Modelling and simulation of intermodal terminal networks

MINT Deliverable 3

Main authors:
Edith Schindlbacher
Hans Häuslmayer
Manfred Gronalt

Linking Europe with MIND - MINT

MINT Model and decision support system for evaluation of intermodal terminal networks
Basic Material and Documents
Deliverable 1 MINT State-of-the-art
Main authors: Fredrik Bärthel, Bo Östlund and Jonas Flodén.

Deliverable 2 Framework for strategic integrated terminal network evaluation
Main author: Jonas Flodén.

Deliverable 3 Modelling and simulation of intermodal terminal networks
Main authors: Edith Schindlbacher, Hans Häuslmayer, Manfred Gronalt.

Deliverable 4 – Deepening Network Analysis
Main authors: Martin Ruesch, Bo Östlund, Simone Jegerlehner.

Deliverable 5 – MINT Case studies
Main authors: Martin Ruesch, Fredrik Bärthel, Jonas Flodén and Thoraya Rojas-Navas.

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MINT Partners
TFK – Transport Research Institute Borlänge, Sweden (http://www.tfk.se) – Coordinator
h2 projekt.beratung KG, Vienna, Austria (http://www.h2pro.at)
Rapp Trans Ltd, Zürich, Switzerland (http://www.rapp.ch)
Royal Institute of Technology, Stockholm, Sweden, (http://www.infra.kth.se)
School of Business, Economics and Law, University of Gothenburg, Sweden (http://www.hgu.gu.se)
University of Natural Resources and Life Sciences Vienna, Austria (http://www.boku.ac.at)

Editor to the Report
Edith Schindlbacher, Universität für Bodenkultur Wien, edith.schindlbacher@boku.ac.at

Main contributors to the Report
Schindlbacher, Edith, Universität für Bodenkultur Wien, edith.schindlbacher@boku.ac.at
Häußlmayer, Hans, h2 projekt.beratung KG, hh@h2pro.at
Gronalt, Manfred, Universität für Bodenkultur Wien, manfred.gronalt@boku.ac.at
Flodén, Jonas, University of Gothenburg, jonas.floden@handels.gu.se
Bärthel, Fredrik, TFK, fredrik.barthel@tfk.se
Rojas-Navas, Thouraya, Universität für Bodenkultur Wien, thouraya.rojasnavas@gmail.com
Ruesch, Martin, Rapp Trans Ltd, martin.ruesch@rapp.ch
Hagelin, Fredrik, Royal Institute of Technology, Stockholm, fredrik.hagelin@abe.kth.se

Photos on front page: Fredrik Bärthel, School of Business, Economics and Law, Göteborg (all pictures except the upper right) and Christian Krüger and Johannes Gregor, BoxXpress (upper right).
Preface

This report forms a deliverable in the ERA NET ENT16 project MINT – model and decision support systems for evaluation of intermodal terminal networks performed by a consortium consisting of:

- TFK – Transport Research Institute Borlänge – Coordinator,
- h2 projekt.beratung KG, Vienna,
- Rapp Trans Ltd, Zürich,
- Royal Institute of Technology, Stockholm,
- School of Business, Economics and Law, University of Gothenburg and the
- University of Natural Resources and Life Sciences Vienna.

The MINT project is a joint strategic and tactical trans-national project researching models and decision support systems for evaluation of intermodal terminal networks. The outcome of the project will be a system of models and methods to investigate, analyse and evaluate terminal networks as well as single terminals. The system is based on a number of models on different system levels. By combining these models a more complete spectrum of effects can be analysed. This work has been complemented by an additional deepening network analysis which integrates non-modelling aspects in the analysis.

The aim of this report is to show the work undertaken in following the aim of the project to develop a new and improved strategic model and decision support system (framework) for evaluation of intermodal transport and terminal networks. First the scope of the already existing models EvaRail, HIT and SimConT was aligned with the various (sub)areas of the intermodal transport system and research questions for the MINT project were defined. In the next step, the different interaction possibilities of the models were evaluated. Thus a comparison was made which output data of one model can be input data for another model. These evaluations showed the need for complementing and filling gaps of the focus and scopes of the existing models. For this purpose, one model for calculating total costs of intermodal terminal operation (TermCost), and one conceptual model which incorporates terminal operation and link operation (SimNet), were developed.

Hereby, the coordinator, the authors and all project partners would like to address their gratitude to the funding organisations and all industrial representatives who helped us to make this report possible.

Vienna, 15th of April

Prof. Manfred Gronalt

WP leader
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MINT Model and decision support system for evaluation of intermodal terminal networks
1 Introduction

Following the aim of the project to develop a new and improved strategic model and decision support system (framework) for evaluation of intermodal transport and terminal networks, first the scope of the already existing models EvaRail, HIT and SimConT was aligned with the various (sub)areas of the intermodal transport system and research questions for the MINT project were defined. In the next step, the different interaction possibilities of the models were evaluated. Thus a comparison was made which output data of one model can be input data for another model.

These evaluations showed the need for complementing and filling gaps of the focus and scopes of the existing models. For this purpose, one model for calculating total costs of intermodal terminal operation (TermCost), and one conceptual model, which incorporates terminal operation and link operation (SimNet), were developed.

2 Scope of existing MINT models

2.1 The SimConT model

The goal of SimConT is the minimisation of the risk of bad investments and sunk costs when planning and (re)building the infrastructure and capacity of hinterland rail-rail or rail-road container terminals. The SimConT Simulation environment is based on a modular concept which supports a potential user with on-time available and reliable results and reports for efficient planning of capacity and infrastructure for inbound and outbound flows of a rail-rail or rail-road container terminal (HCT). The integration of inbound and outbound flows, which enables the evaluation of infrastructure requirements for train, trucks and vessels is a further essential facet of the model.

The purpose of the model is to implement a simulation based methodology, which can be used while designing new HCTs or extending existing ones and which enables the comparison of different material handling technologies, shift patterns, resource scheduling, operational philosophies and infrastructure capacities. Thus SimConT considers the specific nature of HCTs and their strategic needs:

- The operation of a HCT differs from the operation of a maritime container terminal. This is due to its dimension, throughput, degree of automation, container properties and transport modes involved. Process modelling has therefore to be tailored to HCT operations.

- The model underlying the simulation has to integrate all HCT operations in order to provide valuable support to stakeholders of intermodal transports involved.

- The simulation has to be based on an open configuration which means that any user-defined terminal configuration can be analysed. This is particularly of interest when analysing different scenarios of HCT configuration.
Due to the lack of detailed information about the import and export flows, the simulation has to include a data generation methodology which supplies it with adequate data.

Figure 1 shows the implemented modules. The configurator is the interface used to define the terminal to analyse and hence is used to determine all relevant parameters. These can be separated into two groups. The first set of parameters defines the layout and the infrastructure of the terminal and contains for instance information about the handling equipment, the yard blocks or the train interchange. In the second set parameters describing the terminal operation (arrival rate for trains and containers respectively, transshipment modes, distribution of container attributes, etc.) are defined.

The terminal data is then passed automatically to the simulation which generates based on a few user-defined parameters detailed lists of incoming and outgoing transport modes and containers. Further, the simulation evaluates the performance of the terminal by simulating terminal operations given a period and configuration. Finally, the results of the simulation are passed to a report generator where they are aggregated in a clear and comprehensive overview.

The simulation of container terminals is an approach for efficient resource-planning and effective capacity analysis of HCTs, which is based on modern object oriented simulation techniques. By means of simulation different material handling technologies, shift patterns, resource scheduling and infrastructure capacity are analysed. Further, optimisation is used in order to find optimal configuration parameters. The model was developed in cooperation with an Austrian CT-operating company and an Austrian rail infrastructure operator, ensuring the integration of practice-based data and know-how. SimConT is a framework suited to the needs of HCTs and flexible and quick enough to be applied while planning or analysing HCTs.

2.2 The Heuristic Intermodal Transport Model (HIT)

The Heuristic Intermodal Transport model is a user-friendly model that can be run on an ordinary desktop PC. The model takes its starting point in a competitive situation between traditional all-road transport and intermodal transport, where the theoretical potential of intermodal transport is determined by how well it performs in comparison with only road transport. The model was developed as a part of a doctoral thesis (Floden, 2007). The Heuristics Intermodal Transport model takes its starting point in a competitive situation...
between traditional all-road transport and intermodal transport, where the potential of intermodal transport is assumed to be determined by how well it performs in comparison with all-road transport. The model can also be used as a calculation tool to calculate the costs and environmental effects of a given transport system. The optimisation and calculation functions can also be mixed, where some parts of the transport system design are given by the input data and the remaining parts are optimised.

The model determines the modal split between traditional all-road transport and intermodal transport. The model will also select which lorries and load unit to use, and determine the train time table, train length etc. It is also possible to run the model as a cost calculation tool, where the modal split or transport system is, completely or partly, externally given. The modal choice assumes that the transport mode giving the lowest transport cost is selected. However, intermodal transport must offer, at least, the same delivery times as all-road transport. Time windows and time gaps, in which the delivery times are considered equal, are used to compare times between the modes. The model can perform the calculations according to either societal economic costs or business economic cost. The environmental effects of the transport system are also calculated. The model can also be set to either perform the modal split calculations for each train route or jointly for the entire system. The model can also search for either the system that sends the most goods by intermodal transport without increasing the total system cost compared to a system with only all-road transport system, or to search for the lowest cost system.

It is possible to impose restriction on the types of lorries considered. Restrictions regarding the lorries like delivery times, departure times, etc. can be set individually for each transport link and time period. The length of a time period can further be set individually for each transport link. The modal split can also be controlled by a number of control parameters. A random disturbance can be added in the modal choice, where not all demand assigned for intermodal transport is actually sent by intermodal transport. The cost calculations can also be controlled to force intermodal transport to have a certain percentage higher or lower cost than all-road transport in order to be selected. Further control over the model can be achieved by manipulating of the input data, e.g. testing the effects of different cost valuations. A user interface in Microsoft Access is used to input and output data from the model.

