPACT ON TRANSPORTATION COSTS AND CO2 EMISSIONS IN GLOBAL SUPPLY CHAIN

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Abstract: Global supply chains are becoming more complex with an increased number of challenges that logistics executives must deal with, such as distance, delivery time, numerous parties involved with a single international shipment, language and culture barriers. Numerous studies have found that consolidation can improve customer services. Not only that consolidation can improve customer services, but it can also improve market penetration, flow of product return and delivery time, vehicle utilization, flexibility, while reducing fuel consumption, transportation cost and negative environmental impacts. However, the earlier studies have not explored consolidation in terms of transportation costs and the amount of CO_2 emissions per unit. Therefore, the major objective of this paper was to investigate the effect of consolidation on transportation costs and CO_2 emissions per unit, in order to find out benefits for both customers and logistics providers. The results indicate that an effective consolidation strategy can decrease transportation costs and CO_2 emissions per unit, also achieve significant savings for customers and higher profit for logistics provider.

Keywords: Consolidation, Global supply chain, Transportation costs, CO_2 emissions.

1. INTRODUCTION

Advances in communications and transportation technologies have led customers to change their buying behavior. Customers are no longer willing to wait for weeks to receive deliveries or pay high shipping fees. Nonetheless, they expect the right product in the right condition to the right place and the right time, at the lowest possible price, despite the long distances.

Recent developments in the field of information and transportation technology have led to a renewed interest in cross-border e-commerce. Continuous increase in convenience of ordering products online has led to customers asking for same-day and next-day delivery at the lowest possible rate. According to the research, 54% of customers consider the speed of delivery and free delivery on purchases over a particular value as the most

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important delivery elements [11]. This has led to more frequent and smaller freight shipments.

Due to the change in the volume and structure of end-user requirements, direct transport, which is most often applied in emergency deliveries with limited delivery time, is not a good solution for small and frequent deliveries in terms of costs and ecology. Moreover, direct transport as a solution engenders a less full vehicle and containers, more empty runs and increased demand for rapid, energy-intensive transport [1]. Therefore, companies need an effective supply chain strategy which is responsive to customer requirements. By contrast, transport represents a process that generates high costs, between 30-40% of the total logistics costs, in addition, it is accompanied by high energy consumption, with a high level of CO_2 emissions [4]. Considering that, the strategy needs to provide higher profit and a good position in the market to the company.

There is one widely accepted strategy that aims to tackle challenges in today's global market. In other words, the strategy to utilize unused capacity inside the vehicles is an advantageous solution that balances quality, costs and transport time needed. Further, higher utilization of transport capacity reduces the number of vehicles on the roads. Moreover, reducing the number of vehicles on the roads leads to reduction of emissions, accidents and other negative impacts of freight transport on the environment. In addition to significant environmental benefits, higher utilization of transport capacity also decreases transportation costs.

Vehicle utilization can be improved by shipment consolidation. Consolidation is a powerful logistics strategy that combines two or more small shipments into an aggregate load, so that a larger quantity can be dispatched on the same vehicle [8], [9].

In recent years, global logistics providers apply various consolidation policies, in order to maximize the utilization of expensive transportation. Nevertheless, it is not always possible to implement this strategy. Successful implementation of the strategy depends upon the characteristics of the goods, flow size, frequency, shipment size, departure and destination region [1].

Previous studies have focused on different models of consolidation and its benefits. In order to explore the potential cost-saving for customers and higher profit opportunities for logistics provider, this paper will focus on the effect of consolidation on transportation costs and CO_2 emissions per unit. The aim of this paper is to investigate whether consolidation can decrease transportation cost and CO_2 emissions per unit.

2. LITERATURE REVIEW

The concept of consolidation is not the creation of state-of-the-art technology. As a solution for more optimal vehicle capacity utilization, it is known for hundreds of years. A considerable amount of literature about consolidation has been published. These studies focused on different forms, policies, models and results of consolidation.

