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Intermodal Transport Cost Model and Intermodal Distribution in Urban Freight

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Abstract

This study aims to model a regional rail based intermodal transport system and to examine the feasibility of it through a case study for a shipper of daily consumables distributing in an urban area and to evaluate it regarding cost and emissions. The idea of an intermodal line train is that of making intermediate stops along the route thus enabling the coverage of a larger market area than conventional intermodal services, hence reducing the high costs associated with feeder transports, the congestion on the road network and generated externalities. The results of the case study indicate that the most critical parameters for the feasibility of such a system are the loading space utilization of the train and the cost for terminal handling.

1. Introduction

Road transport has been market leader for a long time and thus has affected the logistical patterns. For rail to regain market share in urban freight it will have to achieve this. Road transport operations have comparatively low infrastructure costs and commonly do not incorporate their external costs (Mortimer & Robinson, 2004). Improvement of the cost-quality ratio of intermodal transport is also needed, due to factors such as a lack of reliability, long lead times, low frequencies and limited slots in the timetable (Botekoning & Trip, 2002).

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Nevertheless, there are also factors in favor of intermodal rail transport within urban freight e.g. the congestion on the road network and the fact that in many cases urban freight flows require unimodal road transshipment due to city logistics constraints e.g. operational constraints on dimensions of road vehicles or on the procedure of loading and unloading. Furthermore, the need for reducing greenhouse gas (GHG) emissions is evident and there is a demand for developing more sustainable transport systems. When sustainability is an objective of combined transport, the principle should be that the freight should be transported as far as possible with rail and then distributed by road with as short distances as possible (UN, 2001). Intermodal rail transport suffers from a number of problems that restrict its competitiveness over short distances. Several intermodal researchers have made contributions in finding the minimum distance that intermodal rail–road transport can compete with unimodal truck services. The European results are found in the range 400-600 km (Klink & van den Berg, 1998; Nelldal, Sommar & Troche, 2008). Intermodal transport must be able to serve more transport flows, and small flows and on relatively short distances, which can be achieved through implementing higher transport frequencies and serving more destinations. An intermodal line train making intermediate stops along its route is a feasible solution as it covers more relations and a larger market area than conventional two-terminal intermodal solutions. Intermediate terminals also imply shorter feeder transport on the roads. A main prerequisite in order to make the intermodal line train efficient is a stable and balanced flow of goods with optimized loading space utilization along the route. As the objective is to consolidate small flows, imbalances along the route will constitute an obstacle for the line train to be competitive. Davidsson, Peraaon & Woxenius (2007) cite several measures that can be undertaken in order to overcome these imbalances: adapt train capacity, adapt departure timing, use trucks parallel to rail lines, adapt train routes, assign terminals dynamically, apply price incentives, improve information sharing and apply decision support systems. Another prerequisite for intermodal line trains to be competitive towards unimodal road services in urban freight is time- and cost-efficient transshipment at the terminals (Behrends & Flodén, 2012). The physical intermodal interface consists of transshipment of loading units (LU’s), conventionally transshipped with gantry-crane or reach-stackers. These types of intermodal terminals involve high volume operations, requiring high investment cost and utilization rate, thus in many cases the number of intermodal terminals are scarce and their network scattered. Hence the concept of Cost-Efficient Small-Scale intermodal terminals, (CESS) terminals, is presented in this study, consisting of the operational use of relatively novel transshipment technologies at terminal sites located at sidings.

The methodology used for evaluating the feasibility of intermodal rail-road transport is based on a developed transport cost model, Intermodal Transport Cost Model, (ITCM), which is based on activity based calculation methods and intended as a generic decision support model with cost as the primary objective function. Modelling and simulation of intermodal networks has become an important tool for planning for carriers and shippers and as a fundament for policy, strategic planning and its associated research. The use of making specific models is evident, however a more general approach from a shippers’ perspective would be logical given that it is commonly the logistics managers at shipping firms who are the actual decision makers regarding mode choice. Furthermore, shippers commonly perceive intermodal services as a single integrated service despite the increased actor complexity of these intermodal networks (Bektas & Crainic, 2007), justifying further a general and integrated approach for shippers. Moreover, there is a need for cost information about rail freight in general and combined transport in specific; in the scientific field improved cost information is crucial as input for mode and route choice models as well as for four step forecasting models (Troche, 2009). Modelling freight transportation differs from passenger transport in numerous aspects of which one is the lack of fare prices, obtaining the price of transporting goods commonly requires either making an inquiry among carriers or to use a cost model. Albeit conflicting objectives exist among the actors in an intermodal transport chain, the main objective of the presented decision support model is to offer support in identifying the transport chain design that generates the lowest total cost for the shipper. The GIS software ArcMAP has been used in order to map freight flows and nodes as well as for the routing on the road network. Data from a major actor within the Swedish consumer goods market has been attained. The assignment consists of the wholesaler’s distribution of consumables and groceries to retail shops within an urban region i.e. the region of Stockholm, Sweden. The shipper’s data will be applied as a case study and input for the proposed model. As a result of the case study, different scenarios and results will be presented for the
given freight data, which will provide comparison of modes, transshipment technologies and principles of operations.

