

High-Capacity Transport Associated with Pre- and Post-Haulage in Intermodal Road-Rail Transport

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Abstract

This paper develops a model for analyzing the potential of longer and heavier vehicles (LHVs) related to pre- and post-haulage in the intermodal rail-road transport chain (IRT). The paper considers the combined economic and emission costs among three different transport networks including intermodal rail-road transport with current Swedish regulatory framework for trucks, intermodal rail-road transport with LHVs, and direct-road transport. The objective is to analyse the potential of high-capacity transport associated with pre- and post-haulage for enhancing the competitiveness of intermodal transport from a full-costs perspective. The model developed is applied to a Swedish context and case study. Research findings reveal that the break-even of the IRT compared to the direct road transport could be significantly lowered, which suggests the LHVs contribute to exploring the market of IRT over smaller flows.

Keywords

Intermodal Transport, HCT, Sustainable Transport, Pre- and Post-Haulage, Modal Shift

1. Introduction

Transport is a fundamental factor to the economy and society, and today more attention is given to improving the efficiency and cutting the external cost of logistics. The two most notable improvement projects related to transport in Europe are intermodal transport and High Capacity Transport (HCT). High Capacity Transport is a term used for vehicle combinations that exceed existing regulations on either length and/or weight. This paper

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aims at analyzing the potential of HCT in pre- and post-haulage (PPH) in road-rail intermodal transport.

In Europe, intermodal freight transport has frequently been seen as a potentially strong competitor to road transportation and environmentally friendlier in many contexts [1]. According to UIC [2], compared to pure road transport, intermodal rail-based transport is reducing the external costs (*i.e.*, emissions of greenhouse gases and unpaid costs to society for accidents) by €0.02 per tonne-km. Consequently in 2007, the European Commission adopted a Freight Transport Logistics Action Plan. This includes potential wider use of European Modular System (EMS) vehicle combinations of 25.25 meters long. These vehicles are in regular use in Sweden and Finland (recently Finland is testing HCT vehicle combinations of 32 meters long) [1]. Broad-based utilization of LHV in Sweden would provide significant benefits in terms of increased efficiency, as well as reduced demand for investments to lower fuel consumption and reduce emissions. Furthermore, in Sweden, considerable research addresses longer vehicles, which are up to 32 m long and capable of carrying two 40 ft containers simultaneously. These studies indicate that there is a huge potential to be more fuel efficient and environmentally friendly.

However, the increase of transport demand in Europe is mainly met by road transport [3], which leads to significant negative impacts on society, especially the environment [4]. The main reason is that the direct-road transportation has strong competition in the transport market over short distance, which is the main market in the EU (about 46% of the demand over distances of 150 - 500 km). Furthermore, the intermodal rail-truck transport is associated with long-distance transport that accounts for only 22% of the demand for transport in the EU. According to the European Commission [5], road freight transport accounts for 73% of all inland freight transport in the EU. Therefore, considering the negative impacts from road transport, the white paper of transport in the EU (2011) suggests that “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”. This goal requires the development of the competitiveness of IRT transport, especially the economic competitiveness.

There is a great deal of research addressing this challenge. The competitiveness of IRT transport reported by much of the research depends on the costs of transshipment and the pre- and post-haulage (PPH) which accounts for 25% - 40% of the total cost of the IRT system [6]-[8]. For this reason, this paper would like to measure the potential of lowering the cost of PPH as it relates to the intermodal transport chain. In addition, many other researches maintain that the size and weight of trucks limit the development of the road freight transport segment in the IRT system. Bergqvist and Behrends [4] suggest using longer vehicles that have a substantial potential to reduce the cost of PPH. Thus longer and heavier vehicles seem to be a potential solution to reduce the cost of the IRT system. The purpose of this paper is to develop a model for analyzing the potential of longer and heavier vehicles related to pre- and post-haulage in the rail-truck intermodal transport chain. Using the case of Jula in Sweden and the developed model, the paper estimates the benefits achieved by shifting truck type from the Swedish current truck regulations to the longer ones with 32 m length. This dispensation for longer vehicles could enable a competitive intermodal solution between Gothenburg harbor, Falköping intermodal terminal, and Jula’s central warehouse in Skara.

The following section addresses previous research on PPH and LHVs. Section 2 relates to PPH and IRT and Section 3 develops the cost calculation for different transport networks. Section 4 gives an analysis of the results after the application of the model using the case data. And finally, conclusions are presented in Section 5.

2. Literature Review

Two streams of research that study the role of PPH related to intermodal rail-road transport and the effect of the LHVs are associated with this paper.

2.1. PPH Related to Intermodal Rail-Road Transport

Since 1990 a substantial amount of research are addressing intermodal freight transport issues. Therefore, there are many definitions of intermodal freight transport and there is little consensus [9]. The definition of intermodal freight transportation according to the United Nations Economic Commission for Europe is used for this research:

“The movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport, without moving the goods itself in changing modes” [10].