Output from the model is the modal choice for a specific shipment occurrence with departure time, arrival time, train departure used, position on train, type of lorry used, number of lorries used, business economic cost, social economic cost, environmental impact (CO₂, CO, SO₂, NOₓ, PM, HC, energy consumption and a monetary estimation). If all-road transport is selected, the model also shows the reason why intermodal transport could not be selected (e.g. violated time constraint, economic constraint, etc.). The suggested train system is output with time tables, train lengths, business economic costs, social economic costs and environmental impact.

A typical case analysed in the model could be the market potential for intermodal transport in a region or a country. The model then decides the modal split between all-road and intermodal transport, which load units to use and which train table to use. This can be analysed to show, for example, the maximum pre and post haulage distance that can be supported, environmental emission, why some locations cannot use intermodal transport etc. The model is flexible and can be used to test different suggested system layouts, conduct sensitivity analyses, and to test the effect of the intermodal transport system on specific factors, e.g.
changed taxes, regulations or infrastructure investments. The model is useful for both large scale national transport systems and small individual transport systems. The geographical level of detail is decided by the user in the input data and could be anything from very detailed addresses to regions, all depending on the availability of input data and question the model should answer. Similarly, the model can be used to model the transport system for a single day or to run long term systems covering several months or even years. This is controlled by the input data which can be freely varied over time, i.e. the input for day one must not necessarily be the same as the input for day two.

The model starts by assuming that all demand for transport is sent by all-road transport, i.e. by lorries only from origin to destination and calculates the cost of transport by all-road. The demand for transport is input as an amount of freight to be sent between two locations at a given time. The model then calculates, for each input demand for transport, the potential cost saving if this demand is sent by intermodal transport. When calculating the transport costs, the model also decides which (of the allowed) type of lorries that gives the lowest transport cost. The demand for transport is then sorted according to the potential cost saving, starting with the demand with the highest potential cost saving. As the intermodal system has not been designed in detail yet, these cost saving will be based on average transport costs in the intermodal transport system. The cost saving might also be negative. Note that these cost saving are only used to sort the demand, and not to calculate the exact transport cost. The model also calculates which of the train departures the demand can use and still fulfil the time constraints, i.e. deliver no later than all-road transport, given time windows and other user constraint settings.

The model then starts with the highest ranked demand and check if there is available capacity on one of the allowed train departures for the demand. If yes, then the demand is assigned to intermodal transport and that train. If no, the model checks if it is possible to add more capacity to the train departure. This is done by checking if the potential cost saving is greater than the cost to add more rail capacity. The model considers that it is more expensive to start up at new rail service than to add a rail wagon to an existing train. The model also considers that any new rail capacity must be financed for the entire train loop, i.e. if a new rail wagon is added to a train that is supposed to run twice a day, then the cost of that rail wagon must be paid during the entire time the train is running. This means that the cost to add more rail capacity might require the combined cost saving of several load units on several departures on the train to be able to “pay” for the new capacity. The HIT model considers this and that each load unit also often have several train departures to choose among. No new rail capacity is added until the cost saving is higher than the cost (unless any user setting has been made to allow load units with a negative cost saving to be sent by intermodal transport). The model continues to try to send the demand by intermodal transport until all demand has been tried. The demand that has then not been sent by intermodal transport is sent by all-road transport.

During the heuristics, the model also considers any special user settings made.

2.3 The EvaRail model

EvaRail is an activity-based rail freight costing model developed at the Royal Institute of Technology Stockholm (KTH), programmed in VBA (Visual Basic for Applications). The model depicts the rail freight system in form of three main levels, the infrastructure, the train services and the freight flows, which are interconnected to each other: The rail network is
depicted by nodes and links, where the nodes represent stations, terminals, etc., while the links represent the railway lines in between.

The next level is the train service level, containing detailed information about the train services offered on the network, e.g. timetables, operating days, train length and weight limits, etc. The infrastructure and train service levels together represent the supply side in rail freight. On the third level the freight flows are specified, i.e. this level represents the demand side. For the freight flows the information comprises the commodity, origin and destination, quantity per year and per shipping occasion, desired departure times and time windows for loading and unloading at the consigners and consignee's location.

A transport cost calculation can be carried out for one single freight flow – or a transport system with multiple flows. The program allows adding freight flows to a transport system subsequently. In this case all freight flows – even those, which have been specified earlier (and already been calculated once) – will be recalculated, since there costs may be (and most likely are) influenced by the added flows. The activities’ costs module is virtually a collection of different modules each for a specific activity, e.g. shunting, marshalling, transloading, etc.

### 2.4 Conclusion on the MINT model portfolio

Even though the existing models SimConT, HIT and EvaRail cover almost all functional areas of the intermodal transport system, their evaluation focus (modal split, costs, equipment utilisation etc.) and the different granularity in the analysis require additional developments in order to apply them collectively and to work on a more complex network analysis. Both the HIT and EvaRail models are limited to the depiction of network links and the SimConT model focuses on the internal operations of terminals. As a consequence, interactions and dynamic interrelations inside a transport network (consisting of several links and nodes) cannot be evaluated with the existing models alone. The limitations of the existing models for performing network analysis can be summarized as follows:

- **SimConT**: model scope of detailed analysis of terminals; does not include shunting.
- **HIT**: includes local road transport (haulier and forwarder) and railway for modal split calculation based on cost comparison; does not include terminal parameters in the calculation, cannot handle shunting or train-to-train transshipment, no dynamic analysis over time possible.
- **EvaRail**: routes transport demand through a given railway network (infrastructure and train products), cost calculation for the flows, includes shunting, no terminal parameters are considered.

As the aim of the project was to define a framework that allows for a comprehensive network analysis, it was decided in the project to fill this gap by designing the concept for a new model named SimNet. Further, to complete the possibility of network cost analysis, the TermCost model was developed to cover the cost calculation for terminals. The scope of these new models can be summarized as follows:
SimNet: covers terminal network with terminals and road and rail connections at a more aggregate view than SimConT and EvaRail. Shunting is not considered.

TermCost: calculates terminal costs for infrastructure and operation.

In the following chapter a description of the two models is provided.

### 3 The TermCost model

Intermodal freight transport is characterised by a subsequent use of different transport modes. These modes are all characterised by differences in frequency, capacity and time, and hence the aim of the bridging terminal is to provide fundamentals for creation of a “seamless transport chain” by a competitive combination of the terminals primary services, i.e. transshipment and storage (Hulten, 1997). But, terminal activities like handling and storage are both time consuming and cost driving. Hence it is often argued that the terminal function is limiting the competitiveness of intermodal transport chains due to high costs for transshipments (e.g. Nelldal, 2010). The literature study conducted in the project (see MINT Deliverable 1) indicates that 10-45 %, with an average of 20 %, of the total costs in an intermodal transport chain consist of costs for terminal handling. The share is volume-distance dependent, i.e. on short distances and small volumes the proportion is high and vice versa.

Primarily, in order to evaluate the costs for transshipment (terminal handling) the functional unit terminal needs to be defined. In Figure 2 the definition of a terminal used in the project MINT is depicted. The functional unit includes the core activities as storage and handling of unit loads (activities within the purple encirclement), but also the supporting activities as shunting of trains/wagon groups between the handling area and the arrival/departure tracks, maintenance area for wagons and storage of empty wagons (activities carried out in the green rhombuses). To each core and each support activity, corresponding resource needs could be allocated for a certain time period and hence the costs for terminal handling could be calculated. The wider scope of the functional unit terminal, including the interface between the terminal and the arrival/departure yard aims to point out that the location of the terminal and the capacity of the access tracks do affect the handling activities.

The TermCost model has been developed as a standalone model and the aim is to be able to calculate the transshipment costs for a certain time period based on a given input and resource configuration, given a maximum utilisation.

The delimitation of TermCost as a standalone model regards operational parameters as utilisation of handling equipment, effects of disruptions and break downs of handling equipment, different storage strategies, effects of poor time reliability of arriving truck/trains etc. Most of these input parameters might be delivered from the simulation model SimConT. Hence, by exchanging model output data between the SimConT and TermCost model, (see also chapter 5), a detailed analysis of the transshipment costs for a specific terminal might be calculated.
The TermCost model consists of three components:

- Attribute module: predefined MS Access database for all possible terminal components, including the respective cost factors.

- Graphics module: graphical user interface (between the user and the attribute model) for the handling and illustration of the model input and output data (see Figure 3). The interface is based on Excel VBA.

- Terminal data: the terminal data is dependent on the other two models and consists of basic components and terminal set. The basic components are always predefined and the terminal sets are either predefined, user defined or a combination of them. The purpose of the terminal data module is to rebuild the actual terminal-scenario.

Used as a standalone model or in combination with SimConT, different terminal alternatives can be evaluated. By changing the objects and attributes, different alternative scenarios might be evaluated relatively to a base scenario.

The results of such an analysis might be, e.g. (1) the total costs for a certain time period, (2) the costs per handled TEU for a given time period and (3) costs per input attribute type for a given time period. The input attribute types in the basic configuration are: (1) investment costs, (2) maintenance costs and (3) operational costs.
4 Terminal Network Simulation Model (SimNet)

As the existing MINT-models focus on the three nearly independent areas of modal split calculation, link operation and terminal operation, the aim of this task was to develop a concept in order to expand the MINT-model scope, in adding the possibility to conduct network analyses by integrating terminal and link concerns.

The SimNet model is conceived as a multi agent simulation tool which intends to compare the performance of intermodal networks, given different network settings (physical network topology or functional network structure) and different operational concepts (train concepts, truck arrivals). Further, the model aims to coordinate the flow of load units in the network in case of network element overload.

The network performance can be evaluated in terms of the throughput time of the load units, overall transportation costs (given cost factors for the usage of the different network nodes and links) or utilisation measures of the individual network elements.