2. Intermodal Transport Cost Model

As illustrated by Fig. 1 the categories of input data required for ITCM are bisected, where one part represents the supply i.e. the evaluated transport chain, and the other part represents the transport demand. However, they are not strictly independent as the supply must match the constraints of the demand. The design of ITCM, as for any model, involves the fundamental decision as to which factors are to be included in the model and at which level of detail, depending on model objectives. Following the objectives of this study, the core of the model consists of three main components: rail operations, road haulage and terminal handling.

![Fig. 1. The conceptual framework for the proposed model ITCM.](image)

The conceptual framework of ITCM consists of parallel and serial processes involved with allocating the shipper’s transport demand to a given transport chain design. This process consists of two main phases: generating an initial plan that matches the constraints of the demand and to process the demand and supply in the three integrated cost modules. The output generated from each module is expressed per loading unit type in order to calculate the total transport cost. The default loading units for the calculations is a twenty foot equivalent unit (TEU) and EURO-pallets. The latter is used as it is the smallest unit in the European Modular System (EMS) and hence a flexible and precise unit. The intermodal assignment based on route trees consists of the following basic steps (Friedriech, Haupt & Nökerl, 2003):

1. Generation of direct route legs between all origins and destinations using a unimodal search.
2. Generation of route legs between transfer points using a unimodal search.
3. Construction of a route tree.
4. Calculation of costs for all routes and transfer points.
5. Distribution of demand on routes.
The total transport cost (TTC) for a combined transport chain would take the following general form:

$$TTC = RC + HC + TC$$

where,
- RC = the total cost generated by the main haul i.e. rail operations
- HC = the total cost for road haulage consisting of pre- and post-haulage to terminals
- TC = the total cost for terminal handling, derived from the estimated cost per transferred unit for each type of terminal.

A system perspective on the logistics processes is a prerequisite in order to avoid sub-optimization on specific business functions or processes, in this case of this study the transport cost. Hence, the impact that the regarded solution has on other processes of the shipper should be evaluated in order to find a candidate solution and achieve system optimization for the entire logistics system. ITCM brings integral comparisons of multimodal alternatives, however further work and a more expansive case-study are needed to make all the costs of the logistics system more explicit.

2.1. The Rail Operations Module

With the study of (Nelldal, 2012) as a base, the rail operations module has been updated and developed in order to conduct calculations for different freight train types. It is intended as a flexible model which can be used for calculations of different engine and wagon types in different countries. The aim is to make the most significant costs transparent; hence the model is rather generic, consisting of an operational train part and a wagon specification part. Table 1 illustrates the structure of the rail operations module. It requires both transport specific and train specific data as input for the cost calculation process. The most significant variables include the distance of operations, time-table transit time and supplement for shunting, number of locomotives, number of wagons, loading and empty run factor. The applied methodology is to calculate all costs for the locomotive as if it was operating without any wagons i.e. the costs for the engineer are allocated to the locomotive. The marginal costs for energy and track access according to the gross tonne-km of the wagons (including payload) are considered. The cost for insurance per wagon is considered to be relative to the investment cost. An overhead cost is considered for administration, planning and risk. It is possible to change all costs according to actual costs in different countries. The basic model has however been developed for Swedish conditions in the year of 2013 and all costs are expressed in Swedish Krona (SEK) (1 USD ≈ 6.5 SEK).