Hall (1987) introduced three forms of consolidation: inventory consolidation, vehicle consolidation and terminal consolidation. The simplest form is inventory consolidation, defined as a process which involves accumulating items produced at different times, in order to transport them as one large shipment. Vehicle consolidation implies loading and unloading items at different origin and destinations. This form of consolidation is used, for instance, in loop distribution and milk run. Loop distribution means that goods are

collected and distributed by fixed routes. Milk rounds refer to a smaller vehicle that collects small parties of goods along a fixed transport route to transport it to a terminal where the goods are consolidated to bigger shipments. (Jonsson & Mattsson, 2005). Similar to vehicle consolidation is terminal consolidation which involves bringing goods from different origins to a terminal where the goods are sorted, loaded onto new vehicles and then dispatched to different destination according to different shipment release policies [1].

Furthermore, Hall (1987) presented four freight consolidation policies: one-terminal-closest, two-terminal-closest, one-terminal-best-nearby and two-terminal-best-nearby. One-terminal and two-terminal routing implies that each shipment must go through exactly one and two terminals, respectively before going to the destination. The author asserted that one-terminal routing strategy is not only suitable for cases involving a low number of origins and destinations, but also in cases when travel time is an issue. On the other hand, for the two-terminal routing, both the number of origins and destinations should be large [5].

The closest routing requires that the shipment is served by the terminal closest to the origin or the destination, while each origin and destination is served by exactly one terminal. Moreover, the closest routing is appropriate to use when the shipment is small and the destination and the origin are close to each other. The term 'best-nearby' indicates that the shipment is loaded from any terminal that is closest to the destination. According to the definition above, the best-nearby is appropriate when the shipment is large and the origin and the destination are far apart. The results of this study indicate that the higher shipment volume increases the number of terminals. Furthermore, when the number of terminals increases, the average distance will decline. Therefore, the average distance is lower when one-terminal routing strategy, rather than two-terminal routing is implemented. Finally, the average distance in best-nearby routing is shorter than in closest routing approach. On the other hand, trade-offs are necessary when reducing travel time by adding terminals, changing from two-terminal routing to one-terminal routing, or shifting from closest routing to best-nearby routing [5].

They also found that terminal ownership, cost of operation, and the number of vehicles and routes may increase when new terminals are added. Further, switching to one-terminal routing may require additional vehicle routes, decreased delivery frequency, and deceased load sizes. Thus, changing to best-nearby routing may require additional delivery routes, decreased delivery frequency, and deceased load sizes. In other words, appropriate freight consolidation policies are dependent on the business operation and policies of each firm.

According to Min (1996), there are three different consolidation methods: spatial, product and temporal consolidation. The spatial method concerns selecting consolidation points and assigning the product supplying points to the consolidation points. Temporal consolidation refers to aggregating shipments over time, until the moment when optimal utilization of vehicle capacity is reached and is then transported. Green departure and Fixed distribution days are examples of approaches based on this consolidation method [5].

Cetinkaya (2004) emphasized the difference between pure and integrated policies of freight consolidation. Integrated policy combines inventory and shipping decisions when applying the consolidation strategies. The author proposed three integrated policies of

freight consolidation: time-based, where planned shipments are accumulated during a fixed-length period, quantity-based, where weight or volume limits stop the accumulation process and hybrid, or time-and-quantity, consolidation policy as a combination of the first two, where the accumulation process stops as soon as one of limits mentioned above is reached [5].

Cetinkaya and Bookbinder (2003) developed stochastic models for the dispatch of consolidated shipments and derive the optimal solutions under two dispatch policies and two carriers, respectively. One dispatch policy is quantity-based policy where weight limits stop the accumulation process, the other one is time-based policy. Two carriers consist of private and commercial carrier. The authors employed renewal theory in their model to obtain the optimal target weight or the optimal cycle length by minimizing the total cost including transportation cost and inventory cost.

According to key results for private carriage, the expected dispatch quantity under time-based policy is larger than the optimal critical weight. Nevertheless, it is smaller than the mean load dispatched under the quantity-based policy. Furthermore, quantity-based policy has a mean cycle length longer than that of the corresponding optimal time-based policy. Additionally, the time-based policy offers superior service to customers [10].

