AGENT-BASED SIMULATION FOR PLANNING AND EVALUATION OF INTERMODAL FREIGHT TRANSPORTATION NETWORKS

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ABSTRACT

This work presents an agent-based simulation model for the planning and evaluation of intermodal freight transportation networks with a system-wide scope. This approach covers actors, transportation infrastructure, terminal operation strategies and train services. The relevant actors in continental intermodal freight transport, their contributions and tasks are identified and their specific planning rules are as well as the dedicated coordination structures and the code of conducts between the agents are modelled in order to analyse the overall behaviour of the system. Each agent acts according to its own goals and rules and has to consider its domain specific restrictions. They have the ability to make autonomous decisions. These may be set actively or according to system's restrictions or requests. Typical agents considered are terminal agents, link agents, train operator, route planner and container owner respectively. The developed class model structure is also shown. The developed agent-based simulation model enables the dynamic performance evaluation of the whole intermodal freight transport system, as well as on the level of individual elements.

We define an arbitrary freight network with 15 terminals to supply 23 demand regions. Source-sink relations are generated from databases of joint research centres of the EU commission. Also we consider empty container depots in the network. Model trains and corresponding schedules for each terminal and load units are defined in order to generate a basic network load. The modelling approach is applied to standard processes like execution of regular transportation orders, balancing of empty container stocks and introduction or close down of transportation services. A deviation management is applied for booked load units which are too late, late arrivals of trains, insufficient terminal capacity (loading tracks, container storage) and availability of load units.

We apply a scenario approach to observe system's behaviour if we are changing transportation demand, modify terminal network or adopt train schedules.

We can conclude that the agent-based simulation is an appropriate approach for evaluation the intermodal freight network.

Keywords: agent-based simulation, intermodal freight transportation, network evaluation

1. INTRODUCTION

Future prospects in the development of intermodal transport clearly show that Eastern Europe actually faces challenges in terminal network evolution. Figure 1 displays an overview of the expected network in Eastern Europe (UIC, 2010). It can be used to derive transhipment and line capacities in the region and for setting up an intermodal freight network in the area.

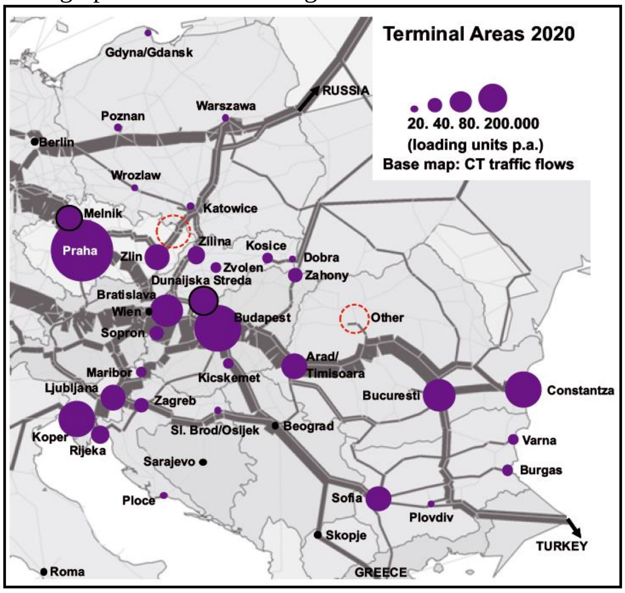

Figure 1: Estimated terminal areas and transportation volumes for 2020 (Source: UIC 2010)

The challenges are now in the timely planning of the development of transport infrastructure and the introduction of more efficient operational concepts, both for terminals as well as for services in intermodal freight transport. In order to strengthen these activities sea ports in the area must be adopted and their hinterland connectivity improved (EC, 2005).

Usually, in intermodal freight transport a number of different actors are involved to organize and transport an ITU. Figure 2 shows the different actors the information flow and the flow of the load units.