The intermodal network is rebuilt in terms of container terminals, their connections via rail and the road connections to the corresponding catchment areas. Shunting and marshalling facilities and functionalities are not considered. Conceptually, the simulation model consists of three different levels. In the first level the physical network is defined by rebuilding the physical components (intermodal container terminals, roads, railway links and waterway links) of the analysed network. The second level implements the service network, which specifies the operational parameters of the physical elements, e.g. the terminals opening hours or the offered train connections and schedules between them. The criteria defining the flow of the load units in the network are specified in the third modelling step.
4.1 Physical network

A network is constituted through nodes and links. In this case the network nodes are either container terminals or so called “junction nodes” which have no other functionality than connecting two or more rail network links. The terminal nodes represent the single container terminals performing lifting and storage functionality according to their individual characteristics. Each terminal node has a corresponding catchment area (CA), where load units enter or leave the network by truck. This area is specified by the average transport distance and average transport time to the terminal. Further, each terminal node has assigned at least one residual area (RA) which aggregately depicts other connected container terminals which are external to the investigated network and therefore not explicitly modelled. They are connected through railway links, and also function as sources and sinks of load units for the evaluated network (see Figure 4).

The links of the network are the connections between the terminal nodes and the sources and sinks of load units by road and rail. By now, waterways are not considered in the model. Topologically, network links are defined through the mode they represent, their direction and distance.

![Figure 4: Physical network](image)

4.2 Service network

The service network provides the network topology with parameters defining the transport service the network “offers”. There are several roles a terminal can fulfil in the network, marked by different characteristics like transshipment and storage services, capacities and priority rules, or also the opening hours for truck and train acceptance and hours of internal operation.

Furthermore, the transportation potential within the network is determined, respectively limited, by the capacity and utilisation specifications of road and rail links. Here the travel time, which is partly dependent on the utilisation and status of every single link, is one important factor influencing the load unit throughput.
4.3 Load unit flows

The transport demand has to be input data in terms of load units in time with specification of origin and destination. As already mentioned, the locations of the network inflow are given through the catchment areas of the terminal nodes and the residual areas. The model defines the network path for each load unit according to the existing physical network. The actual throughput time is a result of the service network and according decisions made in the terminal nodes. On the one hand, train schedules and truck arrivals induce the transshipment requests to be served, and on the other hand, present other load units to be transhipped and available lifting capacities determine direct moves or storage times. The combination of these factors determines the proceeding of every load unit in the terminal and the network.

4.4 Model components and agent structure

- The simulation model contains the terminal process modules and

- several different agent modelling components like: terminal agents, link agent, catchment area agents, residual area agents, environment agent, administrator agent. The agent based modelling is used to cope with negotiations between terminal actors.

![Intermodal network agents](image)

Figure 5: Intermodal network agents

The representation of the terminal nodes is realized through two different elements. First, for each node a module processing the transshipment and storage functionality of the specific container terminal evaluates, if the planned tasks can be completed. Based on this outcome, the corresponding terminal agent can decide whether coordination with the other network components becomes necessary, or not. Steps to be taken include providing information to the others about e.g. delays in service or problems in accepting load units to tranship, or to
request the rerouting of load units. The announcement of information addresses to all network agents except the environment agent and the administrator. Rerouting requests only affect to the terminal nodes, thus the terminal agents.

One link agent is responsible for the management of all network links. This means that it routes the trains and trucks through the network and checks for feasibility in case of rerouting requirements. The agents of every catchment area and the different residual areas can’t be involved in a rerouting process since their only function is to provide for network inflow and outflow of the load units, hence they do not need transshipment functionality.

The first job of the administrator is to structure the simulation run. Secondly, it is applied to avoid problems due to concurrency issues by controlling and leading the agents’ communication. Figure 5 schematically shows the agent-representation of an intermodal network.

5 Data exchange between existing and new models

The next step in the project was to define how the “old” and the new models could be integrated, respectively interact with each other. To figure out the models’ similarities and dissimilarities in depicting (parts of) the intermodal system, a pair wise comparison of the models was done in order to explore suitable model interfaces. The different items for the depiction of an intermodal network and how they are implemented by the models SimConT, HIT, SimNet and TermCost are shown in Table 1 - Table 3. In Table 1 the models are compared with respect to the System’s Entities while in Table 2 resources and the terminal network is analysed. Finally, modal split and demand (shipment) are compared with the MINT models.

The evaluation of comprehensive questions in functional and contextual regard, exceeding the individual model scope, can be carried out by interactions of the different models. The difficulties in the cooperation of the models are given through their already mentioned varying application focus and input and output data granularity. Thus, it is of special relevance which data transformations are required to enable model interaction and data exchange. For different research questions different constellations of model combination and sequence will be adequate to be solved. Figure 6 shows the generally possible data flow between the models and their application sequence. If one of the models is not used potential missing input data will be substituted through external sources, or may already be given through a model earlier in the chain. A rough overview of which output data of one model can be input data for another model, thus the pairwise data exchange possibilities, is shown in Table 4.
### Table 1: Intermodal network items - entities

<table>
<thead>
<tr>
<th>Entity</th>
<th>SimConT</th>
<th>HIT</th>
<th>SimNet</th>
<th>TermCost</th>
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<tbody>
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<td><strong>Train</strong></td>
<td> </td>
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<tr>
<td>Arrival/departure time</td>
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<td>Number of containers delivered or to pick up</td>
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<td>Type (shuttle, block, single wagon)</td>
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<td>Cycle time (total and decomposed)</td>
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<td>Departure delay</td>
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</tr>
<tr>
<td>Cost per train type (business and/or social economics) cost to insert a new rail car on the train and cost to use the rail car; the costs are also divided into time dependent and distance dependent costs</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Available train length for loading (train capacity defined as no of meters)</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Average speed</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Environmental effect per km (CO2, CO, NOx, PM, HC, energy consumption and a monetary estimation) in the same three levels as for the costs</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Length of train</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Number of trains</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Train type</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Train route</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Schedule (departure times)</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Length of the train</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
<tr>
<td>Costs per train</td>
<td> </td>
<td> </td>
<td> </td>
<td></td>
</tr>
</tbody>
</table>

| **Truck** | &nbsp; | &nbsp; | &nbsp; | &nbsp; |
| Arrival/departure time | &nbsp; | &nbsp; | &nbsp; | |
| Priority | &nbsp; | &nbsp; | &nbsp; | |
| Cycle time (total and decomposed) | &nbsp; | &nbsp; | &nbsp; | |
| Cost per truck type (business and/or social economics) divided in time dependent and distance dependent costs if the truck type is for all road transport or intermodal transport | &nbsp; | &nbsp; | &nbsp; | |
| Loading capacity | &nbsp; | &nbsp; | &nbsp; | |
| Average speed | &nbsp; | &nbsp; | &nbsp; | |
| Number and types of ITUs carried on each truck type (if intermodal) | &nbsp; | &nbsp; | &nbsp; | |
| Length required on the train for the ITUs (if intermodal) | &nbsp; | &nbsp; | &nbsp; | |
| Environmental effect per km (CO2, CO, NOx, PM, HC, energy consumption and a monetary estimation) | &nbsp; | &nbsp; | &nbsp; | |
| Length distribution for trucks | &nbsp; | &nbsp; | &nbsp; | |
| Costs per truck usage | &nbsp; | &nbsp; | &nbsp; | |
| Number of trucks handled per terminal (import, export, full or empty container) | &nbsp; | &nbsp; | &nbsp; | |
| Truck space (length, # arising) | &nbsp; | &nbsp; | &nbsp; | |

| **Load unit** | &nbsp; | &nbsp; | &nbsp; | &nbsp; |
| Type (container, swap body, trailer) | &nbsp; | &nbsp; | &nbsp; | |
| Length in feet | &nbsp; | &nbsp; | &nbsp; | |
| Weight (a must when stacker defined as equipment) | &nbsp; | &nbsp; | &nbsp; | |
| Stackability | &nbsp; | &nbsp; | &nbsp; | |
| Storage time | &nbsp; | &nbsp; | &nbsp; | |
| Belonging to empty container service | &nbsp; | &nbsp; | &nbsp; | |
| Arrival modus (rail, road) | &nbsp; | &nbsp; | &nbsp; | |
| Departure modus (train, road) | &nbsp; | &nbsp; | &nbsp; | |
| Cycle time (total and decomposed) | &nbsp; | &nbsp; | &nbsp; | |
| Included in truck type | &nbsp; | &nbsp; | &nbsp; | |

The table continues with additional data columns for each entity, including cost and emissions per truck, aggregate costs, and other relevant metrics.
Table 2: Intermodal network items – resources and network

<table>
<thead>
<tr>
<th>Items</th>
<th>SimConT</th>
<th>HIT</th>
<th>SimNetT</th>
<th>TermCost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resources</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- type (brake, handling)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- technical specification (lifting speed, horizontal speed, etc.)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- assigned to other resources (storage areas and sidetracks)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- allocation to other resources (rail tracks, equipment)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- type (crane, stacker)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- technical specification (hoisting speed, horizontal speed, etc.)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- assignment to other resources (storage areas and sidetracks)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- allocation to other resources (rail tracks, equipment)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td><strong>Storage area</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- type (brake, stacker, empty container, load, etc.)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- dimension (number rows, tiers, bays, etc.)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- assignment to other resources (sidetracks, equipment)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- allocation to other resources (sidetracks, equipment)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- state statistics (failure, blocked)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- performance (total number stored)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td><strong>Yard tracks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- assigned to other resources (storage areas and sidetracks)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- allocation to other resources (sidetracks, equipment)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- allocation to other resources (sidetracks, equipment)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- state statistics (failure, blocked)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- performance (total number served)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td><strong>Terminal operating area</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- type (crane, stacker, empty container, load, etc.)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- dimension (number rows, tiers, bays, etc.)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- assignment to other resources (sidetracks, equipment)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- allocation to other resources (sidetracks, equipment)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- state statistics (failure, blocked)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>- performance (total number stored)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
</tbody>
</table>

