Logist. Res. (2012) 4:127–136
DOI 10.1007/s12159-012-0066-0

ORIGINAL PAPER

The effect of transhipment costs on the performance of intermodal line-trains

Sönke Behrends · Jonas Flodén

Received: 27 October 2011 / Accepted: 2 January 2012 / Published online: 12 January 2012

Abstract Intermodal line-trains with intermediate stops between start and end terminals are regularly advocated by intermodal transport researchers as a means to compete with all-road transport on small volumes and short distance markets. A prerequisite for line-trains are innovative transhipment technologies facilitating fast and efficient transhipments, which is likely to increase the terminal costs. The major implementation barrier of line-trains is the uncertainty regarding costs of these innovative terminals and their network benefits. The purpose of this article is to analyse the effect of terminal costs on the network performance of intermodal line-trains. The paper is based on a case study, which assesses the potential modal share for an intermodal line-train on a corridor in Sweden. The results confirm that *in theory* intermodal line-trains can provide competitive services on short and medium transport distances in case transhipment costs are kept low. Naturally, lower transhipment costs reduce the production costs, but of even greater importance is the ability to achieve higher load factors, which decreases the door-to-door transport costs per load unit. This opens business opportunities for operators and cost-saving potential for shippers in a market segment, which is dominated by road transport.

S. Behrends (✉)
Division of Logistics and Transportation,
Chalmers University of Technology, Gothenburg, Sweden
e-mail: sonke.behrends@chalmers.se

J. Flodén
Department of Business Administration, School of Business,
Economics and Law, Logistics and Transport Research Group,
University of Gothenburg, Gothenburg, Sweden
e-mail: jonas.floden@handels.gu.se

Keywords Intermodal transport · Line-train · Modal shift · Modelling · Rail transport · Transhipment technology

1 Introduction

Freight transport demand is closely linked to economic development, and for several decades, there was a close correlation between the growth of freight transport and economic growth [1]. This increase in freight transport demand has mainly been met by road freight, which imposes significant negative impacts on the society, economy and environment. As a response, the EU Commission's 2nd White Paper on a European transport policy [2] emphasized a modal shift from road towards more sustainable modes like rail as a key policy objective. However, despite a series of initiatives aimed at revitalizing rail freight, rail's modal share of inland freight transport in EU-25 continues to decline [1]. Though intermodal rail–road transport (IRRT) has grown in absolute figures in countries that have liberalized their rail transport market [3], this increase has only led to rail being able to maintain its modal share due to the underlying growth in total transport demand.

Direct terminal-to-terminal shuttle services are relatively easy to operate and provide good transport quality and economy for transport flows over long distances. This production system typically reflects mass production principles applied to transportation on the basis of economies of scale [4]. As a result, IRRT competes on cost with all-road transport for large flows over long distances, for seaport hinterland flows and for bulk commodities [4]. However, most freight flows are transported over shorter distances and/or are too small to facilitate full trains, limiting the market potential of IRRT significantly. According to an analysis made by Lammgård [5], shippers in Sweden see only limited possibilities to implement modal shift measures due to lack of quality of today's IRRT services. This is supported by Rich et al. [6] who show in an analysis for the Scandinavian region that a majority of all transports <500 km have truck as the only alternative. This imposes a strong inelasticity for modal shift for shorter trips for which truck is the dominant option. Policies aiming for an improvement of rail's competitiveness by incremental improvements in the rail system and charging policies in road transport may have only limited modal shift effect because there is no alternative to road.

A means to compete with all-road transport on small volumes and short distance markets are intermodal line-trains with intermediate stops between the start and end terminal [7–9]. A *short distance* is usually regarded as shorter than the 500 km, often mentioned as the break-even distance for IRRT and a *small volume* refers to a volume less than economically viable for direct trains [10]. Since line-trains provide access to rail not only to the region in the vicinity of the start and end terminal but also to the areas along the corridor, more destinations are served and door-to-door transport times can be reduced significantly.

The transport cost and time of an intermodal chain increase markedly at the terminal point [11]. Hence, if the node operations are executed by the present conventional terminals that are adapted to the conventional rail operations with morning arrivals and evening departures of trains, they would absorb too much time and money, leading to unattractive integral lead times and costs [12]. A prerequisite for intermodal line-trains is therefore fast and efficient transhipment operations at the intermediate nodes. A wide range of sophisticated alternative terminal concepts have been proposed by inventors and evaluated positively by researchers, but with very few exceptions they have not been implemented [7, 13]. Direct trains between large-scale transhipment terminals using gantry cranes and reach stackers is the dominating production paradigm in Europe [7], and according to Woxenius and Bärthel [14], the trend of abandoning networks and instead focusing on direct links between major conurbations and ports continues. Gouvernal and Daydou [15] find that the use of dedicated trains has increased dramatically in the UK, and also Woodburn [16] states that most intermodal freight flows in the UK are operated as direct trainloads from terminal to terminal.