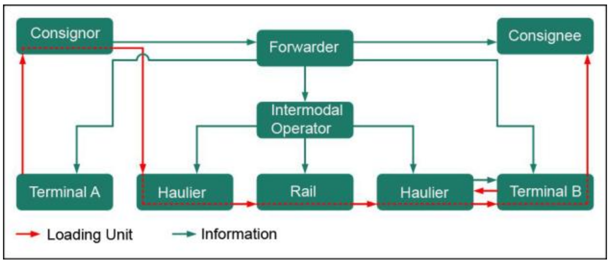

Figure 2: Information and load unit flow in intermodal freight transport (source: Posset et al. 2014)

2. MODELLING INTERMODAL FREIGHT NETWORKS

The first step in planning of transportation networks is to define its topology. Alumur and Kara (2008) give an overview of location planning problems, so-called Hub Location problems. In Yamada et al. (2009) a combined optimisation approach for the design of multimodal transport networks is applied. The proposed method on the one hand decides on infrastructural level on improving or re-introduction of roads, railways, waterways and terminals, and is combined with an allocation method for the transport flows, which takes into account the earlier decisions on infrastructural changes. Etlinger et al. (2013) show an approach to determine the basic topology and allocation of transport flows for intermodal networks. A Mixed Integer Linear Program for site planning of terminals is applied. Based on the total cost of container transportation and handling for a specific transport demand from a set of possible terminals it aims at determining optimal locations. A selected terminal corresponds to a certain terminal type which differ according to capacity and cost structures.

At the strategic planning level in order to forecast multi-mode freight traffic so called macro traffic models are used. For instance, the model STAN (Guélat et al, 1990; Crainic et al, 1990) was applied in Scandinavia to support national transport planning. In DSSITP - Decision Support System for Intermodal Transport Policy (Macharis et al, 2011) three models were compiled to enable an overall approach. The model NODUS combines (see Jourquin and Beuthe, 1996 and Geerts and Jourquin, 2001) transport mode and route selection decisions. Forecasting freight transport at a national level for Germany and determination of the modal split and the terminal selection is used by the SimuGV model (Schneider et al., 2003). SimuGV is also part of system MOSES - integrated Strategic Simulation and Modelling Tool for Rail Freight Transportation. It is applied by the German Railroad, Inc. (Schneider, 2003). Going one step further we will now present models that are specifically designed towards the optimization and simulation of intermodal freight transport.

Rail network simulation models allow for detailed description of general-train movements and specific analysis of rail network capacities, where model output parameters are then given as the summation of delays, the number of delayed trains or average delays. Models with this functionality include SIMONE, RailSys, SiSYFE, SIMU, IS SENA (CAPMAN, 2004) or Open Track (Nash and Hürlimann, 2004; Open Track, 2010).

On a tactical level Wieberneit (2008) provides an overview of the treatment of problems in the design of transportation services by means of mathematical optimization approaches. The tasks there include decisions about the frequency, mode, the schedule and the route of a transport service, as well as the routing in a cargo service network.

In a further literature review on multimodal freight transport planning SteadieSeifi et al. (2014) confirm these findings. Their analysis which focused on tactical planning problems shows that simultaneous planning for various different resources, dynamic and stochastic aspects in the data should be considered.

Using an optimization model for tactical planning level objectives Andersen et al. (2009) aims to identify potentials for improving the interoperability of cross border transports. The aim of the model used is an improved integration of fleet management and the design of the service network. The main objective is to minimize the processing time for a certain amount of demand for a given timetable of services. The approach takes into account also waiting and processing times at network nodes. Another approach is presented by Anghinolfi et al. (2011) for planning of container transports in rail networks where terminals are equipped with special technology for quick container handling. The route through the network and hence selected trains are to be determined so that the arrival time of the different shipments can be met.

Many works address the objective of minimizing costs of the overall transport systems. For example, Lindstrom Bandeira et al. (2009) present a decision support system for full and empty container transportation in order to minimize the overall cost of transportation, handling and storage. The method suggests the splitting of the problem in a static model for cost-effective allocation of containers, including transport, handling and storage, to the demand points without taking into account the transport times. This solution is used as a starting point for detailed planning.

Ballis and Golias (2002, 2004) and Abacoumkin and Ballis (2004) perform a comparative cost and pricing analysis for different bimodal terminal designs. Taking into account both various parameters in terms of infrastructure and technology and organizational flow parameters such as arrival time distributions of trucks and different train products. The question of how intermodal transport can be competitive to monomodal road transport is raised by Bierwirth et al. (2012). The authors develop a planning model for consolidation of freight flows at the tactical level, taking into account cost factors on transport mode, transport services and terminals.