Accordingly, intermodal rail-road freight (IRT) transport combined the two modes in which road transport is

used in the short-haul transit for collection or delivery, while rail transport is related to the long-haul transport [11]. In this definition, loading unit is “a consignment of freight—invariably, but not always, comprising a combination of small consignments, as in a group age load, which is unitized to save trans-shipment and repacking time and cost at each individual stage of the journey, and also for ease of handling [12]”. The same loading unit means a standard loading unit that is related to an ISO container or other swap bodies that are internationally recognized.

There is little in the literature that clearly defines PPH. However, the PPH activities are easy to understand. The activities of PPH in an IRT system are always performed by trucks in the initial and final legs of the IRT, which we mentioned in the category of drayage [12]. **Figure 1** is a model of IRT activities, which shows the clear role of PPH, transshipment, and rail haulage [13]. The core activities of IRT are transshipment, rail haulage, coordination activities, and PPH [13], which include the operations of the intermodal loading unit (ILU) from the time it is filled until it is emptied [14].

PPH plays an important role in IRT. In fact, few IRT systems operate without taking PPH as their initial and final legs [12]. The flexibility and convenience of PPH that takes place by truck is unmatched by any other mode. The truck can go almost everywhere and is significantly competitive in the short-distance transport demand. In Europe, the distance of most PPH operations around inland terminals is 0 - 25 km, with only a few cases over a longer distance than 100 km [15]. Therefore it is the most predominant modal choice in the PPH operation. However, the cost of PPH is also comparably high.

PPH accounts for about 25% to 40% of the transport costs, despite the distance of PPH being significantly shorter compared with rail haulage [9]. The PPH costs even account for more than 70% of the total costs over a distance of about 300 km in some cases [16]. Generally speaking, the shorter the transport distance, the higher the proportion of PPH costs of total costs. The cost of transshipment accounts for another 20% of the transport costs [13]. Therefore, Ballisand Golias [6] [7] and Niérat [8] pointed out that the competitiveness of IRT transport highly depends on the costs of the PPH and transshipment operations. PPH and transshipment operations, therefore, seriously affect profitability and competition of IRT [4]. This feature makes the IRT transport more suitable for large flows over longer distances because of the high fixed costs of terminals and PPH [17]. Over distances of less than 400 km, the competitiveness is generally low for IRT transport compared with unimodal road service [18]. Bärthel and Woxenius [17] specified that long distance transport accounts for only 22% of the demand for transport in the EU, while 46% of the demand is over distances of 150 - 500 km, which falls into the category of short-distance transport. This situation makes the direct-road transport more competitive in comparison with the IRT transport. Much research focuses on resolving this conflict by making IRT transport suitable for smaller flows over short distances. According to some research, reducing the PPH cost by 30% can decrease the break-even distance of intermodal transport compared with direct road by 40% [19]. Kim and Van [20] reported that reducing PPH cost is an effective way to decrease the intermodal break-even and increase the intermodal mode share at the same time, suggesting that better PPH operation is the key for short-distance IRT market gain.

2.2. The Effects of LHV's

The size of trucks plays an important role in PPH operations. There are significant operational differences

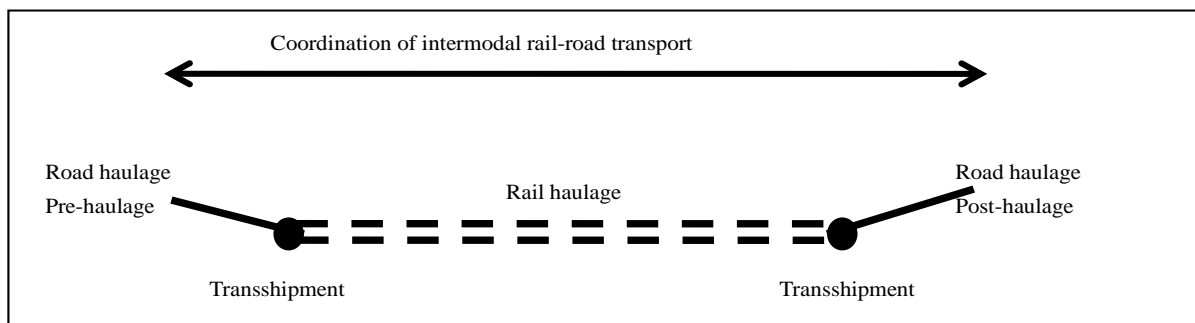


Figure 1. A system model focusing on activities in the intermodal chain. Source: Modified from Woxenius & Bärthel [13].

between different vehicle types for PPH and intermodal transport. The most significant dimension lies in the length of the truck, which is related to how many containers or swap bodies can be carried per vehicle [12]. The size of the vehicles greatly influences the costs of the PPH. Bärtheland and Woxenius [17] used the Swedish truck as an example to demonstrate that high-capacity trucks significantly decrease the average haulage costs. Meanwhile, Bergqvist and Behrends [4] illustrated that longer vehicles with 32 m length had a substantial potential to decrease the cost of PPH. Trip and Bontekoning [21] indicated that it was possible to integrate small freight flows by “getting higher degree of loading, a higher frequency and a larger geographical coverage of the network” by applying a new terminal operations concept in specific cases.