A significant barrier to the implementation of alternative terminal concepts is the uncertainty among actors about the concepts' costs and benefits [17]. In particular, little attention has been paid to the cost and performance of line-train networks and line terminals [18]. This article aims at filling part of this knowledge gap. Accordingly, the purpose of this article is to analyse the effect of transhipment costs on the network performance of intermodal line-trains.

The paper is based on a case study, which analyses the potential modal share for an intermodal line-train on a corridor in Sweden. The method is based on modelling a competitive situation between traditional road transport and IRRT. The case study takes a transport systems perspective and does not focus on the implications for the individual actors in the IRRT chain. The case is based on theoretical data constructed by the authors, and consequently, it does not aim for identifying what can be achieved in the real-world transport system. The aim of the case study is to assess the importance of the transhipment costs for the general modal shift potential of an intermodal line-train and its related environmental and economic performance.

The structure of this paper is as follows. Section 2 provides the theoretical background for the case study. Concepts of rail production networks in general and line-trains in particular are introduced, and their implications on transhipment technologies are reviewed. Section 3 presents the methodology. First, the case is briefly introduced, followed by a short description of the Heuristics Intermodal Transport (HIT) model developed by Flodén [19], which is used for the case study modelling and analysis. Section 4 presents the modelling results. In Sect. 5, the implications of the results for transhipment technologies and modal shift policies are discussed. Section 6 summarizes the conclusions and outlines possibilities for further research.

2 Literature review

2.1 Intermodal consolidation networks

If freight flows are not large enough to fill larger transport units such as trains, consolidation of freight belonging to different origins and/or destinations during common parts of the route is a necessary operation. The advantages of consolidation are relatively higher service frequencies, higher loading degrees and/or more economies of scale, more destinations from each origin and possibly also the smoothing of handling peaks at terminals. The disadvantages are additional transhipments and detours, which result in increasing chain transit time and costs [17].

If flows are consolidated, it is generally done systematically, i.e. according to a transport network design [10]. Different options for transport network design are discussed by several IRRT researchers [10, 13, 20]. Although the research has not arrived at common definitions yet, all researchers distinguish several basic network designs: direct link, corridor, hub-and-spoke, connected hubs, static routes and dynamic routes (Fig. 1).

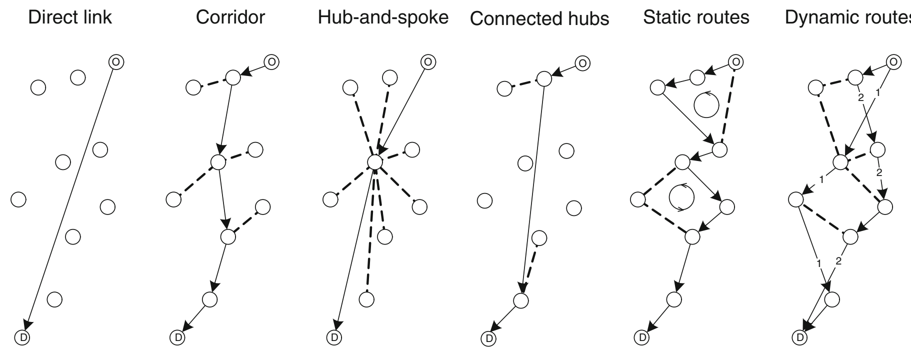

Fig. 1 Six options for transport network design [10]

Woxenius [10] provides an overview of the characteristics of these different theoretical designs from the perspective of a transport system operator. In a *Direct link,* trains run directly between an origin and a destination terminal without handling on the way. Direct links are the best rail product wherever full trainloads with the required frequency can be organized. In this setting, IRRT is easy to operate and provides good transport quality and economy for transport flows over long distances. Line-trains operated in a *Corridor* pass several terminals on their route between start and end terminal. They offer regular service and higher frequencies and allow for the integration of terminals with smaller demands in a network of IRRT and are therefore often proposed as a measure for competing in the market segment characterized by small volumes and short distances. In a *Hub-and-spoke network* one node is the hub and all unit loads call this node for transfer. In this design it is possible to offer connections between a large number of origins and destinations with medium and small terminals. However, this design implies long train formation and bundling times in the hub and detours even for transports between adjacent spoke terminals. In *Connected hubs networks,* short feeder trains connect several terminals of a region to a hub where the loads are consolidated for the long-distance transport between the hubs. It can thus be described as a direct link with regional consolidation. In a *Static routes design* a number of links are used on a regular basis and several nodes are used as transfer points along the route. Transfer is not needed at every node. *Dynamic routes* provide maximum flexibility by assigning links depending on actual demand.