Other works focus on the conditions for transport systems and coordinating processes between system participants. Miller-Hooks et al. (2007) develop a framework for simulation and dynamic allocation of transport orders to different variants of a multimodal transport network along the Baltic Adriatic transport network link. First, a set of paths and combined transportation modes are determined by means of a costly and time-based routing algorithm, which is then used by a mapping component for the generation of the network flows. Finally a simulation model is applied to analyse the time requirements for transport orders in the overall network (Mahmassani et al., 2007).

Puettmann and Stadtler (2010) propose a cooperative approach for managing inter-modal transport chains and multiple service providers. They present a system for minimizing the overall shipping costs for three parties, a carrier, a rail operator for the main run and shipper for the follow-up where each actor optimizes its own decisions first. The solution is generated by iterative negotiations and solution updates between the actors. An interesting and important issue of that contribution is that confidential data need not be disclosed during the negotiation process. Other works (Zhang et al., 2010 Nossack and Pesch, 2013) focus on the planning and control of container transports by truck between shippers, receivers, terminals and depots. Solution were generated by using either exact or heuristic methods. Zehendner und Feillet (2014) build a MIP model in order to improve the quality of services for road transport. They also consider terminal operations and restrictions of other transport modes to facilitate the due date setting for truck transports. The results of this model serve as input for a discrete event simulation model for allocation of cargo handling equipment.

In recent years simulation has evolved into a reasonable method for analysing freight transport and its decision processes. Boschian et al. (2011) apply meta modelling to describe a generic reference model for intermodal transport. Holmgren et al. (2013) apply a multi-agent simulation system to model a regional transport network with a certain number of supplier and customer. The approach fosters to find an appropriate shipment for given constraints on resources and infrastructure. A detailed and comprehensive description for an agent based simulation model for analysing intermodal freight transport network is provided by Schindlbacher (2014). This paper is based on this work and on findings of the research project SimNet (2013).

3. AGENT BASED SIMULATION APPROACH

Usually, agent based simulation is used for complex systems where the behavior of agents influences the overall system. Each agent may independently choose its decisions and applies its own control strategies. Also agents communicate with others and somehow are also interfering the decisions of others. Each agent has its own goals or some given targets to fulfill. The collection of decisions of all agents results in the overall network behavior.

We develop an agent based simulation model for analyzing the behavior of an intermodal freight network. In a first step a generic transport process is defined to identify relevant activities and entities. These are: transport order, network routing, train booking, empty container supply, pre haulage, terminal handling, main haulage, terminal handling, onward carriage and empty container repositioning. We present now the constitutional elements of our simulation system which support the transport processes.

The elements are structured in organizational units (actors), information flow, transportation, transportation units, services and framework conditions, and network infrastructure. The corresponding class model is shown in Figure 4, where the network infrastructure contains the classes:

- *Terminal Agent*
- *Terminal Module*
  - *Equipment*
  - *Tracks*
- *Rail Link*
- *Road Link*
- *Catchment Area and*
- *Residual Area*.

Transportation and transportation unit use the *train*, *truck* and *load unit* classes. Organizational units were modelled with the classes: *Entity Generator*, *Route Planner*, *Container Owner* and *Link Agent*. Figure 3 displays the statechart for a terminal agent. It handles (loading) track and equipment assignment for processing incoming and outgoing trucks and trains.

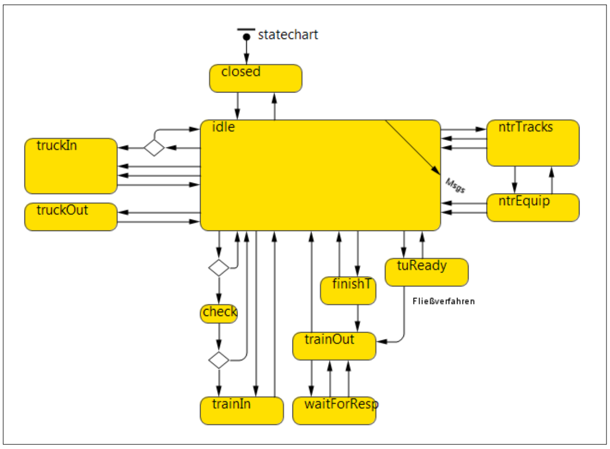

Figure 3: Statechart Terminal Agent

This system's architecture allows for analyzing both standard transportation processes and deviation management. The standard processes include the handling of regular transports, the balancing of empty container stocks and the introduction of new transport connections or the stop of transport relations with low utilization.