**Network**

<table>
<thead>
<tr>
<th>Items</th>
<th>SimConT</th>
<th>HIT</th>
<th>SimNetT</th>
<th>TermCost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal / NW-nodes / sources / sinks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- variable cost per handled truck type (CO2, CO, SO2, NOx, PM, HC, energy consumption and a monetary estimation)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- fixed cost for the terminal (in the input, the fixed costs are distributed between the train routes trafficing the terminal)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- terminal area (which terminal a demand location belongs to)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- types of trucks that can be handled at the terminal</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- environmental emissions from handling (CO2, CO, SO2, NOx, PM, HC, energy consumption and a monetary estimation)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td><strong>Road / service network</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- distances between origins and destinations and to/from all terminals</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- length (time, distance)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td><strong>Rail / service network</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- distance between all terminals</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- number of trains allowed and time periods they are allowed in</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- cost factor per transshipment / cost factor for terminal usage</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- cost factor per handled truck type (CO2, CO, SO2, NOx, PM, HC, energy consumption and a monetary estimation)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- fixed cost for the terminal (in the input, the fixed costs are distributed between the train routes trafficing the terminal)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- terminal area (which terminal a demand location belongs to)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- types of trucks that can be handled at the terminal</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>- environmental emissions from handling (CO2, CO, SO2, NOx, PM, HC, energy consumption and a monetary estimation)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
</tbody>
</table>
Table 3: Intermodal network items – modal split and demand

<table>
<thead>
<tr>
<th>Item</th>
<th>SimConT</th>
<th>MIT</th>
<th>SimNet</th>
<th>TermCost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modal split</td>
<td>n/a</td>
<td>n/a must, (+) optional</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Demand</td>
<td>n/a</td>
<td>n/a must, (+) optional</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Figure 6: Model data flow and sequence
**Table 4: Model data exchange**

<table>
<thead>
<tr>
<th>Model</th>
<th>Data exchange description</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>SimConT</td>
<td>Input:</td>
<td>Variables</td>
</tr>
<tr>
<td></td>
<td>&lt;- HIT: total demand</td>
<td>Input: demand in load unit information</td>
</tr>
<tr>
<td></td>
<td>&lt;- EvaRail: demand on rail side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- TermCost: terminal cost per year (investment and maintenance)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output: can be used to define in detail some terminal data used in the other models</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; EvaRail, HIT, SimNet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; TermCost: load unit costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>demand in load unit information</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output: dwell time of load unit or train in the terminal, average handling time per</td>
<td></td>
</tr>
<tr>
<td></td>
<td>terminal equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Term resource utilization</td>
<td></td>
</tr>
<tr>
<td>HIT</td>
<td>Input:</td>
<td>Variables</td>
</tr>
<tr>
<td></td>
<td>&lt;- EvaRail: train costs (including shunting cost)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- SimConT: terminal times and feasibility check</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- SimNet: feasibility check for flows (trains)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- TermCost: terminal costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; EvaRail: total flow per train</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; SimConT: arrival times for train and truck</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; SimNet: train information, train costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; TermCost: demand flows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>rail cost data in the three cost levels used in HIT, handling times per load unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>type and terminal, terminal cost per load</td>
<td></td>
</tr>
<tr>
<td></td>
<td>unit type and terminal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>train time table, train length, modal choice for the demand and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>assignment to trains (if intermodal), arrival and departure times for trucks (can be</td>
<td></td>
</tr>
<tr>
<td></td>
<td>translated to time windows for the arrival and departure)</td>
<td></td>
</tr>
<tr>
<td>SimNet</td>
<td>Input:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- TermCost: costs per load unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- HIT: train costs, train information</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- EvaRail: flow information and costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; flow verification for HIT and EvaRail</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; flow change for SimConT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>transport demand in load unit information, cost per item per terminal, cost per item</td>
<td></td>
</tr>
<tr>
<td></td>
<td>per link, train products and schedule</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(possibly new) network load (items per terminal, items per link), rough terminal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>resource utilization, train schedule feasibility, link utilization</td>
<td></td>
</tr>
<tr>
<td>EvaRail</td>
<td>Input:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- SimConT: terminal utilization and dwell times for load units, trains and trucks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- HIT: total demand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- SimNet: flow verification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- TermCost: load unit costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; SimNet: flow information and link costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; HIT: train costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; TermCost: load unit shunting cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>demand quantities in units (m³, t, load units), train products and schedule</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>costs of transport (including shunting), costs of empty wagon allocation</td>
<td></td>
</tr>
<tr>
<td>TermCost</td>
<td>Input:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- HIT: Nr of handled load units per year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- SimConT: utilization information (h/year)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;- SimNet: rough utilization information (h/year)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; SimNet: cost per load unit at terminal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; HIT: cost per load unit at terminal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-&gt; EvaRail: cost per load unit at terminal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input: equipment utilization, nr of load units</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>annual terminal costs, costs per load unit at terminal</td>
<td></td>
</tr>
</tbody>
</table>
6 Implementation of needed model extensions

One of the aims of the MINT project was to highlight the conclusions from the TERMINET project (Trip and Kreutzberger, 2002), i.e. to put attention on the line networks and line terminals. The intermodal bundling concept (network structure or operational philosophy) are important for small and dispersed freight flows or as regional feeder systems for the national/international trunk lines. However, the importance of line networks has been underestimated, and little has become known about their costs and performance. Hence, to cope with this special form of intermodal networks, the MINT model-portfolio was adapted by developing an extension of the HIT model and implementing a SimConT mini applet for line train terminals. These extensions, including adapted measures for internal and external performance, were also a prerequisite for Case Study 1.

6.1 Description of the line terminal system

The concept of line terminal networks and the supporting intermodal operational philosophy/bundling concept - for an overview of the intermodal bundling concepts (network structures, operational philosophy) see MINT Deliverable 1 - has been promoted by researchers for the last 20 years, but transport systems based on the concept have only been implemented as customer pilots in Sweden (SJ Light combi) in 1998 and in Switzerland (InterRegioCargo) in 2009. The reasons for poor market entry are several, but in general terms neither the infrastructure authorities nor the rail operators have knowledge or resources for a large scale implementation of such a network.

The concept is called Liner train by Kracke and Siegmann (1992), Line train/Line network by Trip and Kreuzberger (2002) and Static Routes by Woxenius (2006). Hence, the concepts are named according to the (1) system, (2) network or (3) the tactical scheduling in the network. However, referring to the bundling concept as Static Routes does not reflect the opportunities of tactical and operational rescheduling of trains, i.e. as a function of variable spatial demand.

The fundamental in this concept is to (1) increase accessibility to intermodal transport, while (2) maintaining the competitive average transport velocity in a transport from Begin-terminal (B-terminal) to End-terminal (E-terminal) as well as (3) utilising the high O/D-related economies-of-scale in the rail system. Hence, for the system designer the engineering challenge is to develop and utilise both, efficient train bundling concepts (e.g. train-train bundling) as well as efficient low cost terminals. High market coverage, i.e. accessibility, increases the probability of short distances between the terminal and the consignor/consignee and thereby cost-quality-ratio of the pre and post haulage activities.

In general terms a line terminal network is a network of intermodal terminals interconnected by frequent and scheduled intermodal line train services. Each line train service is routed from a B-terminal to an E-terminal while making short stops at intermediate terminals to enable transshipment of load units. This is in general terms explained in Figure 7. At dedicated hubs a number of line trains are interconnected and hence a network of interconnected line trains is created. This permits large market coverage on the prerequisites of short terminal time windows (passive node time should be kept at minimum) and a high cost-quality-ratio. This
allows transport volumes on short and medium distances to be bundled with freight flows on long distances permitting higher frequency on the trunk lines.

Hence, a line terminal is an intermediate road-rail terminal located along a main railway line (trunk line) between two BE-terminals. The line terminals are designed with an infrastructure interface to allow “passing” rail services to make stops for exchange of intermodal loading units within a limited time window without the need for shunting of wagons or to exchange locomotive to access the transshipment area. The logistical effects of the design of the terminals and terminal interfaces are explained by Figure 8 showing the lead time (separated into active and passive lead time for a line terminal system) based on dedicated or conventional intermodal system design. The abbreviation IFT indicates a conventional system and the numbers the maximum velocity of the trains. The light-combi system relates to SJ Light-combi design.

In Figure 8 the lead time for intermodal transport, including one intermediate stop, on a 450 km long transport chain between two BE-terminals is presented. The first three columns represent three conventional system designs, making one intermediate stop based on a maximum transport velocity of 100, 120 and 160 km/h. In the fourth column the line train concept, SJ Light-combi (max velocity 100 km/h), indicates the benefits of such a design. The graph shows that in an adapted line train system only 10 % of the lead time is classified as passive node time (the passive node time includes time for shunting to/from terminals, switching engines, break tests, and security tests; the active terminal handling time and the main line operation is included in the active lead time) compared to 40-45 % for a conventional system. Hence, the lead time for the dedicated system is significantly shorter, even if the maximum speed is raised to 160 km/h in the conventional transport system.

From a technical point of view a line terminal has to be designed to allow both, time and cost efficient transshipment within a limited time window. To facilitate both time and cost
efficient handling the terminal infrastructure, the interfaces between the main line and terminal and handling equipment have to be thoroughly designed.

In general terms the terminal has to be able to handle 8-10 swap bodies class C during a time window of 20 minutes provided a handling cost less than 10 Euro. Hence, the main question for the system designer is how to design a terminal, including handling resources, that, especially during an implementation phase, has to be dimensioned for high performance but only for a very short time window. The second question is how to handle all non-standardized load units that are circulating in the intermodal system, i.e. the technical openness of the terminal system (Sjöstedt et al., 1994).

To conclude, a line terminal system could:

- Substantially increase the geographical and economical accessibility to intermodal freight transport services.
- Decrease pre- and post-haulage transport distances and hence its costs.
- Increase the opportunities for bundling of freight flows on short, medium and long distances and hence increase the opportunities to increase frequency along the main trunk lines.
- Increase the potential for intermodal transports on the market for small and dispersed freight flows (less-than-train flows).