2.2 Terminals and transhipment technologies

Transhipment performed in terminals is a necessary operation in consolidation networks. The terminal functions and performance requirements of the terminals depend on freight flow characteristics, the type of consolidation network and its location in the network. Generally, IRRT researchers distinguish between four terminal types, which differ in their function in the intermodal network [11, 13, 21]. These are start and end terminals, intermediate terminals, hub terminals and spoke terminals.

Woxenius [21] provides a detailed assessment of the crucial performance characteristics of terminals and an overview of the implication on the transhipment technologies. *Start and end terminals* in direct links or corridor networks handle large volumes, which are split into smaller flows for further transport on road. The demands on the transhipment technology are comparably low. Since the trains normally stay at the terminal throughout the day and are operated overnight as full trains between terminals the performance requirements on the transhipment technology regarding capacity, transhipment time, technical reliability and technological flexibility are moderate.

Intermediate terminals in corridors are serviced by line-trains and handle a limited number of unit loads, which are transhipped at intermediate nodes for distribution in the terminal region. The terminals can include value-adding services, e.g. consolidation of different flows into shipments for customers. Since the train waiting time in each terminal needs to be short in order to keep the trains total travel time acceptable, transhipment technologies need to provide rapid transhipments. It is of utmost importance that the transhipment technology has low fixed costs and can access any load unit on the train, because only a few load units on each train are handled.

Hub terminals in a hub-and-spoke or connected hubs network handle an extensive throughput of load units. The load units are transhipped between different trains; no collection and distribution takes place here, implying that they are actually no intermodal terminals. All unit loads handled in the entire network go through the hub, and a breakdown would paralyse the whole network. Hence, transhipment capacity as well as technical reliability is a crucial requirement for the transhipment equipment. It is also important to provide access to any unit load on the train.

Spoke terminals in a hub-and-spoke or connected hubs networks consolidate small volumes of load units into bigger flows. The transhipment technology requirements are comparably low. Due to the limited amount of load

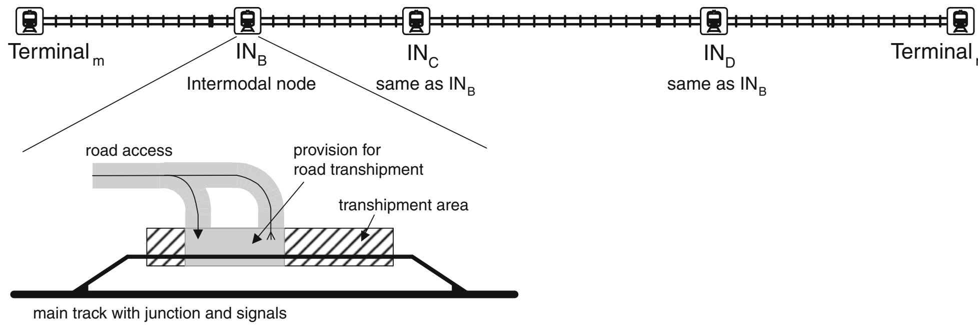

Fig. 2 Intermediate terminal in a corridor network design [25]

units handled, the transhipment technology should have limited fixed costs.

2.3 Transhipment technologies for intermodal line-trains

Intermodal line-trains with intermediate stops between start- and end terminal are often proposed as a measure for competing in the market segment characterized by small volumes or short distances. They are not a new invention; except for passenger intercity services, intermodal line-trains were used for IRRT in Japan [22], Switzerland [23] and some hinterland shuttles stop on route to or from the Port of Gothenburg. Furthermore, in the Swedish Light-Combi project, intermodal line-trains were operated between 1998 and 2001 [7].

A typical line-train that covers the intermediate markets would stop for transhipment for 15–30 min approximately every 100 km at sidetrack terminals along the route with quick transhipment operations in order to avoid the need for co-ordination of trains and road vehicles at terminals [24]. Figure 2 shows a typical example of the use of an intermediate terminal in a corridor design.

Various concepts for small-scale transhipment technologies for meeting the requirements of intermediate terminals have been developed in recent decades [21]. Both horizontal and vertical transhipment technologies exist. They promise low fixed costs and therefore allow for economic operations at comparably low transhipment volumes. The big advantage of small-scale horizontal transhipment compared to small-scale vertical transhipment is that only a small vertical lift is needed to tranship the unit load. This allows transhipping under the catenary as well as a slimmer dimensioning since only a small force is needed to tranship the load units horizontally. However, these advantages often come with the drawback of technical complexity. Most of them require adaptations of load units, rail wagons or lorries as well as human interaction, which limit their flexibility. Furthermore, some technologies depend on the simultaneous presence of road and rail vehicles at the terminal.