The EU defines longer and heavier vehicles (LHVs) as “all freight vehicles exceeding the limits on weight and dimensions established in Directive 96/53/EC” [22]. The LHVs in the EU generally refer to the Lorries, which are 25.25 meters in length and 60 tonnes gross mass [1]. These LHVs, which are used in Sweden and Finland, are also used under trial conditions in Belgium, Denmark, Germany, and the Netherlands [1] [22]. Currently, the European Commission has begun to review the case of allowing the use of LHVs and several governments are considering the implications in order to deal with the increasing road congestion and environmental problems. For the purpose of this paper, the LHVs we want to introduce are longer trucks that have a maximum length of 32 meters and a maximum gross weight of 60 tonnes and are expected to carry 2×40 ft or even 2×45 ft containers simultaneously.

According to research, based on available data, changing the current trucks in the EU to LHVs will reduce the road transport cost by approximately 15% to 30% on average [22] [23]. Secondly, the LHVs will cause a mode shift from rail to road by about 5% - 18% [23] [24]. With regard to the environment, De Ceuster [23] reported LHVs (60 t) were not only more efficient in fuel consumed per ton-km than the standard ones but also contributed to the reduction of CO² emissions by 3.58%, NO_x emissions by 4.03%, and PM by 8.39%. Moreover, it was recognized that the number of vehicle-kms would be reduced to move the same amount of goods because of the greater loading weights, which suggested a likely increase in traffic safety [25]. With regard to infrastructure, the LHVs significantly increase the stress on bridges, which may increase the cost around €4 - €8 billion in the EU [26]. From the literature review, there is no direct evidence that proves the LHVs would lead to negative consequences in the aspects of safety and environment. However, there is a possibility that plenty of the rail transport would shift to road if LHVs are allowed. In sum, current research has not gained a conclusive answer whether the LHVs are feasible or not. But all of the researches above mention LHVs as highly capable of improving the efficiency of road transport, thereby reducing the cost of road transport. In the context of the case of Jula, the term LHV corresponds to the capacity 4 TEU.

3. Cost Calculation Model

3.1. Cost Structure

Through a transport system, there are internal and external costs associated with cargo movements. Internal costs usually refer to the operation costs [27] and in this paper relate to the economic cost of moving units from origin to destination. In addition, the transport system imposes the external costs on society, which includes congestion costs, environmental costs, and accident costs as well as other external costs [27]. Therefore, this paper will consider both economic costs and environmental costs when calculating the performance of the different scenarios.

3.1.1. Economic Costs

The internal costs of the transport network are determined by all the operations associated with the movements of goods from production to consumption as shown in **Table 1** [27]. Daganzo [28] pointed out these operations incur costs related to motion and “holding”. The motion costs are the costs derived from the handling and transport while the holding costs refer to the waiting time costs. This paper only considers the motion costs, which are so-called economic costs according to the situation of the case studied.

The economic costs in this paper refer to the direct costs of the company. There are various cost components as shown by Daganzo [28]. When it comes to calculating the costs, the cost structure can also be divided into fixed costs and variable costs [29]. Flodén [29] also pointed out that the division was completely dependent on the time period. Many fixed costs are also shared costs such as overhead costs, and some of the variable costs are considered as fixed costs in many calculations such as vehicle taxes. When calculating the economic costs of

Table 1. The activities of the cargo moved from production to consumption.

-
- carried from the production area to a storage area
 - stalled until a vehicle becomes available in storage area
 - loaded into a vehicle
 - transported to the destination
 - unloaded, handled, and held for consumption at the destination
-

Source: Daganzo (2005), p. 30.

the company, this paper will consider the costs from the company perspective as well. The costs also can be counted by the items including the cost of vehicle taxes, insurance, salary, repair, overhead costs, fuel cost, taxes, and so on. To calculate the costs, this paper will classify these cost items into fixed costs and variable costs.

3.1.2. External Costs

The external costs refer to “those costs that are incurred by other parties as a result of an operator’s transport or terminal activities” [30]. The general external costs include the five groups of costs of “air emissions, accidents, noise, global warming and congestion [30]”. The moving of the vehicles usually causes air emissions called air pollution that results in damage to people’s health and the environment. The traffic accidents lead to the damage of the affected people and are considered in each operation step due to the different frequency, character of occurrence, and consequences in the transport system [27]. The congestion will significantly increase the time costs of the traffic network and incur the external emission. The noise and congestion are usually considered in the operations of collection and distribution in urban areas. This paper will only consider the costs of air emissions.

The external costs of the operation depend on three factors that are “the scale of the initial production of emissions, the physical impact of these emissions such as the damage of the health and delay and finally the valuation of these impacts [30]”. There are many research outcomes that contribute to evaluation of the external cost of different transport modes and the monetary values of the environment costs. Coincidentally, there are numerous Internet calculators used to identify the environmental impacts of a freight operation. To clearly state the costs, we will place monetary values on the environment costs, which mean a conversion of physical impacts into the common economic metric. The valuation will be based on the previous estimates built by the researchers. The structure to calculate external costs of the intermodal system in this paper is to summary is each section of the traffic network, with the economic costs similarly calculated.