But, competitiveness of a line terminal network calls for increased efficiency and effectiveness in the spatial and temporal consolidation of freight flows without negatively influencing economies of scale and economies of density.

**Line terminal system SJ Light combi**

During the last decades a large number of line train systems or functions/resources supporting the line train systems have been developed and marketed by inventors, entrepreneurs, rail operators and by the academia. The majority of these systems are described in Bärthel (2011) and Gronalt et al. (2010). The analysis reveals that all these RD&D projects primarily focus on the terminal function, i.e. development or redevelopment of the handling technology (ibid.). Examples of such projects are CCT Plus, Fast’R Cargo, Flexible Intermodal Horizontal Transshipment Techniques (FL.I.H.T.T), MetroCargo, Rolling Transport System (IDOMA), Neuweiler Tuchschmid Horizontal Transshipment (Neths), Cargo Beamer, CargoSpeed, Megawing, Flexiwagon and Modalohr. Few technologies have been developed as transport systems. However, it is a fact that the only systems implemented are those systems that are either developed from a system-approach and based on standard equipment/resources, or technologies adapted to the wagon load paradigm (ibid.). The systems implemented as customer pilots are the SJ Light-combi system in Sweden and the InterRegio Cargo system in Switzerland.

In the MINT project the SJ Light-combi developed by SJ Freight during 1995-1998 and implemented in the customer pilot “the Dalecarlian Girl” in 1998 was chosen to be modeled in Case Study 1. For detailed descriptions see Bärthel and Woxenius (2003) and Bärthel (2011). Hence, from here on the concept will be described as SJ Light-combi in order to not to
mix up this adapted version of a line terminal system with the general concept. The name Light-combi refers to the restricted technical openness, i.e. limited to swap bodies less than eight meters.

The SJ Light-combi system is based upon a fixed formation train sets operating along a BE-terminal route, while making short stops of 15-30 minutes at the low cost terminals. Each terminal is based on a flat asphalt surface along a signal regulated side track which could be entered by a train from both sides (see Figure 9 from SJ Freight during the 1990s and Figure 10). Thus, the trains could stop at the terminals like InterCity passenger trains do.

At the terminals, swap bodies are transhipped under the overhead contact line using a fork lift truck. A prerequisite for an intermediate line terminal is the ability to handle load units disrespect of loading order. However, handling of load units under the catenary is strictly regulated by safety regulations. To conclude, the transshipment under the catenary is restricted to the horizontal or diagonal direction or by using an adapted fork lift truck. In the latter case, the handling is restricted to load units equipped with fork lift tunnels.

In order to minimise the investment costs during the first implementation phase the fork lift truck was carried by the train on a special wagon and loaded/unloaded at the terminals by a ramp. When arriving at the terminals the train driver drove the fork lift truck off the wagon and started the loading/unloading operations. After finishing the handling activities, the train driver drove the fork lift truck back onto the train. After securing the fork lift truck on the wagon the train can depart from the terminal. The actual stopping position of the trains on the track depends on the location of the forklift on the train. In fact, the wagon holding the forklift needs to stop at the position of the ramp, as it is needed to load and unload the forklift.

To allow detachability between the transport modes without stationary handling equipment at the terminals, an interface consisting of a storage rack was constructed. These storage racks were used as intermediate storage and implied neither the rail engine driver nor the lorry driver had to fold up the support legs manually. Hence, the racks were a working environment requirement for using unmanned terminals, since the driver was prohibited to leave the fork lift truck during the transshipment process.

Figure 9: Picture of a potential Light-combi terminal
The fork lift truck used was of standard model weighing 34.5 tons and with a lifting capacity of 25 tons. Hence, the terminal surface did not need any reinforcements. To increase the safety during the transshipment process the fork lift truck was equipped with a locking device to prevent crossing the height limit of 4700 mms above the rail edge. The contact wire was heightened by 150 mm. In the morning when the distribution lorries entered the terminals they drove backwards under the swap bodies and lifted the units by using the air suspension.

![Diagram of Standard Layout Line Terminal](image)

**Figure 10: Standard layout line terminal**

Apparently, the scope of the model extension for the HIT model was to implement the line trains, and for the SimConT model to generate a mini applet for the functions and layout of this simplified terminal concept.

### 6.2 Mini SimConT Applet for line terminals

For implementing line terminals in SimConT, a model applet was generated in order to be able to simulate and evaluate a network of line terminals. The applet enables the contemporaneous analysis of several terminals.

The basic step in the model adaption was the design of the basis-layout for a line terminal and the implementation of the standard functionality of line terminals. This includes processes like the forklift getting on and off the train, or the definition of the possible paths of the forklift and the trucks in the terminal (see Figure 11). Another relevant factor is the specification of the delivery and pick-up behaviour of trucks at a terminal, which is related to train arrivals and departures.

The line terminal layout has, inter alia, to be defined according to the length of the rail tracks, number of storage lines and the number of racks (for the positioning of the swap bodies). The configuration of the single terminals and their (individual) layouts eventually results in the network specification.
Another important part in modelling line networks is the train definition. In the SimConT applet, for each train the number of wagons and the corresponding loading list has to be defined. Also, the wagon carrying the fork lift needs to be determined. The loading list includes information about the terminals for loading and unloading of a load unit, as well as the position of the load unit on the train (which wagon). Further, each train has a predefined route through the network (see Table 5).

![Figure 11: Layout and path definition of SimConT line terminal applet](image)

<table>
<thead>
<tr>
<th>Route information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal ID</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

The arrival and departure times have to be respected in each terminal as they are defined by the network schedule. Therefore the modelling of the travel time between terminals is not necessary.

Table 5: Train route information SimConT line terminal applet

### 6.3 Line train extensions to the HIT model

From a modelling perspective, for the HIT model the challenge with line trains is how to prioritise the allocation of capacity dynamically between the different stretches of the line. For example, if a train runs A-B-C, is it better to send one load unit A-C or one load unit A-B and another B-C? Both alternatives occupy the same capacity on the train. The answer will be different depending on the demand at each location and how this interacts with the demand at other locations. To further complicate it, the extension has to be made within the framework of the existing heuristics framework of the HIT model (see chapter 2.2). The challenge has
been to integrate the line trains characteristics within this framework, as it was not possible within this project to develop a completely new model. The focus has been on making the allocation dynamically, i.e. that no fixed rail capacity is assigned to any destinations, e.g. not to always allocate the capacity of X load units between A-B and Y load units between A-C. Fixed capacity line trains can already be handled in the original HIT model, by inputting each possible transport link (A-B, A-C etc.) as a separate “train”, although it in reality is the same physical train making stops.

The original HIT model prioritises which load units to send by intermodal transport according to the potential cost saving of transferring the individual load unit from an imagined all-road transport to intermodal transport. The challenge with line trains is that two (or more) load units with a low cost saving and short transport distance can be combined along the line and share the same train capacity. Together they might give a higher cost saving than sending one single load unit with high cost saving the entire line (see Figure 12). It is obvious that the number of potential combinations of load units on a train can be very high. For example, each load unit might have several trains to choose among, the train itself might make several stops and have a large number of load units that potential could use the train at each stop, with different destinations for the load units. To ensure a mathematical near optimal solution, all load units and combinations of load units, should be considered. Unfortunately this is not possible within the current heuristics framework, as it builds on that the load units are sorted in order of their potential cost saving and that the heuristics starts with the load units with the largest cost saving.

![Figure 12: Line trains cost saving examples](image)

**Basic line train heuristics**

The original HIT model assumes that shuttle trains are used, as this is the most common way intermodal transport is operated today. In a shuttle train, the train is completely offloaded at each terminal. This means that all load units on the train is transported the same distance. The calculation of potential cost saving can then be made according to the total cost saving, divided by the rail capacity (length of the train occupied) used by the load unit (approximately: potential cost saving per rail wagon meter used).

For a line train model, the cost saving must also include the distance it occupies on the line train, i.e. the distance that it is transported (approximately: potential cost saving per rail wagon meter kilometre used). This includes the distances transported and allows for the heuristics to separate between a load unit with low cost saving being transported a short distance and load unit with high cost saving being transported a long distance. However, the drawback is that this will benefit short transports as a short transport will be considered equal to a long transport, if the cost saving per km is the same. This gives the risk that the train capacity used will be very fragmented. The heuristics might decide to start sending load units on a short stretch in the middle of the line, thus automatically blocking this train capacity for longer transports that would need this short stretch in the middle. This will make it harder for
longer transport to get capacity on the train. In the end, the train might be filled up with load units with low cost saving, as they are the only ones that fit on the left over capacity, thus resulting in a less optimal total cost saving. On the other hand, if the original heuristics is used where only the total cost saving is considered, then the shorter transport will have harder to compete. It is well known that intermodal transport increases it competitiveness over longer transport distances. The cost per load unit kilometre is lower in rail than in all-road transport, but this cost saving must also outweigh the extra costs of transshipment and pre- and post haulage. Thus, the total cost saving will increase with the distance transported causing the model to priorities the long distance shipments and then missing to possibility to combine several shorter shipments.

Which principle that will give the best results will depend on the input data set. A data set with a few short profitable (per km) shipments on the middle of the line and then an equal number of almost as profitable (per km) long haul shipments would probably benefit from the original heuristics as this would select the longer shipments. On the other side, a data set with many short distance shipment spread across the line with a high cost saving (per km) and a few long haul shipments with a low cost saving (per km) would probably benefit from the other heuristics that includes the distance transported as this would combine the many high cost saving shipments. It can therefore not be decided than of the principles always is the better one. The HIT model has therefore been equipped with a combination of the two principles. The user inputs the share of the cost saving, called the cost saving split, which shall be calculated according to each principle, e.g. 75% on the total cost saving and 25% on the cost saving per km. The load units are then sorted according to this combined value. Note that this is only used for the sorting and of course not to calculate the actual transport cost. Line trains are then modelled in an iterative procedure where several values on this cost saving split is tested until the best solution is found. The model user changes the input value on the cost saving splits and re-runs the model.