Table 1. The cost calculation module for rail operations.

| Transport data          | Train data                      |
|-------------------------|--------------------------------|
| Running distance        | Number of locomotives          |
| Scheduled transit time  | Number of wagons               |
| Supplement for shunting | Ttractive power/locomotive      |
| Trips / year            | Weight / locomotive            |
| Number of LUs / year    | Weight / wagon                 |
| Loading Space Utilization | Length / locomotive          |
| Empty run factor        | Length / wagon                 |
| **Overhead cost**       | **Max load / wagon**           |
| Administration and planning | Emission factor                |

| Cost for wagons          | Cost for locomotive             |
|--------------------------|---------------------------------|
| Maintenance for wagons   | Engineer                        |
| Energy for wagons        | Maintenance locomotive          |
| Track fees for wagons    | Energy for locomotive           |
| Insurance                | Track fees for locomotive       |
| Capital cost             | Insurance                       |
2.2. The Road Haulage Module

The road haulage accounts for the asymmetry of transport costs on the road network as each link direction is represented separately and transport costs could be summarized over a path. The optimization problem requires the specification of an objective function that can assess alternative freight plans. Different criteria could be defined for the reconsideration of distribution plans e.g. deviation from initial transportation time or cost can be used as a generic performance measure. Evaluating a distribution plan \( p(Y_p) \) would take the following form:

\[
Y_p = \sum_{i \in T_p} HC_{i}^p
\]  

Where \( HC_{i}^p \) is the haulage cost associated with carrying out trip \( t \), based on transport distance, time and the number of trips. \( T_p \) is the set of trips undertaken on plan \( p \). The freight assignment can be based on heuristics methods as a means to compare the sum of the performance measure for all distribution plans and identify a candidate solution. There are numerous methods for routing purposes and solving road vehicle routing problems, in which the most common techniques are based on gravity models or linear programming for specific optimization objectives. The latter is in the form of a minimization approach for total haulage costs subject to supply and demand constraints (Ortuzar & Willumsen, 2011). As the emphasis of the study is on rail operations and transshipment, the GIS software ArcMap has been used for routing as well as for mapping points and nodes on the road network. The cost components in the road module, as shown in table 2, have a similar structure as in the rail module - categorized as capital, operational, infrastructural and overhead costs, and then derived to cost per trip and distance per loading unit.

| Transport data       | Vehicle data       |
|----------------------|--------------------|
| Distance per trip    | Gross weight tonne |
| Average speed        | Tare weight tonne  |
| Running time         | Capacity           |
| Marginal time        | Emission factor    |
| Number trips/day     | Capital cost       |
| Number of operating days / year | Investment cost /vehicle |
| Number of trips / year | Investment cost total fleet |
| Number of LUs / year | Depreciation       |
| Mileage / year       | Interest rate      |
| Empty run factor     | Infrastructural cost |
| Loading Space Utilization | Toll fee |

| Overhead cost         | Operational cost   |
|-----------------------|--------------------|
| Administration and planning | Driver cost |
| Insurance             | Maintenance        |
|                       | Energy consumption |

| Total annual cost     |
|-----------------------|
| Capital costs         |
| Operational costs     |
| Overhead costs        |
| Infrastructural costs |
2.3. The Terminal Handling Module

There are several factors associated with large-scale conventional intermodal terminals based on gantry-crane or heavy reach-stackers that make them unsuitable for all freight flows and thus limit the competitiveness for combined rail road transport. Albeit the operational marginal transloading costs achieved may be relatively low, a main obstacle for intermodal transport is still the associated transshipment cost, as high investment costs and high utilization rates are prerequisites for efficiency. Some of the underlying reasons for the inefficiency of conventional intermodal terminals are:

- Terminals are designed for the heaviest LUs i.e. semi-trailers and heavy containers
- They require large areas that need to be hardened for high axle loads
- The majority of semi-trailers still cannot be transloaded using conventional transshipment technologies i.e. there are not lift on- lift off (LOLO) trailers.
- In electrified rail networks, many terminals are not fully electrified – thus requiring additional diesel driven shunting engines and thus time-consuming shunting movements where track capacity is limited.
- Limited flexibility in time as opening hours are limited.
- The number of intermodal terminals is commonly scarce and their network scattered.

Hence, there is also a need for cost-efficient small-scale intermodals terminals - CESS terminals, and for operationally utilizing cost-efficient transloading technologies. A number of transshipment technologies have been developed in recent decades, both horizontal and vertical. Horizontal technologies enable transshipment under the catenary and commonly require less force, on the other hand they often require customization of loading units and/or chassis and can be technically complex. Three of the most promising technologies are identified and evaluated in this study. The concept of CESS terminals originates from the previously implemented and evaluated Light-Combi concept, an intermodal line train where forklift-trucks were used for horizontal transshipment of loading units under the catenary (Bärthel & Woxenius, 2003; Kordnejad, 2011). The system consisted of terminals located at sidings connected to the main line at both ends that served a 400-metre train consisting of twenty 2-axle wagons carrying 40 TEUs at the most. Alongside the siding the surface is hardened, enabling loading units to be handled with a forklift. The forklift is a simple and cheap technology which can be handled by the train driver, thus enabling savings on valuable man hours. The limitation is that forklifts can only handle customized 20-foot containers and swap-bodies and not semi-trailers, 40-foot containers and larger units.