The deviation management is activated if

- the booked load unit has not arrived the terminal when the corresponding train is just leaving,
- incoming or outgoing trains are delayed,
- no handling capacity is available and

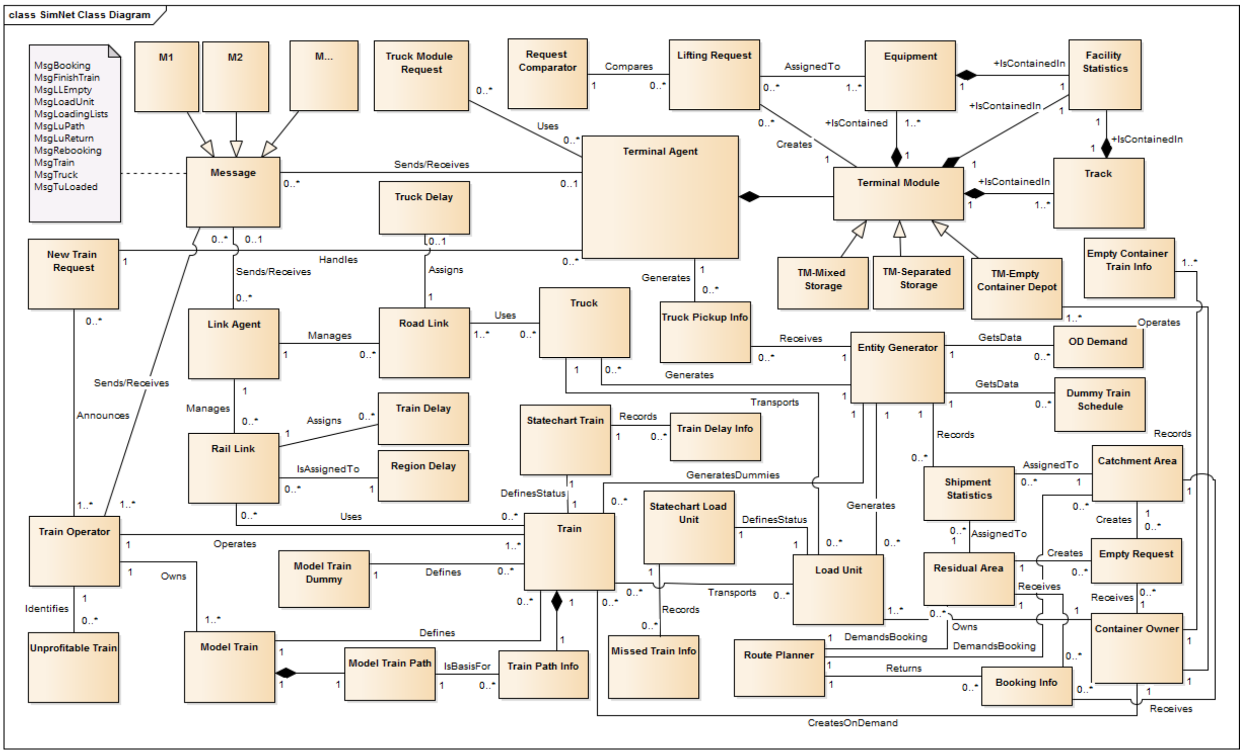

Figure 4: Class diagram of the intermodal network

- no container is available in the catchment area.

The overall system is implemented with AnyLogic®.

3.1. Performance measurement

The performance of the intermodal network is evaluated on different levels and of different actors. On system's level this is provided by 1. General Data, 2. Rebooking, 3. Transportation Order and 4. Train delays. For each category a set of output parameters have been defined. Next for each terminal (*Terminal Agent* and *Terminal Module*) the terminal operation and the storage of load units are collected for analyzing the performance at this level. At the next level indicators for the *Container Owner* are defined. There, for example empty container trains in the system are captured. For measuring the *Train Operator* indicators like cycle time for each train relation are recorded in order to support decisions on their actual and future operation. The overall set of indicators can be found in Schindlbacher (2014).