3.1.3. Cost Calculation Structure

According to Daganzo [28], the costs of the transport can be generally described as:

$$C_{\text{total}} = c_f + c_v \times v \times d$$

where C_{total} is the total cost of the transport, c_f is the fixed cost per shipment, c_v is the rate of variable cost increased per shipment size, v is the volume of the cargo, and d is the transport distance. Considering the case scenarios, the total economic cost of the intermodal system can be divided into the cost of the rail haulage, handling, and the road haulage.

Daganzo [28] reported that if one used a public carrier to transport the cargo, the total costs were the sum of each transfer unit. Consequently, the costs of rail-haulage in this case depend on the volume and distance and the mathematical relationship is:

$$C_{\text{rail-haulage}} = c_{f\text{-rail}} + c_{v\text{-rail}} \times v \times d_{\text{railway}}$$

where $C_{\text{rail-haulage}}$ is the total cost of the railway transport, c_v is the rate of variable cost increased per shipment size, $c_{f\text{-rail}}$ is the fixed cost for rail transport, v is the volume of the cargo, and d_{railway} is the distance of the railway haulage (see **Table A1** for details on railway cost parameters).

The costs of road can be calculated in the same way. As the road haulage is operated by the company, the costs of salary and general overhead costs are regarded as fixed costs. And the fixed costs are assumed to be just

related with the number of shipments.

$$C_{road} = c_{f-road} + c_{v-road} \times v \times d_{road}$$

where C_{road} is total cost of the road haulage, the c_{f-road} is the fixed cost of the road.

Handling costs are incurred by the operations of loading and unloading the ILUs. The handling costs depend on the cargo flow:

$$C_{handling} = c_{v-handling} \times V$$

where $C_{handling}$ is the cost of handling that happened in the terminal, c_v is the rate of variable cost of handling per loading unit, and V is the total volume of the cargo.

Therefore, the final economic costs are the sum of the costs mentioned above and the mathematical relationship is:

$$C_{total} = C_{rail-haulage} + C_{road} + C_{handling}$$

This is the structure to calculate costs of the intermodal system in this thesis.

3.2. The Calculation Modal

Given the components illustrated above, the calculation of the cost of the transport network is constructed in **Table 2**.

Where $C_{rail-haulage}$ is the total operating cost of the rail transport section; c_f is the fixed cost; h is the number of hours associated with the operation; c_v is the rate of variable cost of each item; i is the number of types of fixed costs; j is the number of the types of the variable items; d_{rail} is the distance of the rail haulage; c_{fr1} , c_{fr2} , c_{vr1} , c_{vr2} , c_{vr3} , c_{vr4} , c_{vr5} , c_{vr6} respectively refer to the different items of the costs of the rail haulage and the rate is given; n_{train} is the number of the trains required depending on the scale of cargo; w is the gross weight; a is the charge of electricity consumption, which is 0.0212 KWH per gross tonne published by the Swedish Transport Administration; t is the number of train holding hours per operating day (assumed 24 h per day); $d_{operation}$ is the day of operating train assumed to be 53 days per year since one day per week according to the case; V_{TEU} is the total volume per year (TEU); n_{TEU} is the average shipment size for the train assumed to be 45 TEU per train; w_{ac} is the average weight per TEU, which is 5.7 ton per TEU evaluated from the Jula case; c_{re} is the rate of variable emission cost increased per kilometer and is set to be 0.21014SEK per kilometer; V is the total shipping volume; $C_{handling1}$ and $C_{handling2}$ respectively refer to the total economic and emission costs of the terminal; $c_{v-handling1}$ and $c_{v-handling2}$ are the rates of variable costs increasing with the cargo volume; the N_{ILUs} is the number of the ILUs,

Table 2. The calculation model.

Rail section	Handling section	Road section
$C_{rail-haulage} = \sum_i c_{fr} h + \sum_j c_{vj} v_j$ $= c_{fr1} h + c_{fr2} h + c_{vr1} n_{train} d_{rail}$ $+ c_{vr2} w d_{rail} + c_{vr3} n_{train} d_{rail}$ $+ c_{vr4} n_{train} d_{rail} + c_{vr5} a w d_{rail}$ $+ c_{vr6} n_{train} d_{rail}$ $n_{train} = \frac{V_{TEU}}{n_{TEU}}$ $w = V_{TEU} \times w_{ac}$ $C_{rail-emission} = c_e \times V$	$C_{handling1} = c_{v-handling1} \times N_{ILUs}$ $C_{handling2} = c_{v-handling2} \times N_{ILUs}$ $N_{ILUs} = \frac{V_{TEU}}{(s_{40ft} \times 2 + s_{20ft})}$	$C_{road-economic} = c_{fr} h_t + c_{v1} N_{truck} d_{road}$ $C_{road-emission} = c_{v2} N_{truck} d_{road}$ $N_{ILUs} = \frac{V_{TEU}}{(s_{40ft} \times 2 + s_{20ft})}$ <p>As the 3 TEU truck is the only truck:</p> $N_{truck} = s_{40ft} N_{ILUs}$ <p>As both 3 TEU and 4 TEU are used:</p> $N_{truck} = s_{20ft} N_{ILUs} + \frac{s_{40ft} N_{ILUs} + s_{20ft} N_{ILUs}}{2}$ $h_t = N_{truck} \left(\frac{d_{road}}{s} \right)$
<p>For the intermodal network:</p> $C_{total-economic} = C_{rail-haulage} + C_{handling1} + C_{road-economic}$ $C_{total-emission} = C_{rail-emission} + C_{handling2} + C_{road-emission}$ $C_{total} = C_{total-economic} + C_{total-emission}$	<p>For the direct road transport:</p> $C_{total-economic} = C_{road-economic}$ $C_{total-emission} = C_{road-emission}$ $C_{total} = C_{total-economic} + C_{total-emission}$	