In the Swedish Light-Combi project, swap bodies were transhipped under the catenary using a standard forklift truck carried by the train and operated by the rail engine driver. Although the service did not pass the commercial pilot phase, it was proven that using simple and conventional technology at unmanned terminals with intermediate storage racks technically works and fulfils the shipper's logistical demands [7]. In Switzerland, the line-train concept Cargo Domino is operated today in several cases [25]. The transhipment technology is based on a double fork mounted on a conventional road truck. It can load and unload swap bodies and ISO containers from rail to road and vice versa. The lifting equipment can be equipped on a conventional truck and by that transform the truck into a kind of mobile terminal. No further infrastructure is needed; the only requirement is available space along the rail sidings. Swap bodies as well as rail wagons need certain adaptations to allow for transhipments [8].

The simple operational design of these small-scale horizontal transhipment technologies keeps the costs at a low level, but the drawbacks are in some cases needed adaptations of resources as well as handling speed and operational flexibility limitations due to the need of human operations. Automatic handling processes, on the other hand, promise better handling speed, handling damage reduction and cost reduction, and they allow for operation at uneasy working hours [26]. Reduction of terminal cut-off times can be achieved, which can increase the flexibility of the intermodal services [27]. An example of a small-scale horizontal transhipment technology is developed in the project FastRCargo.[1] It is based on automatically handling the intermodal transport units in vertical, transversal and lateral directions. This is achieved by gripping the intermodal transport units at their bottom corners. The concept operates with two subsystems, one handling all vertical load movements with four *load unit lifts*, one at each corner of the load unit, and a second subsystem, the *load unit handling tray* handling all transversal and lateral load movements. All movements are

[1] FastRCargo is a project financed by the European Commission within the 6th framework programme. The project aims at developing a small-scale horizontal transshipment technology for automated transshipments of intermodal loading units below active contact lines.

automatically controlled and coordinated. The design provides a short transhipment time since it allows transhipments below active catenaries and can access any load unit on the train. Since there are no dimensional train passing restrictions and road and rail transport vehicles do not require any modifications, the equipment is fully compatible with the existing infrastructure and standardized rolling stock. The scalability of the transhipment equipment allows a capacity design, which can be tailored to the demand. For details about the technology's design and functionality, see FastRCargo [28].

3 Methodology

In order to explore the modal shift potential of an intermodal line-train service with intermediate terminals based on fast and efficient transhipments, a theoretical case has been constructed. For transport flows along a corridor, direct road transport is compared with an intermodal alternative using a line-train. The aim of the case study is to analyse the critical transhipment unit costs (TUC) for the mode choice as well as the transhipment unit cost's influence on the minimum distance between the intermediate terminals, i.e. how the transhipment costs that an transport system operator has to pay influence the modal split along the corridor. In this section, the case is briefly introduced, followed by a short description of the HIT model developed by Flodén [19], which is used for the case study modelling.

3.1 The case study: intermodal line-train between Gothenburg and Stockholm

The case is based on a transport corridor in Sweden starting in Gothenburg and ending in Stockholm. Intermediate terminals are located in Herrljunga, Skövde, Örebro and Västerås (Fig. 3). Two train sets are operated overnight, one in the direction from Gothenburg to Stockholm with stops in Herrljunga, Skövde, Örebro and Västerås and one in the opposite direction. The trains depart in the evening, and arrival is in the morning of the following day. One train circulation therefore takes 1.5 days, i.e. departure in Gothenburg in the evening of day 1, arrival in Stockholm at the morning of day 2, departure in Stockholm in the evening of day 2 and, finally, arrival in Gothenburg in the morning of day 3. This service allows overnight deliveries in the same way as all-road transport.

The capacity of the train is assumed to be 32 swap bodies, which corresponds to 16 standard container wagons and approximately 300 m of train length, using electric traction where the electricity is produced by hydropower. Train cost is calculated at 51.37 Swedish kr (SEK) per train Km (approximately 4.8 €). For the all-road alternative, trucks with a capacity of 2 swap bodies are used. The same truck type is also used for pre- and post-haulage (PPH) in the intermodal alternative. The truck cost is calculated at 12.25 SEK per Km (approximately 1.15 €). All costs are production costs and not price. No consolidation is done in PPH, e.g. the flows Gothenburg–Örebro and Gothenburg–Skövde are performed separately with two trucks and are not consolidated even though the capacity of the truck would allow this. The environmental costs are based on the cost estimates determined for the national transport planning in Sweden [29].

The start and end terminals in Gothenburg and Stockholm are conventional intermodal terminals. Time is not a critical factor since the train remains in those terminals during the day. The intermodal nodes are small-scale sidetrack terminals equipped with a small-scale horizontal transhipment technology. Since the horizontal transhipments can be performed under active catenaries, no shunting of trains is needed and train dwelling times are short.