Crainic et al. (2009) introduced the concept of proactive order consolidation in the global retail supply chain. Consolidation concerns physical flows once movements are already decided, on the contrary, the aim of proactive order consolidation is to effectively group the orders before they are communicated to suppliers, in such a way that the total costs of transportation and inventory of the firm is minimized. A one-dimensional bin packing model is used to group the orders and a simulation approach is developed to compare proactive order consolidation strategies with a full-container ordering strategy. They came to the conclusion that an order consolidation strategy could save substantial costs on inventory and transportation. The results revealed that proactive order consolidation policy is the most favorable policy, which achieves 4.6 percent cost savings over the less than container load (LCL) ordering policy, and 7.5 percent savings over the full container load (FCL) ordering policy even though it has more ordering costs. In addition, the results also imply a FCL ordering policy is not appropriate for slow moving products. What is more, proactive order allows wholesalers to give their 3PL partners better information earlier, regarding the numbers and types of containers required in future period [5].

Considering that the information required to realize cargo consolidation has not been explored too much Wu (2013) created an analytical model to investigate the cost performance of cargo consolidation. The cost model consists of four scenarios and one general case. Simplified assumptions are applied in the scenarios, in order to ensure that the cost functions are comparable for the subsequent analysis. On the other hand, as some of the assumptions in these scenarios are overly simplified, a general case is provided to illustrate the costs of cargo consolidation in a more realistic environment where mixed cargo flows are allowed. The results of the study indicate that the load factor of incoming containers and the unit truck cost have the overall largest positive impact on the minimum cost, while the prefixed load factor for the outgoing containers has the largest negative impact on the minimum cost. Another important finding was that although the average cost performance might be the same, the larger uncertainty makes cost control more complicated and less accurate.

Furthermore, the author stated that cargo consolidation is viable when the load factor of incoming containers is low and/or unit truck cost is high. Moreover, the author concluded that the accuracy of information on container load factor has added value in reducing the operational cost, when applying cargo consolidation. What is more, a larger penalty cost helps to keep the best barge departure time within the planning horizon, as it counteracts the benefits brought by cargo consolidation and barge shipment [10].

Surveys such as that conducted by Mesa-Arango and Ukkusuri (2013) have shown that consolidation can improve economic performance if shipments are consolidated inside vehicles. The authors investigated benefits of in-vehicle consolidation in less-than-truckload freight transportation operations and provides insights on the competitiveness and challenges associated with the development of consolidated bids. Consolidated bids are constructed using a multi-commodity one-to-one pickup-and-delivery vehicle routing problem that is solved using a branch-and-price algorithm. The results of numerical experiment showed that non-consolidated bids are dominated by consolidated bids. This finding implies that this type of operation can increase the likelihood of a carrier to win auctioned lanes, while increasing its profit margins over non-consolidated bids, and keeping the reported benefits that combinatorial auctions represent for shippers. The most interesting finding was that the cost of serving a bundle with in-vehicle consolidation is always less than or equal to the cost of serving it with direct shipments. Therefore, LTL carriers can submit bids with prices that are less than or equal to the costs of TL carriers for the same bundles and getting profits. In contrast, TL carriers could just reach the breakeven point [6].

The authors highlighted that this strategy only covers in-vehicle consolidation. In other words, this strategy does not apply for typical LTL firms where shipments are consolidated in facilities that are strategically located over the transportation network, for instance, terminals, or hubs. Since LTL shipments that are consolidated in facilities are associated with high transportation times, which is not beneficial for shippers/commodities with high value of time, differentiating these two types of consolidation is important [6].

Indeed, combining several orders into one shipment can reduce the total shipping costs. On the other hand, waiting to consolidate current orders with some future ones may require expedited shipping, thus, increasing the costs. Wei, Jasin and Kapuscinski (2017) studied the optimal consolidation policy, focusing on the trade-off between economies of scale (combining multiple orders) and expedited shipping costs (shorter delivery window). The authors demonstrated that the optimal policy can be characterized by a sequence of time dependent thresholds with only fixed cost, whether all orders are shipped from the same warehouse. The optimal policy with two warehouses and overlapping availability of products is complex, in general. Despite the complexity of the actual optimal consolidation policy, sellers can apply the two simple heuristic policies the authors proposed to get near-optimal performance in various cases. The study highlights that the optimal policy in the simplest symmetric case, can be characterized by six non-linear boundaries in three-dimensional space. In two-warehouse case with asymmetric fixed costs, the authors proved that heuristics that replace the six boundaries with no more than three constant thresholds, perform very well in most of numerically tested cases. Besides that, the difficulty of analysis increases with both fixed cost and variable cost [3].