Utilizing forklift-trucks for transloading, albeit cheap and simple, composes certain restrictions as well e.g. limited weight/size lifting capability and requiring customization on the LU i.e. forklift tunnels. CESS-terminals – broaden the previous notion as forklifts are not the sole technology considered. Novel wagon technologies and innovations e.g. the Megaswing wagon\(^1\) can also be regarded as candidate technologies as they enable transloading on sidetracks under the catenary without any additional transloading equipment, thus overcoming the problems associated with conventional terminals. The wagons are designed for semi-trailers; a similar but non-electrified wagon (Sgnss) exists for swap bodies. Consequently, the market for combined land transport can be broadened as more standardized loading units can be transloaded. However, the rail investment cost increases as the wagons are more costly than conventional intermodal wagons and standardized heavy containers cannot be transloaded. Another technology that could potentially be used in CESS-terminals is CarConTrain (CCT) – a horizontal transshipment technology consisting of hydraulic poles on which LUs are placed during the transloading process (Nelldal, Sommar & Troche, 2008). Hence, the transfer between modes does not have to be synchronized, offering a higher degree of operational flexibility. The system is still at a development stage and is designed for handling all types of LUs; however the system requires customization on truck and wagon chassis as well as a sliding transfer unit.

\(^1\) http://www.kockumsindustrier.se/en-us/our-products/productdetail/?categoryid=3&productid=11 (2013-04-08)
The cost structure calculated in the terminal cost module is based on a model developed in the study of Nelldal, Sommar & Troche (2008), which has been modified to incorporate the Megaswing wagon and updated with current values. The basic model is on a highly detailed operational level, however for the sake of clarity only a schematic structure of the components is illustrated in table 3. The transfer cost for six different terminal types has been calculated as illustrated by Fig. 3, with one conventional reach-stacker based and medium-sized intermodal terminal (handling 50 000 TEU’s/Year) and five types of CESS-terminals (handling 15 000 TEU’s/Year):

1. Conventional Intermodal Terminal - Medium sized, using reach-stacker.
2. CESS Terminal 1A: Light-Combi. Forklift trucks stationed at transfer terminals.
3. CESS Terminal 1B: Light-Combi. Engineer handles the forklift truck, thus reducing the operator cost.
4. CESS Terminal 1C: Light-Combi. Multipurpose forklift trucks are used half of the time for other purposes at terminals, thus reducing the cost for transloading equipment.
5. CESS Terminal 2: Specialized wagon - Megaswing
6. CESS Terminal 3: CarConTrain (CCT) technology

Table 3. The main structure of the terminal handling module.

| Infrastructure | Transloading Resources | Shunting | Overhead |
|---------------|------------------------|----------|----------|
| Annuity       | Annuity for transloading equipment | Annuity for shunting engine | Total Cost → Transshipment cost/LU |
| Maintenance   | Operator                | Operator |          |
|               | Maintenance             | Maintenance |      |
|               | Energy Consumption      | Energy Consumption |   |

2.4. Emissions

Carbon dioxide (CO₂) is the predominant greenhouse gas (GHG) emitted by motor vehicles and is directly related to the amount of fuel that is consumed by vehicles. Vehicles also emit other GHGs, including methane (CH₄), nitrous oxide (N₂O), and hydro fluorocarbons (HFCs). In this study an activity based approach for the estimation of CO₂ emissions is applied where the main methodology is expressed by formula (3). Data for energy consumption is derived from the three modules of ITCM.
where,

\[ E(CO_2) = EC \times EF(CO_2) \]  

It is important to select the most appropriate emission factor values for each transport mode and terminal handling. Energy consumption and emissions in freight transport do not only occur during the actual shipment, but also at a much earlier stage in the processes leading up to the supply of the tractive energy. The main energy sources used in freight transport processes are diesel fuel and electricity. To compare the environmental impacts of transport processes with different energy sources, the total energy chain has to be considered. As to emissions, in the case of electrically-powered rail transport vehicles, the emissions are produced entirely in the pre-chain whereas for diesel powered transport vehicles, the main part of the emissions are produced during the transport itself. The magnitude of the emissions is also influenced by other factors e.g. the weather, driving style, vehicle maintenance and type of engine. (Cefic-ECTA, 2011). Hence, the results of these calculations have to be seen as an indicator of the magnitude of the environmental impact of the case study rather than exact data.