The transport demand is assumed to be in units of whole swap bodies. Short swap bodies (approximately 7.82 m) are used since these are the most common in domestic Swedish IRRT. Semi-trailers are not included since semi-trailers can often not be handled by horizontal transhipment technologies. Neither does the case include maritime containers to and from the port of Gothenburg, since the scope of this study is limited to domestic goods. Therefore, the trains in this case study do not stop at the terminal in the port but at the intermodal terminal in the city of Gothenburg.

It is assumed that one shipper with large transport flows, e.g. a retailer company with a warehouse in Västerås, provides the base flow for the intermodal line-train, which accounts for approximately 50% of the total train capacity. There is a certain unbalance in the transport flow since the retailer mainly uses the line-train service for the flows from Västerås. It is assumed that the flows to Västerås that use the line-train service account for 75% of the flows from Västerås. In addition to the base flow, various shippers along the

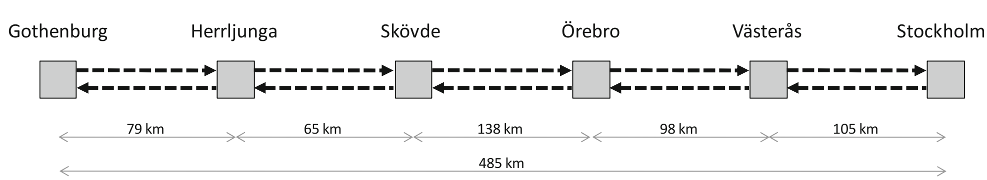

Fig. 3 Corridor between Gothenburg and Stockholm with four intermediate stops

Table 1 Origin–destination matrix of transport demand along the corridor in number of swap bodies per day

	Gothenburg	Herrljunga	Skövde	Örebro	Västerås	Stockholm
Gothenburg	0	2	3	2	8	0
Herrljunga	2	0	2	2	2	2
Skövde	4	2	0	2	3	3
Örebro	3	2	3	0	4	3
Västerås	13	1	3	5	0	14
Stockholm	0	2	4	4	14	0

corridor use the line-train service. The volumes of these flows to the other destinations along the corridor are distributed in relation to the population in the respective city.

The transport demand in the surroundings of a terminal is distributed randomly to demand locations around the terminal with a distance to the respective terminal from 10 to 50 km. Seventy-five per cent of the demand locations have a demand for two swap bodies, and 25% have a demand for one swap body. No transport demand is assumed to exist between Gothenburg and Stockholm since a successful conventional IRRT service already exists on the route. It is not realistic to assume that intermodal line-trains can compete with large-scale point to point services. Table 1 shows the total transport demand between the destinations on the corridor.

Figure 4 shows the distribution of the total demand along the corridor. The diagram shows the flow imbalances, i.e. that the transport demand towards Gothenburg is bigger than in the opposite direction towards Stockholm. Also, the demand varies along the route and is biggest between Västerås and Örebro where it is equal to the total train capacity (32 swap bodies). Hence, the capacity of the intermodal alternative suffices for the total transport demand.

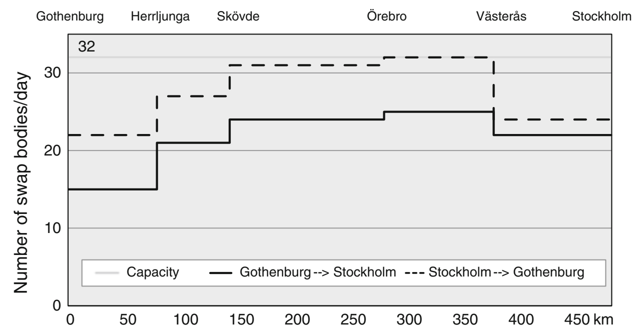

Fig. 4 Daily demand in number of swap bodies along the corridor

3.2 The HIT model

The HIT model was used to calculate the model split for different TUCs. The HIT model is a heuristic computer model that takes its starting point in a competitive situation between traditional all-road transport and IRRT, where the theoretical potential of IRRT is determined by how well it performs in comparison with all-road transport [19]. A transport buyer is supposed to select the mode of transport offering the best combination of transport quality, cost and environmental effects. Given the demand for transport, the model determines the most appropriate modal split and calculates business economic costs, societal costs and the environmental effects of all parts in the transport system. IRRT must match or outperform the delivery times offered by road transport while offering an equal or lower cost to be selected. Furthermore, the model calculates the emissions of carbon dioxide, nitrogen oxide, hydrocarbon, carbon monoxide, particulate matter and sulphur oxide and energy consumption. It also estimates the economic effect of the emissions. The HIT model also has further functions, which are not used in this case.