3. PROBLEM FORMULATION

This section presents the mathematical formulation to identify the benefits of consolidation to customers and logistics providers. The focus is on transportation costs and CO_2 emissions per unit.

In this paper, three scenarios will be analyzed in order to investigate the difference in transportation costs and CO_2 emissions per unit. All three scenarios considered the shipment consolidation in the terminal where different shipments are collected and then transported together in one vehicle to end-customer. The difference between the scenarios is the load factor which increases with the number of the shipment consolidated and transported in the same vehicle (Scania truck). The maximum capacity of the vehicle that was considered in all three scenarios is 40 tonnes.

In scenario 1, 16 tonnes were transported in the vehicle, in other words, the load factor of the vehicle is 40%. In scenario 2 the load factor is 60%, according to 24 tonnes transported in the same vehicle. The load factor in scenario 3 is 100%, which is hard to reach when customers expect fast delivery. The reason for this is the time needed to collect the required quantity of the shipment. However, the purpose of scenario 3 formulation is to identify how transportation costs and CO_2 emissions per unit change in regard to the maximum load factor.

So that we would be able to compare those three scenarios, we choose one shipment of 20 kilos as a unit to analyze its share in transport costs and CO_2 emissions. Therefore, scenarios will be compared according to the shipment share.

3.1 The Effect of Consolidation on transportation costs

The total transport costs in this model are calculated as the sum of the fixed and variable costs. Fixed costs include the cost of depreciation and maintenance of the vehicle, personal income, administration, insurance and information systems, as these costs do not change with the change in the degree of exploitation. In all three scenarios, fixed costs are 339 € per vehicle. Variable costs are fuel costs that are calculated on the basis of total fuel consumption and fuel prices.

The ratio between degrees and fuel consumption is shown in equation 1. The FC equation represents the fuel consumption for transporting a particular load to the vehicle, and FCpr and FCpu the fuel consumption when the vehicle is empty and when it is full [2].

$$FC = FCpr + (FCpu - FCpr) * LF \qquad (1)$$

Based on this equation, it can be concluded that fuel consumption does not increase linearly with the increase in the amount of cargo being transported. If the fuel consumption is unknown, then it could be calculated indirectly based on the total fuel cost and the average fuel price companies may refer to.

When the vehicle is full, the fuel consumption is about 40 l/100 km and when the vehicle is empty it is about 28 l/100 km in all three scenarios (according to the specifications of Scania truck). The transport costs per unit in this model are calculated as a share of the shipment (as explained earlier) in total costs (the sum of fixed and variable costs). The share of the shipment in total costs is proportional to their share in the total freight transported (TKM) measured by tonne-kilometres.

The results of the transportation costs per unit for each scenario are presented in Table 1. According to the results, transportation costs per unit of scenario 1 are the highest with 660 €, then scenario 2 with 445,63 €, while costs of scenario 3 are the lowest with 283,24 € for the same shipment.

Table 1. Transportation costs per unit

Scenario	The load factor	Transportation costs per unit (€)
Scenario 1	40%	660
Scenario 2	60%	445,63
Scenario 3	100%	283,24

Firstly, by comparing scenario 1 and scenario 3, we found that cost-saving is 57% (376,68 €) per unit. In other words, the vehicle that uses the full capacity saves up to 57% of transportation costs per unit compared to a vehicle with the load factor of 40%. Secondly, by comparing scenario 2 and scenario 3, we found that cost-saving is 36,4% (162,39 €) per unit when the vehicle is full. Finally, by comparing scenario 1 and scenario 2, cost-saving is 32,47% (214,28 €) per unit when the load factor increases from 40% to 60%.

3.2 The Effect of Consolidation on CO_2 emissions

There are a number of methods used to calculate the amount of carbon dioxide emissions (CO_2 emissions) emitted in freight transport. The calculation of CO_2 emissions from transportation essentially is based on the weight of the load, type of the vehicle and fuel used and the distance.