which is estimated based on the Jula case; V_{TEU} is the total volume per year (TEU); $s_{40\text{ft}}$ is the share of the 40 ft container; $s_{20\text{ft}}$ is the share of the 20 ft container; $C_{\text{road-economic}}$ is the total economic costs of the road transport; $C_{\text{road-emission}}$ is the total emission costs; c_f is the fixed cost rate increasing with the required work hours; the h_t is the required work hours; c_{v1} is the rate of variable economic costs increasing with the cargo volume; c_{v2} is the rate of variable emission costs increasing with the cargo volume; N_{truck} is the number of the shipments related to the truck; d_{road} is the distance; s is the speed of the truck based on Sweden's transport regulation.

4. The Modal Application and Analysis

4.1. The Case Scenarios

The aim of this case is to study the effects of a new transport solution for Jula's container transports between Port of Gothenburg and the central warehouse in Skara. The cargo is transported from Port of Gothenburg to the intermodal terminal in Falköping and subsequently loaded onto a truck with an exceedance of the maximum length of vehicles, which can carry two 40-foot containers simultaneously.

This dispensation for longer vehicles enables a competitive intermodal solution between Port of Gothenburg and Falköping intermodal terminal. The project is expected to provide opportunities for studies of haulage to and from the intermodal terminals and competitiveness of intermodal transport, and allow for generalizations on other similar situations.

Currently, the annual volume transported between Gothenburg and Jula's warehouse in Skara is expected to be about 7,000 containers (TEUs: twenty-foot units) on the road, which will be approximately 4 - 5000 trucks (one way) on the road (based on >75% of the number of containers are 40 ft). The annual growth of the volume is estimated to be about 15% annually.

There are three alternative transport solutions of cargo between Gothenburg and Skara in the case of Jula. When we compare these scenarios the units must be defined. According to the standard container unit in transport, a 20 ft container is referred to as 1 TEU (Twenty-foot Equivalent Unit) and a 40 ft container is equivalent to 2 TEU. Consequently, the truck that can carry one 20 ft container and one 40 ft container is called a 3TEU truck while the truck that can carry two 40 ft containers simultaneously is called a 4 TEU truck. Therefore, the three alternative transport solutions refer to the IRT with a 3 TEU truck, which is the current network of Jula, the IRT with a 4 TEU truck, and the direct-road transport with a 3 TEU truck.

The three alternative transport networks are the scenarios illustrated in **Figure 2**. Scenario 1 refers to the solution that uses a 3 TEU truck in the PPH of the IRT. In Scenario 1, the cargo is transported from the port of Gothenburg to Falköping by train and from Falköping to Skara by general 3 TEU LHV's. As this kind of truck can carry maximum 3 TEU, such scenario is named 3 TEU Intermodal transport. By the way, this scenario is the one currently implemented by Jula. Scenario 2 refers to the solution that uses a 4 TEU truck (HCT) in the PPH of the IRT. In scenario 2, cargo is transported from Gothenburg to Falköping by train and from Falköping to Skara by 32 m (HCT). As this kind of truck can carry maximum 4 TEU, such scenario is named 4 TEU Intermodal transport. In scenario 3, the goods are transported from the port of Gothenburg to the terminal of Skara directly by general LHV's on highway E20. This scenario is named Direct Road transport, which was the solution previously used by Jula.

4.2. Applying the Model

The model is applied to the three scenarios of the Jula case making use of Swedish related data. For the purpose of the analysis, the volume of shipments is the independent variable. The default value of the basic parameter and variables defined above is shown in **Table 3** for Jula. The other variables are derived on the volume. The default values are based on the Swedish Transport Administration [31] and the estimations of truck cost and railway cost reported by Flodén respectively in 2007 [32] and 2011 [29].