In this case study, the intermodal system matches the delivery times of the all-road transport system (overnight transport). The basis for the modal choice is the business costs. The TUCs are assumed to contain all costs associated with the terminal activities in the terminal. An IRRT requires two transhipments, i.e. 2 times the transhipment costs. In the first scenario, transhipment costs were 0 SEK, so that for all transports, the intermodal alternative is chosen. Then, additional scenarios are calculated by gradually increasing the TUCs by 50 SEK, i.e. in the 2nd scenario, a transhipment costing 50 SEK is used, in the 3rd scenario 100 SEK, and so on until the TUCs reach the level at which for all transports the all-road alternative is chosen. 1 SEK is approximately 0.1€ (February 2010).

4 Modelling results and analysis

In this section the *modal split*, the resulting *business costs* and *environmental impact* of the different scenarios are described and analysed.

4.1 Modal split

The modal split of the calculated scenarios is depicted in Fig. 5. Generally, the transhipment costs have a significant impact on the potential of intermodal line-trains. The higher the TUCs, the lower the share of the intermodal

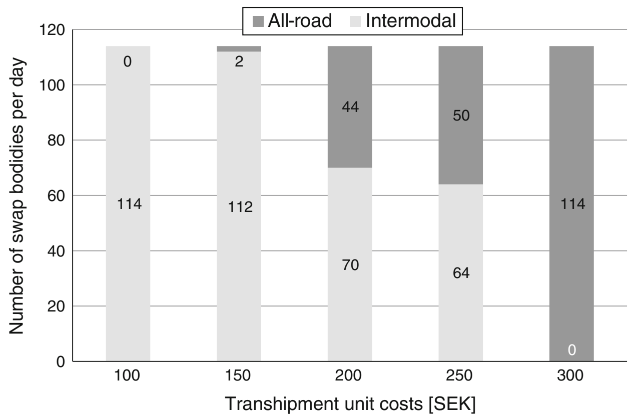

Fig. 5 Modal split for different TUCs

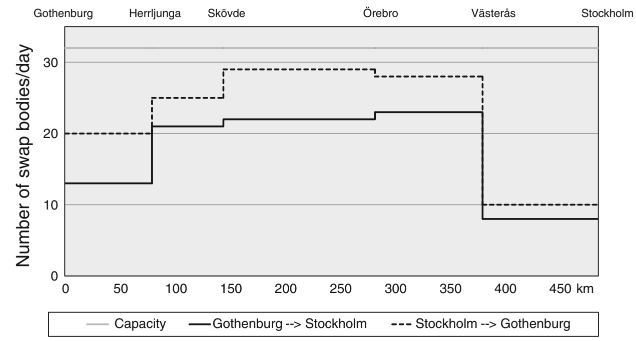

Fig. 6 Train capacity utilization for TUC of 200 SEK

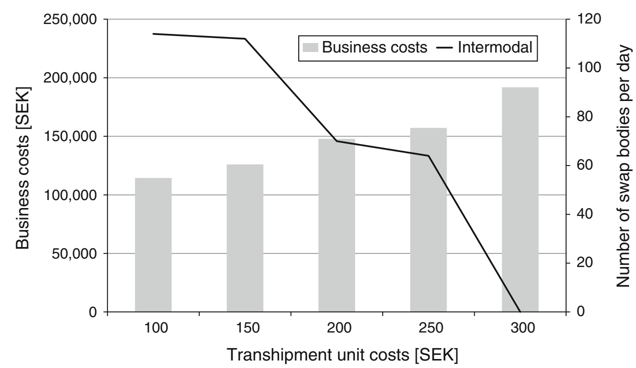

Fig. 7 Total business costs of the entire transport system for different TUC. The *bars* show the business costs (*left axis*). The *line* shows the number of swap bodies transported by the intermodal alternative (*right axis*)

alternative. If TUCs are lower than 100 SEK, IRRT is competitive for all transports. This is also the case for TUCs of 150 SEK except for the transport flow between Herrljunga and Skövde (65 km). For 200 and 250 SEK, the modal share of IRRT significantly decreases. Hence, a cost range of 200–250 SEK is identified as a critical TUC. For this cost range, the line-train is not competitive on the links between two terminals with very short distances (65 and 79 km). IRRT is partly competitive for transports between adjacent terminals where the distance is somewhat longer (98 km). For borderline cases, the competitiveness also depends on the number of swap bodies on the truck. In case of one swap body, IRRT is competitive. In case of two swap bodies, the all-road alternative is chosen, since these transports have double transhipment costs at the terminal. The different PPH distances do not have any major effect on the competitive situation since the differences are relatively small. For a TUC of 300 SEK, IRRT is not competitive on any relation.