2.5. Time

The total transportation times is composed of running times between sites and the service time at these sites. The time for loading and unloading depends on the amount of delivered goods, vehicle and loading unit type and site specific attributes e.g. equipment, layout and labor. A default dwell time function takes the form of a linear function increasing with the amount of delivered goods where the loading time per unit is site or vehicle type specific. Moreover, time windows create planning requisites and capacity constraints for inbound and outbound flows. Thus longer delivery time by intermodal transport is not necessarily a disturbance, as long as they are on-time according to the plan, albeit longer delivery times lead to higher capital costs for rail operations. For shippers to consider a shift they must be convinced that their specific requirements for inbound and outbound transportation are met. A number of studies have been conducted regarding these requirements and their stated importance. The study of Lundberg (2010), which was based on surveys and data analysis, states the following requirements: Cost, transportation time, reliability, punctuality, flexibility, frequency and environmental impact.

However, it is not only these requirements that the shippers base their choice upon - the perception of the performance of the modes and services can have an even higher impact on the overall decision making process (Bektas & Crainic, 2007). The mode choice decision is also usually a long term decision as contracts between shippers and carriers last for years and altering these relations usually generates a cost. Thus, the quality of intermodal transport, in specific regarding reliability and punctuality, has to be ensured for it to be regarded as a feasible alternative, no matter what price is offered. Hence, testing and validation in demonstration projects are essential, especially when considering novel technologies e.g. vehicles and transshipment systems.

2.6. ITCM – Results for Fictive Transport Chains

The introduced model ITCM has been applied in order to evaluate the transport cost associated with a set of conceptual transport chain designs under Swedish conditions in the Stockholm city region. The transport assignment consists of 45 TEUs that are transported in an average distance of 550 km, of which 450 km can be transported by rail. The number of TEUs is based on supply constraints i.e. maximum train length and a loading factor of 80%. The results from the model on fictive transport chains indicate where combined rail road transport can be most competitive:

- In flows where, the costs of pre- and post- haulage to terminals commonly only occur at one side of the transport chain e.g. in urban freight flows requiring unimodal transshipment and for intermodal maritime flows.
• In intermodal line train concepts where CESS terminals are used.
• On relations with relative high unimodal road costs e.g. subject to road or congestion charges.
• In concepts with long trains and high loading factors or with trains with a fast circulation.
• In large scale transportation, over long distances, where a high utilization rate at terminals and loading factor of the train are achieved.

3. Case Study

The REGCOMB research project is funded by Swedish Transport Administration through the virtual research center SiR-C (Swedish Intermodal Research Centre). Based on a case study for the greater Stockholm region, the feasibility of creating a regional rail based intermodal transport system around the region is evaluated. This region is one of Europe’s financially most vibrant regions where a number of consumption intensive and some production intensive cities are located in proximity to each other. Accomplishing the objective of the project requires a description of the current market for regional combined transport and to try to identify the existing needs of connections in the freight market. As a way of evaluating such a system, freight volumes from a major actor within the Swedish consumer goods market have been attained. The assignment consists of the wholesaler’s distribution of consumables and groceries to retail shops within the region of Stockholm. The shipper’s data is be applied as a case study and input for the proposed model. As discussed in the introduction there are two main operational prerequisites for the line train system to be competitive on short and medium distances, firstly optimized loading space utilization of train and secondly time- and cost-efficient transshipment at terminals. The latter can be achieved by using CESS-terminals. Hence, the task that arises is to search for the break-even point towards unimodal road transport concerning the loading space utilization of the train. The cost per unit for the shipper will depend on the overall train loading space utilization, hence the total transport costs are presented as a function of the train loading space utilization, where the shipper’s volumes have been consolidated with other shipments in the train.

3.1. Demand Input

ITCM consists of two main phases: generating an initial plan that matches the constraints of the demand and to process the demand and supply in the three integrated cost modules. Thus the first step is to examine the constraints of the demand. As seen in Fig. 4a the shipper has three distribution centers (DCs), each handling a separate goods class; common goods (i.e. no need of cooling), refrigerated and frozen goods. The attained demand data is expressed in the units of EURO-pallets and rolling cage units (RCU).