Apart from the cost saving split, there are no new input data required compared to the original model. A line train is defined in the input according to its train loop number. Train time tables are input with each part of the line, e.g. C-D, input as a separate train, but using the same train loop number. These are then combined by the model to one line train.

**Detailed heuristics extensions**

The new heuristics has been implemented in the C++ programming language. The heuristics of the original model can be found in Flodén (2007). A brief description of the extended heuristics will be given here. It is assumed that the reader is already familiar with the original heuristics. The main components of the original model have been possible to maintain. The original heuristics uses “waiting lists” at terminals where the load units are put until the aggregated cost saving is large enough to insert any new capacity. In the new line train heuristics, each load unit is duplicated and input at the waiting list at each terminal it passes on the line. The heuristics then check that all parts of the same load unit will be sent by the same train.

The model has also been extended to include that two line train can take two different paths and still reach the same destination. A check is also made that a load unit do not return to its origin, e.g. if the line train should made a loop before heading towards the final destination. Then the load unit will only use the train the second time it passes the terminal.
In the input data, a line train is defined according to its train loop number. Line train time tables are input with each part of the line, e.g. C-D, input as a separate train, but using the same train loop number. These are then combined by the model to one line train. The formatting of the output data has also been adjusted slightly to give better information on the line train.

7 MINT-model validation

Generally, model verification and validation are essential parts of the model development process if models are to be accepted and used to support decision making. For the MINT project this is essential to ensure that the specification is complete and that mistakes have not been made in integrating the models for their application on the case studies.

The existing models of the MINT-portfolio were validated and tested successfully on their own. As no physical combination of the models will be made, there are no further validation processes necessary for them. However, regarding the new developments this step has to be done. The TermCost model, the line train functionality of the HIT model and the SimConT mini applet for line terminal networks will be tested by their application in case studies. In the preparation of the case studies, the data requirements and model data exchange possibilities have been evaluated according to the model interaction possibilities presented in chapter 5. On basis of the user cases defined in WP 2, two case studies have been elaborated in order to answer questions regarding the performance of an intermodal network. The case studies were carried out conceptually by using the existing simulation models HIT, EvaRail and SimConT and the new models TermCost and SimNet.

7.1 Case study 1 – SJ Light-combi

In Sweden there is a large potential for intermodal transport on medium and long distances (Nelldal, 2005, Bärthel et al., 2009, TFK, 2011). However, due to insufficient market accessibility and poor cost-quality ratio the intermodal service supply does not meet the shippers’ requirements and preferences (Nelldal, 2010, Bärthel, 2011) and hence the market potential is still unexploited.

Previous research indicates a correlation between the potential for intermodal transport and a dense intermodal terminal network (Rutten 1998). However, a dense terminal network has to be supported by efficient intermodal bundling concepts in order to not to affect the cost-quality ratio negatively (Vleugel et al., 2001), and is a prerequisite if intermodal transport should re-enter the market for small and dispersed freight flows (Woxenius et al., 2004). According to Bukold (1996) this requires a change from the approach of industrialization, aiming at higher productivity by means of mass production, concentration and economies of scale, to the approach of flexible capacity management, supporting low-risk capacity utilisation and less concentrated facilities. In other words, in order to enter the market for small and dispersed freight flows new intermodal systems, characterized by new bundling concepts, low cost terminals served by handling equipment with high capacity/cost ratio which are supported by a new intermodal organisation, adapted regulations and supporting intermodal planning and control systems, adapted to these complex systems and working environment, are necessary (Bukold, 1996, Bärthel, 2011).
The conventional intermodal systems have, supported by the dominating rail transport paradigm, abandoned the markets for small and dispersed freight flows and hence left this market entirely to road transport. The present supply entirely focuses on the markets for large flows over long distances and has penetrated the markets for base goods, i.e. the cost focused market segment (Bärthel, 2011). However, the conventional intermodal transport system has had a poor growth in the cost-quality sensitive market segments, as non-durable products (ibid.). The potential in the market is large, especially for transporting food and everyday commodities (Storhagen et al., 2008, Bärthel et al., 2009) between suppliers and wholesalers as well as for distribution. These segments are from now on referred to as time-sensitive shipments.

The developments of intermodal transport systems for time-sensitive goods have been highlighted in numerous research projects at both national and international level. In the EU-funded project CREAM, load units for temperature and stress/shock sensitive shipments have been developed and tested. Groothedde et al. (2005) analysed the impact of vertical cooperation between wholesalers in order to ensure a base volume for an intermodal transport system. In the DagTrans project the opportunities and barriers to increased shipments in the Swedish grocery sector were analysed (Storhagen et al., 2008). On the one hand, the study indicates that large frequent flows on a dedicated number of links, connecting production zones and consumption areas, and an increasing interest in intermodality among the largest groceries in Sweden exist. On the other hand, the statistics show a decreasing amount of transports by rail, and thus the great potential for an increased proportion of modality is unrealized. However, both COOP and Axfood introduced intermodal transport on some transport links during 2009.

However, the implemented transport systems follow the dominating design of intermodal systems, i.e. follow the wagon load paradigm and hence do not fulfill the cost-quality needs in the cost-quality sensitive category. Thus, the potential to enter the transport market more than marginally, without the need for major changes in their intermodal logistics systems, is limited. To recapture the markets for small and dispersed freight flows for time sensitive shipments, a fine-meshed network operated by fast and frequent trains is needed. One such line terminal system, with high interoperability and high compatibility with the distribution function, is the SJ Light-combi system, developed and tested in a customer pilot from 1995 to 2001.

The MINT-model portfolio can contribute to an increased understanding of the cost-quality ratio of an intermodal line terminal system and hence the abilities to enter the market for time sensitive shipments, i.e. the cost-quality sensitive market segment. The case study is based on the user case “performance evaluation of the network”.

### 7.1.1 Aim, Scope and delimitations

The overall aim is to put attention on the line terminal networks and line terminals with a specific focus on the costs and performance of such a network. The performance evaluation of the network will focus on the following dimensions:

- Transported volume (no of shipments) in a defined line terminal network.
- Scale of line terminal network (fixed or variable location/number of terminals).
All demand transported by intermodal rail-road transport or modal competition with road transport (modal split).

In more detail, the aim consists of sub aims related to two different, but sometimes overlapping, perspectives - the terminal and the terminal network: The aims related to the terminal are:

- How to design intermodal line terminal?
- What is the performance of intermodal Line terminals? What parameters do affect the time and cost efficiency?
- Identify the effects of varying demand on the line terminal system’s potential, i.e. compare different scenarios.

The aims related to the terminal network are:

- What is the market potential for intermodal line transport services (here: within the branch Wholesaling, Food and Brewing industries) compared to road transport?
- What is the performance of intermodal line terminal networks? How to measure the terminal performance for one or for a sequence of terminals? Effects on terminal performance for terminal [X] from strategies of loading and unloading of trains to/from terminal [X-1].
- How to implement an intermodal line terminal network – parameters affecting strategies to implement and extend a network, with low business economic risk.

Hence, the line terminal system will be analysed under different markets conditions (volumes, demand patterns), supply conditions (network design) while considering the modal choice decisions by the customers by a parametric evaluation.

In the MINT project it was decided to model the SJ Line terminal system, SJ Light combi, developed by SJ Freight during 1995-1998 and implemented in the customer pilot “the Dalecarlian Girl” in 1998. Only freight flows for the grocery industry will be considered. Data from 1999 (six months) will be used for validation and calibration of the tools (real data from the Light-combi project). The modelling will focus on the terminals and on the bundling concept. The performance evaluation is carried out based on four different scenarios. For the base case empirical data from SJ Line terminal system is used. These have originally been collected by Bärthel and Woxenius (2001-2003) and have been analysed and published in Bärthel and Woxenius, 2003 and 2004). The model Eva Rail will not be used, since line trains are more or less fixed formation train sets, i.e. shuttle trains, and hence there is no need to model the train operations in detail.

In order to make a parametric evaluation of the system under different market conditions (volumes, demand patterns), supply conditions (network design) while considering the modal choice decisions by the customers three complementing scenarios have been created. These are mentioned as extended scenarios 1-3. The extension for scenario 2-4 is based on scenario 1, which is based on the empirical data collection from Bärthel et al. (2009). The base scenario and the three extended scenarios are explained in the three subsequent chapters. The line terminal system itself has already been described in chapter 6.1.
7.1.2 Scenario Base Case “The Dalecarlian Girl”

The first scenario, also denoted base scenario, is an evaluation of the SJ Line terminal system, SJ Light combi. The basic characteristics of the customer pilot were:

- 90% of the shipments were loaded in Borlänge (DC) and transported to local terminals along the two loops. Some back haul transport, shipments from suppliers to the warehouse, did occur, but the volume represented only 10% of the outbound volumes. In the system all kind of shipments except from frozen foods were transported.
- Logistical delivery time windows are fixed (i.e. fixed distribution customer demand)
- The network is fixed with fixed formation train sets.
- Terminal windows are fixed, i.e. a fixed train schedule exists.

7.1.3 Scenario Extended 1

One of the main drawbacks of the SJ Line Terminal pilot was insufficient transport volume in order to benefit from the economies-of-scale in the rail system. Hence, the aim of the first scenario is to scale up the demand under the following circumstances:

- The demand of shipments (distribution) from the warehouse in Borlänge DC increases and the number of shipments from suppliers (local terminals) to Borlänge increases. I.e. O/D fixed, transport routes fixed and terminals fixed.
- Logistical delivery time windows are fixed (i.e. Fixed distribution customer demand)
- The network is fixed with longer trains
- Terminal windows

7.1.4 Scenario Extended 2

In the second scenario the effects on the performance of higher demand and variable logistical delivery time windows will be analysed. Hence, the aim of the second scenario is to scale up the demand and also discuss the effects on the system performance if the loading and unloading activities in Borlänge and at the local stores are more variable (not stable). The demand of distribution shipments increases in Borlänge (DC) and shipments from suppliers (local terminals) to Borlänge increases, i.e. O/D fixed, transport routes fixed and terminals fixed.