With growing TUCs, less freight is transported intermodally, and consequently, the cargo capacity utilization (CCU) of the intermodal line-train decreases. Figure 6 depicts the CCU of the line-train for TUCs of 200 SEK. The CCU is still close to the maximum capacity on large shares of the corridors, while near the start and end terminals of the corridor, especially between Stockholm and Västerås, the train has a large number of empty spaces. This has an impact on the competitiveness of the line-train, since a fewer number of swap bodies must carry the fixed cost of the train and empty wagons, thus resulting in a higher transport cost per swap body. This "vicious circle" causes IRRT to rapidly lose competitiveness when the CCU decreases.

4.2 Business costs

The business cost of the entire transport system, i.e. the sum of all costs for road, rail and terminal operations to transport all freight flows is displayed in Fig. 7. Naturally, the business costs are lowest for a high modal share of IRRT, since IRRT is only chosen for a transport if it is cheaper than the road alternative. Consequently, the business costs increase with growing TUCs and are highest (approximately 192,000 SEK) for a TUC of 300 SEK since in this case all freight flows are transported by road. In the critical TUC range, i.e. 200–250 SEK, total business costs are approximately 150,000 SEK, which accounts for a savings of ca. 40,000 SEK or ca. 20% in comparison with the all-road scenario. Hence, the possible profits that occur in the network can be significant in case of low transhipment costs at the nodes.

In absolute cost, the cost of rail transport is the same in all scenarios. The total PPH costs decreases with the reduction in volumes sent by IRRT. The total transhipment cost is more complex as it is affected by both the number of units transhipped and the transhipment cost per unit. The total cost is the highest for TUC 150, followed by TUC 250 (95% of highest cost), TUC 200 (83%), TUC 100 (68%) and TUC 50 (34%).

The distribution of the business costs of the IRRT system between PPH, transhipment and rail haul costs for the different TUCs is displayed in Fig. 8. The share of rail does

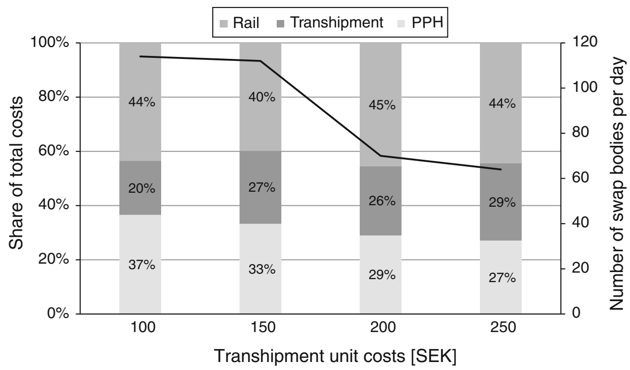

Fig. 8 Distribution of the IRRT business costs. The *bars* show the business costs (*left axis*). The *line* shows the number of swap bodies transported by the intermodal alternative (*right axis*)

not significantly change for different TUCs and accounts for approximately just under half of the total costs, while PPH and transhipment costs together account for the other half. However, the cost share of transhipments increases with the TUCs (from 20% for TUCs of 100 SEK to 29% for TUCs of 250 SEK), while the relative share of PPH decreases (from 37% to 27%).

4.3 Environmental impact

The development of the total transport system's carbon dioxide (CO_2) emissions is shown in Fig. 9. Not surprisingly, the results show the same picture as for the business costs, i.e. the higher the modal share of IRRT, the lower the CO_2 emissions of the total transport system. The CO_2 emissions are highest (approximately 15 tonnes) for TUCs of 300 SEK since in this case all freight flows are transported by road. In the critical TUC range, i.e. 200–250 SEK, the total CO_2 emissions account for approximately 6 tonnes, which results in savings of ca. 9 tonnes in comparison with the all-road scenario (ca. 60%). The external

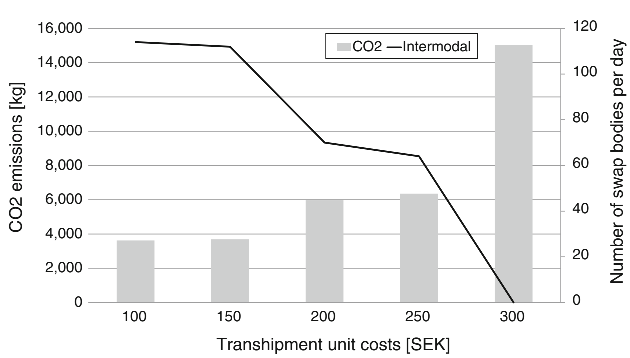

Fig. 9 Total CO_2 emissions of the entire transport system for different TUC. The *bars* show the CO_2 emissions (*left axis*). The *line* shows the number of swap bodies transported by the intermodal alternative (*right axis*)

costs, i.e. the monetary valuation of the transport system's emissions to air, including CO_2 but also nitrogen oxide, hydrocarbon, carbon monoxide, particulate matter and sulphur oxide also follows the same direction as the CO_2 emissions. The external costs are highest (approximately 30,000 SEK) for TUCs of 300 SEK. In the critical TUC range, the external costs account for approximately 13,000 SEK resulting in a savings of ca. 17,000 SEK (60%) compared to the all-road scenario. Hence, in the critical TUC range, both the CO_2 emissions as well as external costs savings are significantly higher (60%) than the business cost savings (20%).