The main operational constraints of the demand are time windows for nodes and the service times at these nodes. The cost for each relation is affected by the nodes location e.g. regarding road vehicle length limitations in the municipality of Stockholm (limited to 12 meters except on dedicated routes) and in the Old town district (limited to 8 meters) as illustrated by Fig. 4b. This globally common situation could favor intermodal transports as it requires either unimodal transshipment to smaller trucks when entering local zones, or smaller truck capacity from the origin.
3.2. Supply Input

3.2.1. Rail Operations

When considering the number of wagons needed for each train set, it is the train length limitation and the required frequency that are the most influential parameters. The initial train length is set to 400 meters, based on the estimated demand and in order to fit sidings when using CESS terminals. The number of wagons needed determines the required tractive force, hence the most suitable locomotive type and number is chosen. The routing of the train is limited to the set of intermodal terminals available. In this study the set of terminals that are considered are actual conventional intermodal terminals in the region and potential sites for CESS-terminals. The scheduling of the train is influenced further by the supply, as infrastructural capacity constraints and other operational aspects have to be considered e.g. directional changes and limited track capacity around Stockholm area during rush hours. The required cycle time of the train is another main parameter influencing the scheduling. The criteria underlying the choice of the route for the train are the following:

- The route should link the main terminals and markets in the region.
- The route should allow a cycle time less than 12 hours; enabling two set of trains per day going in opposite directions.
- The route should allow trains to run operationally efficient and with minimal delays at entry and exit points from the terminals and switches.
- The route should be able to operate in conjunction with other traffic present on the network.

A 466 km long rail route consisting of a loop around the region is evaluated. The rail route connects the set of conventional intermodal terminals and sites for CESS-terminals in the region (see Fig. 6). Table 4 illustrates the main results from the rail operation module as well as conversion parameters for loading units relative to EURO-pallets, due to the dimension of a RCU and the capacity of different loading units; 20-foot container (TEU), swap body (SB) and semi-trailer (ST).
Table 4. Main results and parameters from the rail operations module.

| Reference train: 396 meters, 14 wagons, loading factor 80% |
|-------------------------------------------------------------|
| kWh / SB-km | 0.334 |
| kWh / ST-km | 0.683 |
| Emission Factor Swedish Electricity (kg CO₂ / kWh) | 0.010 |
| CO₂ emissions / SB-km (kg) | 0.0033 |
| CO₂ emissions / ST-km (kg) | 0.0068 |
| Rail haulage cost | Cost / LU-km |
| Wagon type: Sggrss 80' Loading Unit: SB | Cost / LU-km |
| Wagon type: Megaswing Loading Unit: ST |Cost / LU-km |
| Conversion Parameters |
| Euro pallet | RCU | TEU (1 tier) | SB (1 tier) | ST (1 tier) |
|-------------------------------------------------------------|
| 1,7 | 11 | 18 | 33 |

3.2.2. Road Haulage

The initial allocation process of nodes to terminals is decided according to the principles of Fig. 5 and formula (4):

\[
F(i, j) = \begin{cases} 
  i & \text{if } THis + DHis < TRij + DRij + THjs + DHjs \\
  j & \text{if } THis + DHis > TRij + DRij + THjs + DHjs 
\end{cases} \quad (4)
\]

This function is based on the general haulage cost from the terminal to the shop as it includes distance (D) and time (T) components for links, where i and j are intermodal terminals, s is the studied shop and (H) the haulage cost by road and (R) by rail. Moreover, the allocating of a shop to a terminal affects the routing by the truck thus depending on the operational road routing strategy, the border line cases should be reevaluated heuristically in order to reach the final allocation. The routes used in the presented results are based on the initial terminal-shop allocation procedure expressed by formula (4) where the software ArcMap’s extension Network Analyst has been applied and illustrated in Fig. 6. The costs are calculated according to formula (2) and table 2. Table 5 illustrates the main input variables.

Table 5. Main input variables for supply input road.

| Energy Consumption as a Function of Payload |
|---------------------------------------------|
| Gross weight tonne (1 truck) | 44 | 26 |
| Liter/gross tonne km | 0.012 | 0.015 |
| Emission factor (diesel) |
| CO₂ emission (kg CO₂/liter) | 2.56 |
| Road Vehicle Combination (1 Truck) |
| Transport Chain Design |
| Distribution Area | Unimodal Road | Intermodal using SB | Intermodal using ST |
| Stockholm City | 1 SB | 1 SB | 1 ST |
| Stockholm | 1 SB + 1 ST | 2 SB | 1 ST |
| Other | 1 SB + 1 ST | 2 SB | 1 ST |
3.2.3. Terminal Handling

The selection of transshipment technology is not purely based on the technology with the lowest transshipment cost per unit as it also affects the selection of loading units, the rail and road cost components and the overall logistics system. Furthermore, the emissions generated by the transshipment technologies have to be considered. Table 6 illustrates the cost and CO₂ emissions per LU estimated for each of the evaluated technologies.