The results of the calculation are described in **Figure 3** and **Figure 4** for drawing the change of the average cost depending on the shipment volume, and in **Table 4** and **Table 5** for giving the numeric results of sensitive analysis. **Figure 3** shows that for the average economic cost of three scenarios the horizontal axis is the volume of TEUs and the vertical axis is cost in SEK. It is easy to see that Scenario 1 gets the top average economic cost because of the high fixed intermodal cost from transshipment and rail and the high variable cost from the 3 TEU truck in road transport. However, when we change the truck to 4 TEU (Scenario 2), the variable cost for road

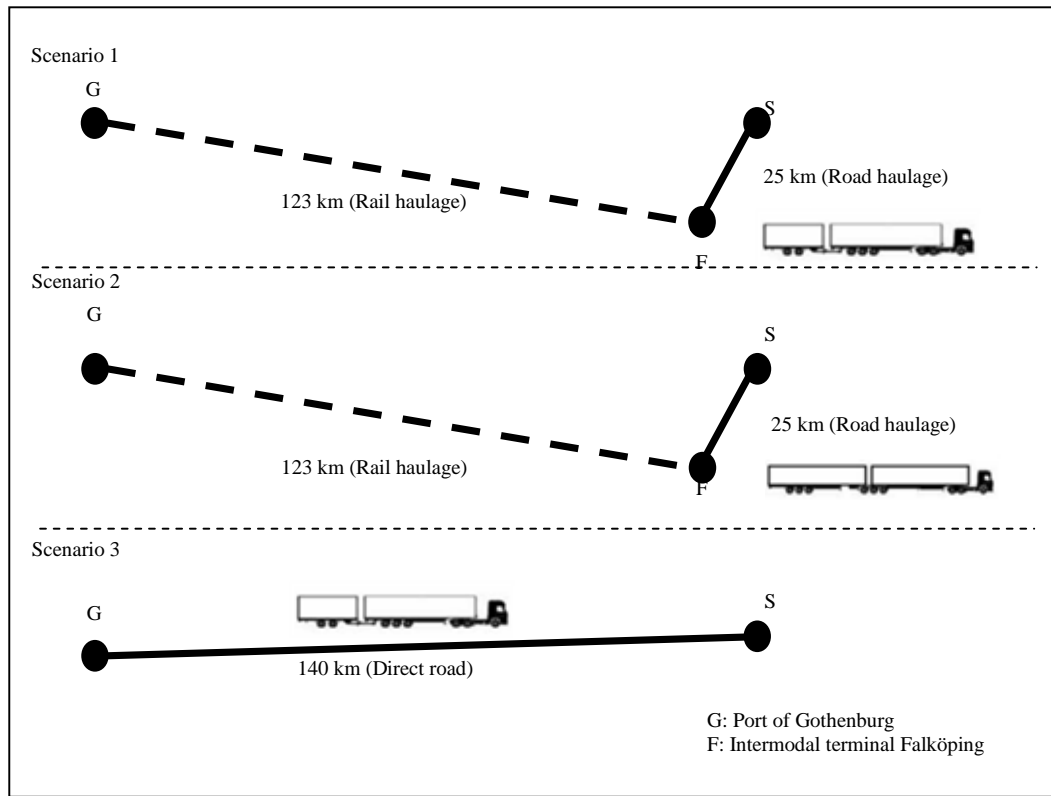


Figure 2. The network of scenarios.

Table 3. The default values from the case for sensitivity analysis.

$c_{rf1} = 548.6$	$c_{rv6} = 7.5$	$d_{rail} = 123.14$
$c_{rf2} = 782.13$	$c_{re} = 0.21014$	$d_{road} = 25 \text{ or } 140$
$c_{rv1} = 4.29$	$c_{vhandling1} = 257$	$s = 110 \text{ or } 60$
$c_{rv2} = 0.0045$	$c_{vhandling2} = 14.22$	$s_{40ft} = 0.6934$
$c_{rv3} = 0.18$	$c_R = 374$	$s_{20ft} = 0.3066$
$c_{rv4} = 0.88$	$c_{vt1} = 4.6$	
$c_{rv5} = 0.661$	$c_{vt2} = 5.52$	

comes down, which makes the IRT more competitive. Furthermore, the average economic cost decreases when the volume of goods increases in IRT. In Scenario 3, as the direct road transport seldom has high fixed cost, the average cost is at bottom when the volume is less than 9500 TEUs, but the average cost will rise when the goods flow gets large because of the high road transport variable cost. Figure 4 shows the average total cost included the emission cost of the three scenarios. Each line shows the average cost. When the LHV is changed from 3 TEU to 4 TEU, the overall average cost comes down no matter how many TEUs are transported. As a result, there is no point of intersection of the line of scenario1 and the line of Scenario 2. In both Figure 3 and Figure 4, as the main types of direct road cost are variable, the line of scenario 3, which refers to the direct road average cost, is almost parallel to the horizontal axis. Table 4 gives the sensitive results of the cost reduction with LHVs and Table 5 provides the sensitive results of the economic cost and total cost dependent on the volume.