- Logistical delivery time windows are variable (modal split).
- Network is fixed, longer trains
- Terminal windows

7.1.5 Scenario Extended 3

In the first three scenarios the source is the terminal in Borlänge and to some extent the local terminals (deliveries to Borlänge). In the fourth scenario the O/D terminals (sources and sinks for the shipments) will be elaborated and the effects on the system performance will be evaluated based on the following circumstances:

- Increased demand from all terminals (more general demand) and hence, new routes have to be allocated from B-terminals to E-terminals.
- Logistical delivery time windows are variable – modal split.
• Terminals are fixed, longer trains
• Terminal windows

Figure 13 shows an overview of the characteristics of the different scenarios.

![Figure 13: Scenario structure for case study 1](image)

### 7.1.6 Potentially addressed actors

The aims of the analysis will follow the user case “performance evaluation of the network”. Potential objectives of intermodal actors and the adequate models for the evaluation are given in Table 6 (if the problem definition can be solved with the MINT-model portfolio).

**Table 6: Objectives case study 1**

<table>
<thead>
<tr>
<th>Actor</th>
<th>Objectives - Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway operator</td>
<td>• High resource utilisation/loading rate in rail system – HIT</td>
</tr>
<tr>
<td></td>
<td>• Low railway operation cost – HIT</td>
</tr>
<tr>
<td>Railway infrastructure manager</td>
<td>• Optimal use of infrastructure (capacity) – HIT</td>
</tr>
<tr>
<td></td>
<td>• Analyse alternative terminal designs – maybe limiting the needs for infrastructure/terminal investments</td>
</tr>
<tr>
<td></td>
<td>• (Maximize revenues of rail infrastructure use)</td>
</tr>
<tr>
<td>Terminal operator</td>
<td>• High resource utilisation for terminals – SimConT Applet</td>
</tr>
<tr>
<td></td>
<td>• Maximize the revenue/cost ratio for terminal operation</td>
</tr>
<tr>
<td></td>
<td>• Maximize cost-quality ratio for the terminal</td>
</tr>
<tr>
<td>Intermodal service provider</td>
<td>• Intermodal system with a high cost-quality ration (door-to-door) - HIT, SimConT Applet, TermCost</td>
</tr>
<tr>
<td></td>
<td>• Improve/optimize cost/benefit ratio of the system/chain</td>
</tr>
<tr>
<td></td>
<td>• Allocate costs and benefits between the system actors</td>
</tr>
<tr>
<td>Authorities</td>
<td>• Modal Shift from road to intermodal transport – HIT</td>
</tr>
<tr>
<td></td>
<td>• Low use of non-renewable energy resources (incl. environmental impact) – HIT</td>
</tr>
</tbody>
</table>
The objectives have to follow the needs of the potential user or customer. In this case, the interested actors would be the Swedish grocery industry, the Swedish rail operators, the Swedish intermodal operators and the Swedish Transport Authority.

### 7.1.7 Models and workflow

The appropriate models for the case evaluation are the HIT model, the SimConT mini applet for line terminals and the TermCost model. The model EvaRail is not applicable for this case study. The reasons for this is primarily that line trains might be regarded as a shuttle train and from both a practical and theoretical point of view the simple rail functions do not need to be modeled. From these points of view rather the performance of terminals and the performance of a series of interconnected terminals are unknown and need to be modeled and evaluated. Depending on the case design, the HIT model will be used for cost calculation or to evaluate the modal split road/intermodal for time sensitive shipments. The HIT model will generate a time table for the cases/scenarios. The timetable has to be validated by the SimConT Applet in order to avoid double occupation of terminal tracks and also to calculate the predictability of double occupation in case of fluctuations in time reliability. Table 7 provides an overview of the model purposes and their input and output parameters.

<table>
<thead>
<tr>
<th>Model</th>
<th>Application purpose</th>
<th>Input parameters</th>
<th>Output parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIT</td>
<td>• calculation of transport costs</td>
<td>• transport demand&lt;br&gt;• road distances&lt;br&gt;• rail distances&lt;br&gt;• terminal areas&lt;br&gt;• terminal data&lt;br&gt;• train types&lt;br&gt;• all-road lorry types&lt;br&gt;• intermodal transport lorry&lt;br&gt;• allowed train loops&lt;br&gt;• allowed lorries&lt;br&gt;• time periods&lt;br&gt;• control parameters</td>
<td>• potential for intermodal freight transport&lt;br&gt;• schedules for trains (loops)&lt;br&gt;• resource utilisation in trains (loops)&lt;br&gt;• number of trains on each train line&lt;br&gt;• number and resource utilisation of trucks around terminals&lt;br&gt;• business econ. cost for system&lt;br&gt;• environmental effect&lt;br&gt;• energy consumption</td>
</tr>
<tr>
<td>TermCost</td>
<td>• calculation of terminal costs</td>
<td>• layout and components</td>
<td>• terminal costs&lt;br&gt; (infrastructure)</td>
</tr>
</tbody>
</table>

Table 7: Model purpose and parameters for case study 1
7.1.8 Information/data needs

- Intermodal freight demand for six month in 1999 (base case) and also freight demand for expanded cases. Usage of data from Bärthel et al. (2009).
- Terminal design for SJ Line terminals including handling equipment and other terminal resources.
- Operational data for handling equipment, train operations and lorry operations.
- Information about infrastructure networks (capacity, velocity, and probability of disturbances) for road and rail.
- Pick-up and delivery times for trucks.
- Railway and road network.

For the evaluation of the terminal network the HIT model and the SimConT Applet are needed. According to Figure 14 a sequence of model usage have been sketched. This sketch shows the supposed workflow for solving the case.

7.1.9 Work flow case study 1

The work has been split into 17 steps based on the modelling sketch shown in Figure 14.

Step 1 Creation of general problem description.
Step 2 Define detailed research questions.
Step 3 General definition of scope and delimitation of the project, including the choice of the transport system to be evaluated, choice of network extension, and delimitation of freight shipment regarded as time sensitive.
Step 4 Define transport demand for the scenarios including O/D matrixes, demand patterns, transport resources available etc. for the base case and extended scenario 1-3.

Step 5 Define terminals including terminal resources. Together with a general description of the Swedish infrastructure (step 5), including its transport regulations, this provided a network definition for the scenarios.

Step 6 Define the infrastructure network for the Scenario base case based on the SJ Light-combi pilot.

Step 7 Preparation of the data for terminals and infrastructure. Adoption of the SimConT Applet for line terminals. Data for the terminals.

Step 8 Preparation of service data for the base case.

Step 9 Preparation of cost data for terminal, rail and road operations.

Step 10 Preparation of extension of flow data for the base case.

Step 11 Model runs HIT including: (1) data conversion, (2) model running, (3) scenario calculation and (4) model output.

Step 12 Model runs SimConT Applet including: (1) data conversion, (2) model running, (3) scenario calculation and (4) model output.

Step 13 Cost calculations of terminals by TermCost, based on the output from step 12 and the terminal definitions from step 5 and step 7.

Step 14 Aggregation of output data for each scenario from step 11-13. The results are compared and analysed in order to identify the needs for further scenarios to be run.

Step 15 Analysing parameters not evaluated by the models.

Step 16 Reporting.

Step 17 Case study completed.

Several modelling loops for a scenario can be reasonable if the model parameters and results diverge too much, and it has to be iterated until the parameters converge. For example, the HIT model uses a predefined cost factor for terminal usage, but the combination of SimConT Applet and TermCost evaluates a “real” terminal cost-quality ratio dependent on the actual utilisation. Hence, the demand on the single terminal has to be evaluated by the other models first and is a prerequisite for determining an adequate terminal cost-quality by the latter models. Finally, the results of all models will be aggregated, and the results for the different scenarios can be compared. Hence, the performance under different markets conditions can be determined and analysed.
Figure 14: Workflow Case Study 1
7.2 Case study 2 – Intermodal network design

7.2.1 Background and problem definition

The Swiss Federal Railways SBB decided to develop the gateway terminal Zürich-Limmattal, with a planned start of operation in 2015. The terminal should operate major part of the Swiss import/export flows (except flows from and to the regions of Basel and Aarau). The new gateway terminal should fulfill a share of 80% train-to-train transshipment and serve regional terminals by rail. Different operational concepts to serve the regions are possible (by now there is no specification of which terminals are going to be connected to the gateway, and thus no further requirement for time tables etc. exist).

Consequently, an evaluation of the Swiss import/export network given one central gateway terminal serving several local terminals and shunting yards should be done (shunting may be necessary at terminals with short loading tracks). The “intermodal connection” to Austria is realized through the terminal Wolfurt, located at the border to Switzerland, which also supplies part of the Swiss terminals.

The MINT-project can contribute by simulating the new gateway terminal and corresponding network for specified import export flows. The case study is based on the user case “performance evaluation of the network”.

7.2.2 Aim

The overall aim is to design an intermodal transport system for the Swiss intermodal import/export with an Austrian connection. The design focus is mainly on different operational rail concepts also taking into account different density structures of terminals.

In order to limit the complexity of the case and to ensure its feasibility, the number of potential system designs and also the scope of analysis have to be reduced. This is, for example, to compare and evaluate one line train system, one shuttle train system and one single wagon transport system connecting the gateway terminal with a well defined number of Swiss’ local terminals.

7.2.3 Delimitations

- For Switzerland only the intermodal import/export flows are considered. The inland traffic has to be considered with aggregated amounts which are not directly modelled, but utilise the local terminals (and also the railway links).

- Shunting is not modelled.