Table 6. Main results from the terminal handling module.

| Transshipment Technology | Cost / LU (SEK) | CO₂ Emissions / LU (KG) |
|--------------------------|----------------|-------------------------|
| Conventional Terminal    | 268            |                         |
| CESS Terminal 1A         | 257            |                         |
| CESS Terminal 1B         | 159            |                         |
| CESS Terminal 1C         | 170            |                         |
| CESS Terminal 2 Megaswing| 143            |                         |
| CESS Terminal 3 CCT      | 106            |                         |
| Medium Intermodal Terminal | 4.5             |                         |
| CESS Terminal 1 - LightCombi | 1.7           |                         |
| CESS Terminal 2 - Megaswing | 0.9           |                         |
| CESS Terminal 3 - CCT    | 0.3            |                         |

3.3. Case Study Results

Table 7 shows the output from ITCM for unimodal road distribution to shops. The goods classes are; common goods, refrigerated and frozen goods. A specific distribution center (DC) is used for each goods class, which are located at different sites in the region. Flows requiring cooling consequently requires higher energy consumption as diesel driven refrigeration units are used. The flows are also separated according to the distribution area; as those located within Stockholm city will have a smaller truck capacity, be subject to congestion charges and slower speeds compared to those located in other parts of the region (in tables 7, 8 and 9 named “other”). The annual cost is calculated to 38,05 million SEK and the annual CO₂ emissions to 1813 tonne, which are the main parameters used in comparison to the intermodal transport chains.
Table 7. Results for unimodal road distribution.

| Goods Class       | Common | Refrigerated | Frozen | All  |
|-------------------|--------|--------------|--------|------|
| Total leg length (km) | 17 336 | 22 176       | 18 806 | 58 319 |
| Leg (Stockholm) (km)       | 11 472 | 18 712      | 14 685 | 44 869 |
| Leg (Other) (km)         | 5 864  | 3 464       | 4 121  | 13 450 |
| Mean trip length (km) (Stockholm) | 74     | 122          | 95     | 97   |
| Mean trip length (km) (Other) | 113    | 67           | 79     | 86   |
| Mean Euro-pallets/day (Stockholm) | 837    | 499          | 127    | 1 463 |
| Mean Euro-pallets/day (Other) | 299    | 173          | 55     | 528  |
| Cost/Euro-pallet-km (Stockholm) | 0,66   | 0,57         | 0,88   | 0,70 |
| Cost/Euro-pallet-km (Other) | 0,35   | 0,59         | 0,76   | 0,57 |
| Annual cost (Stockholm)   | 14 116 367 | 13 709 525 | 3 495 026 | 31 320 917 |
| Annual cost (Other)       | 3 697 003 | 2 043 835  | 989 090 | 6 729 929 |
| Total annual cost         | 17 813 370 | 15 753 360 | 4 484 116 | 38 050 846 |
| CO₂ emissions (kg) / Euro-pallet-km (Stockholm) | 0,029 | 0,033       | 0,039  | 0,033 |
| CO₂ emissions (kg) / Euro-pallet-km (Other) | 0,027 | 0,031       | 0,038  | 0,032 |
| CO₂ emissions (tonne) (Stockholm) | 620    | 603         | 152    | 1 375 |
| CO₂ emissions (tonne) (Other) | 282    | 107          | 49      | 438  |
| Total CO₂ emissions (tonne) | 901    | 710          | 201    | 1 813 |

Table 8 presents the results for intermodal distribution from DC’s to shops using CESS terminals with CCT transshipment technology. A CESS-terminal site is located at the vicinity of each DC. The annual cost is calculated to 44,38 million SEK (16,7 % increase compared to unimodal road) and the annual CO₂ emissions to 613 tonne (66,2% reduction of CO₂ emissions compared to unimodal road).