4.3. Analysis

Woxenius and Bärthel [29] reported that the key to explore the market of the IRT primarily lies in the

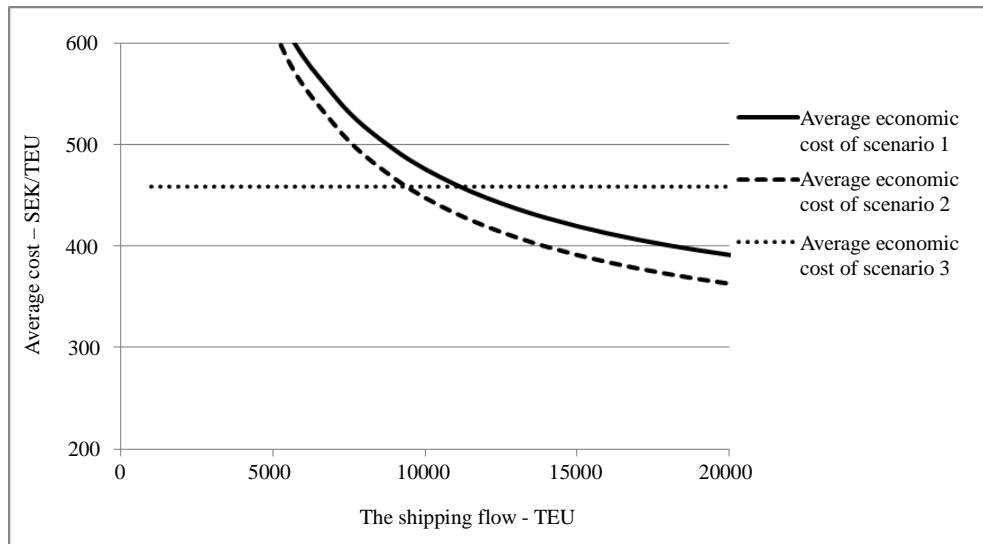


Figure 3. Dependence of the average economic costs of given scenarios on the volume of units.

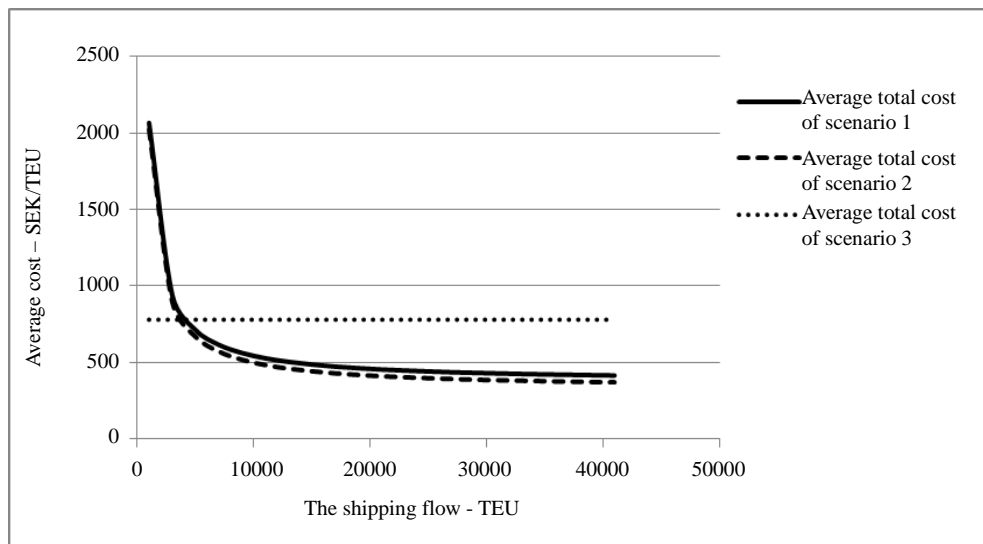


Figure 4. Dependence of the average total costs of given scenarios on the volume of units.

Table 4. The sensitive results of the cost reduction with LHVs.

Volume	Cost reduction
1000	1.44%
3000	3.25%
5000	4.39%
7000	5.16%
9000	6.15%
11000	6.48%
13000	6.75%
15000	6.97%

Table 5. The sensitive results of the economic and total costs.

The economic cost			
Volume (TEU)	Scenario 1	Scenario 2	Scenario 3
1000	1999406	1971101	458608.7
3000	2612841	2527927	1375826
5000	3226275	3084753	2293044
7000	3839710	3641578	3210261
9000	4453145	4198404	4127478
11000	5066580	4755229	5044696
13000	5680015	5312055	5961913
15000	6293449	5868881	6879131
17000	6906884	6425706	7796348
19000	7520319	6982532	8713566

The total cost			
Volume (TEU)	Scenario 1	Scenario 2	Scenario 3
1000	2065622	2021352	779176.2
3000	2811490	2678678	2337529
5000	3557358	3336004	3895881
7000	4303226	3993330	5454233
9000	5049094	4650656	7012586
11000	5794962	5307982	8570938
13000	6540830	5965308	10129291
15000	7286697	6622634	11687643
17000	8032565	7279961	13245996
19000	8778433	7937287	14804348

competition with unimodal road transport. In this section, we will not only calculate the performance of the LHV's related to the IRT based on the Jula case, but also will define the break-even of the different scenarios. The analyses of the break-even will indicate the competition between the IRT and unimodal road transport. The different break-evens we identify by shifting the scenario from scenario1 to scenario 2 imply how LHV's contribute to enhancing the competitiveness of the IRT and explore the IRT market.