5 Discussion

The purpose of this paper was to analyse the effect of terminal costs on the network performance of intermodal line-trains. In a case study, the importance of the transhipment costs for the general modal shift potential of an intermodal line-train and its related environmental and economic performance was assessed. Since the case is based on theoretical data, it does not reveal the potential of a line-train in the described corridor in the real-world transport system. However, the results described in the previous section confirm that *in theory* intermodal line-trains can provide competitive services on short and medium transport distances in case TUCs are kept low. Naturally, lower transhipment costs decrease the production cost, but of even greater importance is the ability to achieve higher load factors, as this decreases the door-to-door transport costs per swap body. For the competitiveness of intermodal line-trains, the critical TUCs have been identified as 200–250 SEK. Note that this refers to the production cost at the transport chain level. In this cost range, intermodal line-trains are competitive for transport flows over distances of approximately 100 km and more. Another critical parameter is the size and type of load carrier used as two smaller load carriers have a higher transhipment cost than one large load carrier with the same loading capacity. This assumes that the same handling equipment is used, which is normally the case in most terminals.

The critical cost level for the TUC of 250 SEK can be achieved by conventional terminals today, but under different operational conditions. In the present rail production paradigm, which is characterized by economies of scale, i.e. full trains that are operated between large-scale terminals, the transhipment operations in the terminals are adapted to the conventional rail operations with transhipments concentrated around morning arrivals and evening departures. A competitive line-train requires that this TUC level is achieved for significantly lower transhipment volumes. According to Ballis and Golias [20], each terminal design is effective for a certain cargo volume range and due to the required high fixed costs of terminal investments, which for conventional terminals account for about 50% of the total terminal costs, the TUCs decrease as cargo volumes increase. Hence, the TUCs are usually relatively high for low cargo volumes. If conventional terminals execute the transhipments in the intermediate nodes with low cargo volumes, the TUCs would be too high, making competitive line-trains impossible.

A wide range of sophisticated terminal concepts have been proposed by inventors; however, there is still a high uncertainty regarding the real economic performance of these innovative concepts. Due to the complex nature of innovative terminal solutions, investment decisions have become much riskier since investment costs of these terminals are high and their cost structure is unclear [13]. A prerequisite for a successful intermodal line-train system therefore is the integration of the terminal with the network and a fair allocation of costs and profits between terminal and network operators [17]. If this can be achieved, line-train systems entail new business opportunities for rail transport operators in markets that are dominated by road transport today. At the same time, transport customers could benefit from lower transport costs and society from lower externalities.

Moreover, an implication of the transport network centralization is that many regions lack access to long-distance relations and hence are dependent on road freight as the only available transport mode [6]. Line-trains increase the geographical reach of rail freight and by that can contribute to additional policy goals, e.g. regional development of peripheral regions with limited access to inter-regional freight transport networks. From a city's perspective, logistics and freight transport capabilities are important for their economic development [30], and they are a frequently used argument in city marketing aiming at attracting more economic activities and settlements in a global economy [31]. Hence, companies in regions with intermodal terminals can benefit from additional transport options, reducing the dependency of road transport and potentially protecting them from higher costs caused by increasing fuel prices and unreliable services caused by growing congestion in the long term.

6 Conclusions

This study confirms that low transhipment costs are a prerequisite for integrating short and medium distance transport in the IRRT system. Intermodal line-trains based on fast and efficient transhipment technologies can be competitive for transport flows over distances of approximately 100 km and more. Naturally, lower transhipment costs reduce the production costs of IRRT, but of even greater importance is the ability to achieve higher load factors, which decreases the door-to-door transport costs per load unit. This opens business opportunities for operators in a market segment, which is dominated by road transport. Furthermore, shippers can benefit from cost savings and additional transport options and society can benefit from lower externalities.

However, there is still high uncertainty regarding the real economic performance of alternative terminal concepts. Further research is needed to clarify whether and under which operational circumstances the required transhipment costs can be achieved. Furthermore, implementing intermodal line-trains is not only a technological challenge but also requires organizational and institutional innovations, which still needs to be developed. Identifying the barriers that hinder and the drivers that can foster the necessary organizational and institutional changes can facilitate the design of alternative policy approaches for achieving the desired modal shift.

Acknowledgments This research is financed by the FastRCargo project within the 6th framework programme of the European Union.

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