Table 8. Results for intermodal distribution using CESS terminal type CCT.

| Goods Class       | Common | Refrigerated | Frozen | All  |
|-------------------|--------|--------------|--------|------|
| Total leg length (km) | 20 460 | 22 176       | 18 806 | 58 319 |
| LU/year (SB)       | 19 702 | 11 868       | 3 535  | 35 104 |
| Transshipment cost/LU | 106   |              |        |       |
| Cost/SB-km (Stockholm) |       | 16,18        |        |       |
| Cost/SB-km (Other)  |       | 14,41        | 2,20   |       |
| Annual cost        | 25 387 750 | 14 593 109 | 4 394 829 | 44 375 688 |
| CO₂ emissions (tonne) | 369   | 186          | 59     | 45   |

Table 9 shows the results for intermodal distribution if hypothetical, medium-sized conventional intermodal terminals where used at each CESS-terminal site. The significant increase in transshipment costs contributes to a high annual total cost of 67.14 million SEK (76.4 % increase compared to unimodal road) and the annual CO₂ emissions to 1198 tonne (33.9 % reduction compared to unimodal road).
Table 9. Results for intermodal distribution using conventional and Megaswing terminals.

| Conventional Intermodal Terminal | All | Road | Rail | Transfer | Sum |
|----------------------------------|-----|------|------|----------|-----|
| Total leg length (km)            | 13215| 57060|       | 61443    |     |
| LU/year (SB)                     |      |      |      | 35104    |     |
| Transshipment cost/LU            |      |      |      |          | 268 |
| Cost/SB-km (Stockholm)           | 16,18|      |      |          |     |
| Cost/SB-km (Other)               | 14,41|      | 2,20 |          |     |
| Annual cost                      | 11661438| 17830238| 37648217| 67139893|     |
| CO₂ emissions (tonne)            | 524  | 44   | 629  |          | 1198|

| Intermodal CESS Terminal Megaswing | All | Road | Rail | Transfer | Sum |
|-------------------------------------|-----|------|------|----------|-----|
| Total leg length (km)               | 13215| 57060|       | 61443    |     |
| LU/year (ST)                        |      |      |      | 19148    |     |
| Transshipment cost/LU               |      |      |      |          | 143 |
| Cost/ST-km (Stockholm)              | 24,27|      |      |          |     |
| Cost/ST-km (Other)                  | 28,83|      | 3,42 |          |     |
| Annual cost                         | 13789161| 15142362| 10974019| 39905543|     |
| CO₂ emissions (tonne)               | 620  | 91   | 65   |          | 776 |

A sensitivity analysis of the results is conducted, as illustrated by Fig. 8, considering the most significant variables; transshipment cost (i.e. terminal type), train loading space utilization, train length and diesel prices.

The analysis shows that the break-even point i.e. when the cost for unimodal road equals the cost for intermodal transportation, with the train loading factor set to 80%, regarding transshipment cost using is 61 SEK/SB when using CCT and 119 SEK/ST when using Megaswing. Note that the ST has a capacity of 33 EURO-pallets and the SB 18 EURO-pallets; hence STs require less transshipment. However using SB enables trucks with higher capacity, 2 SB’s and 36 EURO-pallets, whereas using ST enables a truck capacity of 1 ST and 33 EURO-pallets,
hence a higher cost for road haulage. A break-even point is found when increasing the loading space utilization to 92% for the reference train and using CESS terminals. However, if diesel fuel prices increase by 25% then CESS terminals with CCT attains a break-even point at 99% and if the train length would increase also to 501 meters i.e. 4 Megaswing wagons more, the intermodal cost is equal to the cost for unimodal road haulage at 63% train loading space utilization.

4. Conclusion

This study has provided a methodology for evaluating the feasibility of applying concepts and technologies within intermodal freight transport regarding cost and emissions. From the results of the case study one could conclude that a regional rail based intermodal transport system is on the threshold of feasibility in the studied region. The loading space utilization of the train and the transshipment cost are the most critical parameters. The latter restricting the competitiveness of intermodal services on short distances as it is not proportional to the distance transported but rather to the utilization rate of resources. Hence, the concept of cost-efficient small scale (CESS) terminals was introduced in this study. Regarding loading space utilization, it is necessary to consolidate other freight flows in the train in order to achieve high loading space utilization and a balanced flow along the route. The third parameter which is critical for the results are the fuel prices, where the sensitivity analysis of the results shows that if diesel prices would increase so would the feasibility of the intermodal option. The same is also valid for an increase in train length as long as the loading space utilization is maintained. The train length is however subject to infrastructural constraints e.g. the length on available sidings and the length of take-over and meeting stations on the rail network. In this study no claims are made at integrating mode choice with multimodal route optimization, where further work is recommended. However, the importance of CESS terminals has been illustrated as well as the most significant cost components for a shipper when evaluating different transport chains and mode choice.

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