The result in **Figure 3** indicates that the average economic cost of intermodal network depends on the shipment volume and the average economic cost decrease with the increasing volume due to the high fixed cost of rail haulage. The average cost of direct road transport is assumed to be the same since there is an associated low fixed cost. This indicates that IRT enhances its competitiveness by increasing shipment volume and it is the competitive alternative to the direct-road transport beyond the break-even volume. The average economic cost of IRT with a 4 TEU truck decreases at a higher rate than the network of IRT with a 3 TEU truck. Thus the break-even volume of the IRT compared with the direct road is reduced from 11000 TEU to 9500 TEU. This means that the LHV's achieve the same distance exploring the IRT market over a smaller transport flow. **Table 4** shows the sensitive results of the cost reduction from the comparison between Scenario 1 and Scenario 2 due to the LHV's. The result shows that the cost-decreasing rate increases with the volume.

The result in **Figure 4** combines the average economic cost and the average external cost of three scenarios separately. When the volume of TEU is less than 3400, direct-road transport is the best solution. Otherwise, the

IRT with 4 TEU is the best solution. As the total TEUs of goods transported from Gothenburg to Skara reached 8137 TEU in 2013, even the IRT of a 3 TEU is cost competitive compared to direct-road transport. The break-even shifts from 3800 TEU to 3400 TEU indicating that the 4 TEU truck gains more benefits if costs of emissions are considered. Therefore, we believe that longer truck option enhanced the competitiveness of the IRT to gain more transport demand such as the market of smaller flow transport over shorter distance.

When also considering the external costs, it is obvious that scenario 2 is the most cost-efficient method when the traffic flow is over 3400 TEU. The break-even is 9500 TEU when just considering the economic cost, which indicates the IRT market will be significantly explored if we consider the emission costs. In other words, if the government decided to increase the degree of internalization of external costs, the IRT will become a competitive alternative in the EU transport market. For the case of Jula, the IRT with 4 TEU will bring benefits both in the environmental and economic aspects.

Given the analyses above, it is reasonable to draw the conclusion that the LHV's not only help Jula to achieve cost reduction but also explore the IRT market if the LHV's are used in the PPH. For Jula, the LHV's will get a 5.43% reduction of the economic cost of the volume of 8137 TEU in 2013 and the benefit will increase with increasing transport demand. Meanwhile, as illustrated in the literature review, the IRT is competitive over long distance and large flows. The LHV's decrease the break-even compared with the direct road and thus explore the IRT market over a smaller transport flow and shorter distances.

5. Conclusions

This paper develops a model for analyzing the potential of longer and heavier vehicles related to pre- and post-haulage in the rail-truck intermodal transport chain. The literature review and case study both arrive at the conclusion that the LHV's contribute to improved efficiency, which can reduce both the economic and environmental costs of the PPH related to the IRT. The result of applying the model to the case of Jula shows that PPH plays an important role in the IRT by accounting for 21.5% of the total cost. Both economic and emission costs are lower in the IRT with LHV's compared to the current IRT of the Jula project. In the PPH, the LHV's save approximately 25.2% of economic costs and 24.1% of emission costs. The cost savings for the IRT chain is approximately 5.43% without considering the emission costs and about 7.53% for total cost achieved by LHV's. In addition, the LHV's help to enhance the competitiveness of the IRT compared with unimodal road transport. The break-even of the IRT and direct-road transport moved from 11000 TEU to 9500 TEU indicating that LHV's contribute to exploring the market of IRT over smaller flows. So far this thesis has pointed out the benefits of carrying out the LHV's in the PPH related to the IRT. Other opinions that should be considered are the possible consequences of the LHV's. From the literature review, there is no direct evidence that proves the LHV's would lead to bad consequences in the aspects of safety and the environment. However, there is a possibility that plenty of the rail transport would shift to the road mode if the LHV's are allowed for pure unimodal road transport. To control this risk, this thesis suggests using the LHV's in a specific IRT network.

In sum, the use of LHV's vehicles in PPH constitutes a large potential for intermodal rail-road transport in terms of increased efficiency, reduced need for investments, lower total energy consumption, and reduced emissions. The proposed cost calculation model can be used as a tool for evaluation and analysis related to intermodal transport solutions including PPH activities.

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Appendix

Table A1. The items of rail cost in Sweden.

Items	Fixed or Variable costs	The fee rate (SEK)	The fee rate (evaluted 2014) SEK
Salary cost	Fixed (c_{f1})	517.14 SEK per hour [29]	548.6 (assume 2% increase per year)
The fixed cost	Fixed (c_{f2})	782.13 SEK per hour [29]	782.13 (assume no increase in equipment)
Train path for a freight service	Variable (c_{v1})	4.29 per train kilometre for high level [31]	4.29
Track charge	Variable (c_{v2})	0.0045 per gross tonne kilometre [31]	0.0045
Operating charge	Variable (c_{v3})	0.18 per train kilometre [31]	0.18
Accident charge	Variable (c_{v4})	0.88 per train kilometre [31]	0.88
Electricity consumption	Variable (c_{v5})	0.0212 KWH/gross tonne kilometre, 0.661 per KWH	0.661
Maintenance cost	Variable (c_{v6})	7.5 per kilometre [29]	7.5 (assume no increase)

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