The model presented in this paper is calculated using the following formula:

$$CO_2 \text{ } emissions = EF * \frac{FC}{LF*CAP} * TKM \tag{2}$$

Where

- EF is the emission factor (in kg CO2/litre);
- FC is the fuel consumption (litre per km);
- CAP is the maximum transport capacity
- TKM is the freight transported (tonne-kilometres) [7].

The formula for calculating the emissions in this model is obtained on the basis of the fact that it represents the sum of the total distance performed by vehicle on a certain period (KM), the fuel consumption (VC) and the emission factor (EF) [7].

$$CO_2 emissions = EF * FC * KM \tag{3}$$

The emission factor depends on type of the fuel. The vehicle used for this paper uses diesel, therefore emission factor is 2,7 kg CO2/litre [12].

The load factor (LF) is expressed as a percentage of capacity in tonnes. Equation (4) is used to define the load factor.

$$LF = TON/CAP = (TKM/KM)/CAP \tag{4}$$

Furthermore, equation (5) presents the average load (TON), in tonnes, as a product of the load factor and the maximum transport capacity.

$$TON = LF * CAP \tag{5}$$

Moreover, the total distance performed by vehicle on a certain period (KM) is expressed using equation (4) and equation (5) as

$$KM = \frac{TKM}{TON} \tag{6}$$

What is more, using equation (5) and equation (6) KM is expressed as

$$KM = \frac{TKM}{LF*CAP} \tag{7}$$

Finally, equation (7) and equation (3) can be used to derive equation (2).

Table 2. illustrates the results of the CO_2 emissions per unit for each scenario. According to the results, CO_2 emissions per unit of scenario 1 are the highest with 0,238 $kgCO_2$, then scenario 2 with 0,166 $kgCO_2$, while costs of scenario 3 are the lowest with 0,135 $kgCO_2$ for the same shipment.

Table 2. CO_2 emissions per unit

Scenario	The load factor	CO_2 emissions per unit ($kgCO_2$)
Scenario 1	40%	0,238
Scenario 2	60%	0,166
Scenario 3	100%	0,135

Furthermore, by comparing scenario 1 and scenario 3, we found that the vehicle that uses the full capacity emit up to 43% (0,103 $kgCO_2$) less CO_2 costs per unit than the vehicle with the load factor of 40%. Moreover, by comparing scenario 2 and scenario 3, we found that that the vehicle that uses the full capacity emit up to 30% (0,072 $kgCO_2$) less CO_2 costs per unit than the vehicle with the load factor of 60%. Finally, by comparing scenario 1 and scenario 2, we found that that the vehicle with the load factor of 60% emit up to 18,7% (0,031 $kgCO_2$) less CO_2 emissions per unit than the vehicle with the load factor of 40%.

4. CONCLUSION

This paper is the first step towards enhancing our understanding of the consolidation effect on the global supply chain. Global supply chain became more complex and more challenging. Thus, logistics executives must develop an effective supply chain strategy. Consolidation is a widely accepted strategy that is responsive to customer higher requirements and also provides a higher profit to the company. This strategy improves vehicle utilization that on the other hand reduces the number of vehicles on the roads.

It is important to highlight that in this paper only transportation costs and CO2 emissions were analyzed. In order to analyze the difference in transportation costs and CO2 emissions per unit, three scenarios were compared. Three scenarios considered the shipment consolidation in the terminal where different shipments are collected and then transported together in one vehicle to end-customer, with different load factor. The unit that was used for comparison is 20 kilos shipment.

The numerical results show that consolidation is beneficial for both customers and logistics providers as it decreases transportation costs and negative environmental impacts. As a result of increasing the load factor, costs per unit decrease. Considering that, combining shipments for improving vehicle utilization is lowering overall transportation costs. Reason for this is that fixed costs in transportation are spread for more kilometers and kilos. In addition, improving the vehicle utilization that leads to reducing the number of vehicles decrease CO_2 emissions per unit, and the reason for this is that CO_2 emissions are spread for more shipments.

In spite of the fact that only transportation costs and CO_2 emissions per unit were analyzed, the findings will serve as a base for the future master thesis. The future master thesis will focus on additional costs per unit that increase with consolidation in order to compare them with the savings that were found in this paper.

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