- The terminal Wolfurt is depicted by specified in- and outflows to certain Swiss terminals, and aggregated amounts of load units from and to all Austrian terminals, as well as aggregated import/export flows.

- According to the user case “performance evaluation”, the existing network performance will be evaluated.
7.2.4 Scenarios

The basis for the operational concepts is build by the actual demand forecasts for the Swiss import/export flows (Rapp Trans AG, 2007) and the inland transport (Rapp Trans AG, 2010) for the year 2030. Additionally, the expected flows between Switzerland and Austria have to be defined.

The focus of the evaluation will be on the service of the regional terminals by the new gateway terminal in Switzerland and the connections to Austria. Transport flows from the sea terminals to the gateway and the Austrian terminal are predetermined and not variable.

**Scenario 1:** Test different operational rail strategies for the gateway connections. The number of served terminals may vary between the different operational strategies. For the terminals to be used (existing and planned ones) we can consider actual plans of SBB Cargo and own ideas. The train connections from the gateway terminal to Wolfurt stay constant. The time table of the trains serving the regional terminals has to be coordinated with the international shuttle trains going to/from the gateway terminal. Figure 15 schematically shows the assumed network design.

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![Figure 15: Case Study 2, Scenario 1](image)

**Scenario 2:** Combine “best” Swiss internal concept with a variation in the Wolfurt connections to Switzerland. This variation is to have direct train connections from Wolfurt to Buchs and Landquart.

As a consequence, there are changes in the train schedule for the gateway terminal and the regional terminals in Switzerland, as well as their railway connections (new trains on links, new timetable for incoming amounts from the gateway). Further, the Austrian terminal is also confronted with new operational conditions. Figure 16 schematically shows the assumed network design.
7.2.5 Potentially addressed actors

The aims of the analysis will follow the user case. Potential objectives of intermodal actors and the adequate models for the evaluation are given in Table 8 (if the problem definition can be solved with the MINT-models).

Table 8: Objectives case study 2

<table>
<thead>
<tr>
<th>Actor</th>
<th>Objectives - Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway Undertaking</td>
<td>• Low railway operation cost – HIT, EvaRail</td>
</tr>
<tr>
<td></td>
<td>• Efficient railway operation – HIT, EvaRail</td>
</tr>
<tr>
<td>Railway infrastructure Manager</td>
<td>• Optimal use of existing infrastructure (capacity) – HIT, EvaRail</td>
</tr>
<tr>
<td></td>
<td>• Limitation of infrastructure investments</td>
</tr>
<tr>
<td></td>
<td>• Minimise conflicts with passenger rail transport</td>
</tr>
<tr>
<td></td>
<td>• Maximise revenues of rail infrastructure use</td>
</tr>
<tr>
<td>Terminal operator</td>
<td>• High utilisation degrees of terminals – SimNet</td>
</tr>
<tr>
<td></td>
<td>• Maximise revenues of terminal operation</td>
</tr>
<tr>
<td>Intermodal Service Provider (incl. shipper)</td>
<td>• Low costs of intermodal system (door-to-door) – HIT, EvaRail, TermCost</td>
</tr>
<tr>
<td></td>
<td>• High efficiency of the intermodal system – SimNet</td>
</tr>
<tr>
<td></td>
<td>• High quality of the intermodal service – SimNet</td>
</tr>
<tr>
<td></td>
<td>• Good cost/benefit ratio</td>
</tr>
<tr>
<td>Authorities</td>
<td>• Modal Shift from road only transport – HIT</td>
</tr>
<tr>
<td></td>
<td>• High share of intermodal transport – HIT</td>
</tr>
<tr>
<td></td>
<td>• Low environmental impact – HIT</td>
</tr>
<tr>
<td></td>
<td>• Low use of energy resources – HIT</td>
</tr>
</tbody>
</table>

The main objectives have to follow the potential customer. In this case, the interested actors would be:

- SBB Cargo (Railway undertaking / intermodal service provider)
Canton of Zurich (authority)

7.2.6 Models and workflow

The appropriate models for the case evaluation are HIT, SimNet and the TermCost model. From its model scope, the EvaRail model also would be applicable, but given the complexity in implementing another than the Swedish railway network in the model as basis for the cost calculations, it is not intended to use the model for this case.

Remarks to the HIT model

Depending on the case design, the HIT model might or might not be needed. The case will take a number of possible rail system designs to evaluate them, for HIT the input to the case must be the train time table to use, or that possibly could be used.

If the focus lies on testing the operational network concept and if there are many train possibilities to choose among, then HIT can be used to choose among them before sending the selected system to SimNet. If there are few train systems to choose among, then HIT is not needed. It is then easier to just test all the possible systems in SimNet directly. Note that all possible train time tables must be manually designed.

If no road transport exists as an alternative, then it will also be necessary to develop a new module in HIT to compare the required delivery times to a given input list of delivery times to meet. Table 9 gives an overview of the model purposes and their input and output parameters.

Table 9: Model purpose and parameters for case study 2

<table>
<thead>
<tr>
<th>Model</th>
<th>Application purpose</th>
<th>Input parameters</th>
<th>Output parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIT</td>
<td>• calculation of Costs</td>
<td>• transport demand</td>
<td>• which of the available train loops to use</td>
</tr>
<tr>
<td></td>
<td>• calculation of environmental effects</td>
<td>• road distances</td>
<td>• number of trains on each train loop</td>
</tr>
<tr>
<td></td>
<td>• calculation of social economic costs</td>
<td>• rail distances</td>
<td>• total length of rail cars on each train</td>
</tr>
<tr>
<td></td>
<td>• modal split (not needed for this case study)</td>
<td>• terminal areas</td>
<td>• business econ. cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• terminal data</td>
<td>• social econ. cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• train types</td>
<td>• environmental effect</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• all-road lorry types</td>
<td>• total goods weight on train.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• intermodal transport lorry types</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• allowed train loops</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• allowed lorries</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• time periods</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• control parameters</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Term Cost</td>
<td>• calculation of terminal costs (infrastructure costs, operation)</td>
<td>• layout and components</td>
<td>• terminal costs (infrastructure costs and operation costs)</td>
</tr>
<tr>
<td>SimNet</td>
<td>test, if transport demand can be handled with defined infrastructure and operational concept</td>
<td>terminals and their specification</td>
<td>utilisation parameters for infrastructure and equipment</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>system entry and exit points (regions)</td>
<td>network links and their specification</td>
<td>load units: system handling time, network path</td>
</tr>
<tr>
<td></td>
<td>transport demand (load units with system entry time, entry location and destination)</td>
<td>train concept and schedule</td>
<td>handling costs (if cost factors are given for usage of terminals and links)</td>
</tr>
</tbody>
</table>

### 7.2.7 Information/data needs

- In order to set up the analysis the following data is required:
  - Intermodal freight demand 2015 and 2020,
  - Intermodal service / concept (transport relation, terminals, time table, operational concept, time of pick up / time of delivery),
  - Cost parameters for intermodal transport and at terminals and
  - Railway and road network.

For evaluating the case the mentioned models can be used, but also just one or two of them can be applied for the analysis. According to the model interaction possibilities and the sequence of model usage (see Part 3.3), Figure 17 shows the supposed workflow for solving the case.

The first step includes the detailed definition of the research questions and the specification of the fix elements in the (e.g. gateway terminal in Switzerland, terminal Wolfurt, rail and road links) evaluated network. The definition of the scenarios comprises the determination of the transport demand (import and export flows, as well as inland transport) for a scenario, the specification of the used local terminals in Switzerland and the design of the operational concepts for the terminals under consideration and the train concept and schedule for the network. Next, the infrastructure data, service data, cost data and intermodal flow data have to be defined for each scenario. This is the starting basis for the model calculations:

The first model in use is the HIT model. After the potential data conversions have been made and the results of the model run for the first scenario are available, the process can continue with starting data preparation and the model run of SimNet for the first scenario. The SimNet results will provide input for the TermCost model, so after finishing the calculations for the first scenario, the application of the TermCost can start. If there is more than one scenario, these calculations can take place contemporaneously (as data are available).
Several modelling loops for a scenario can be reasonable if the model parameters and results diverge too much, and it has to be iterated until the parameters converge. For example, the
HIT and the SimNet model use a predefined cost factor for terminal usage, but the TermCost calculates “real” terminal costs dependent on the actual terminal utilisation – so that the demand allocation on the single terminals in the network which has to be calculated by the other two models first, is a prerequisite for determining an adequate terminal cost factor.

Finally, the results of all used models will be aggregated, and the results for the different scenarios – network settings and demand structures – can be compared.

8 Conclusions

In WP 3 Modelling and simulation of intermodal terminal networks the MINT models were presented shortly and their different modelling goals were pointed out. Due to that we defined in a subsequent effort the model interfaces and the corresponding data exchange profiles between the models. A model run sequence completes this model interaction description. In order to complete the MINT models we developed two new models: a) TermCost and b) SimNet. TermCost provides a static tool for calculating various HCT cost parameters. TermCost is a good enrichment of the HIT model and it may get some performance related data from SimConT. The second model to complement the MINT model portfolio is the SimNet model. SimNet aims at modelling an arbitrary terminal network by agent based simulation. It turned out that the development time for this rather new but highly necessary model system can not be completed within the MINT runtime, but we were able to define very clearly the required data structure used by SimNet.

In WP 3 we also developed two different Case Studies. The Case Study SJ Light-combi focuses on the idea of Line Terminals. New calculation heuristics for the HIT model and a SimConT mini applet were developed in order to analyse the line terminal system and its application potentials. The second Case study on Intermodal network design is motivated by plans to build up the gateway terminal Zürich-Limmattal. We defined the data required for this application and point out how HIT and SimNet may be used for analysing and supporting this infrastructure investment.

To conclude we can state that within the MINT framework Modelling and simulation of intermodal terminal networks we were able to further develop modelling approaches for overall analyzing intermodal networks and pave the way for more enhanced model developments.
9 References


MINT Model and decision support system for evaluation of intermodal terminal networks