3.2. Model terminals and model trains

For validation a base scenario is defined which contains a set of model trains and a small number of model rail road terminals in the network. The terminals are categorized in small, medium, large and x-large depending on their transshipment capacity and empty container handling. The functionality of a terminal includes storage capacity, loading and marshalling tracks, handling equipment, operating hours and time windows for trucks. All terminal types may also operate an empty container handling. All terminals are operated according to the train floating procedure.

Starting point for the definition of model trains is data which contains more than 220 real life trains. Trains differ with respect to their length, the portion of different types of intermodal loading units and the function of the train in the network. This could be block trains, shuttle or liner trains. Out of these, 13 model trains were used to generate a train schedule which constitutes a basis traffic load for the terminals in the system. This schedule is also based on real life data. For each model terminal a basic train schedule is defined and the simulation evaluates the system for a six months runtime.

4. USE CASE FRAMEWORK

We apply our agent based approach on a network with 15 terminals out of a set of 35. A single train operator is active. According to the selected nodes we set up a network for connecting the terminals. Also we have to consider traffic flows that leaves this network and vice versa which have their origins outside. To cope with this residual areas were defined. Altogether to connect all areas and terminals 552 oriented network links were established. Each link has a set of attributes like distance, velocity, capacity. For some areas we also introduce a standard delay pattern for the trains. In addition to connect the catchment areas with the terminals and empty container depots 104 non oriented links for road transports are generated.

The schedule of the train operator in the basis scenario contains 549 relations which were covered by various model trains. Out of these, 197 relations are connections within the network and the remainder are either export or import trains. 534 trains are block trains, 14 shuttle trains and a single line train. 2.4% of the trains have a maximum transportation capacity of 50 TEU, 14.8 % of 70 TEU, 22.8 % of 80 TEU and the remaining 59.9 % of 90 TEU. The main portion of the relations are used once a week.

The background for the use case framework constitutes the intermodal freight network in south-eastern Europe. For generating transportation demand on a NUTS 2 level the data of a Joint Research Centres of the European Commission is used (TRANS TOOLS, 2012) and raw data are converted to intermodal units i.e. TEU.

5. SCENARIO ANALYSIS

We apply a scenario analysis to systematically change parameter values and observe system's behaviour. By doing this we distinguish between structural and organisational parameters (see Table 1 and Table 2). Structural ones are: runtime, transportation volume, container volume, empty container depots, depot equipment, basic utilization at terminals and system's traffic. Organizational parameters include: train schedule, maximum booking duration per relation, minimum utilization per relation and number of empty container trains.

Parameter		Value	Description
Runtime	LZ1	8	Simulation Runtime in weeks
	LZ2	12	
transportation volume	TM 1	491.280 TEU	annual transportation demand
	TM 2	982.560 TEU	
	TM 3	1.965.120 TEU	
Container Volume	CM1	100.000 20' 30.000 40'	
	CM2	75.000 20' 22.500 40'	
	CM3	50.000 20' 15.000 40'	
	CM4	30.000 20' 9.000 40'	

Table 1: structural parameters for scenario analysis

train schedule	F1	Basic schedule	train schedule used by train operator
	F2	Adaption of F1	
	F3	Adaption of F2	
maximum booking time offset	MB1	10	Maximum average time between a booking request and the actual availability of a realtion measured in days, required for a new train relation
	MB2	14	
minimum utilization	MA1	0,90	minimum average utilization of a relation
	MA2	0,97	
empty container trains	ALCZ-D1-1	6	maximmum number of of empty container trains
	ALCZ-D1-2	8	
	ALCZ-D1-3	10	
	ALCZ-D2-1	1	
	ALCZ-D2-2	2	
	ALCZ-RA1	6	
	ALCZ-RA2	4	

Table 2: organisational parameters for scenario analysis

We establish a scenario tree (Figure 5) in order to figure out consistently the coherence between changing some parameter values and the performance indicators of the intermodal freight network. This procedures allows not to test all possible parameter combinations but instead iteratively checks the results of a particular branch and then defines new promising or missing parameter settings.

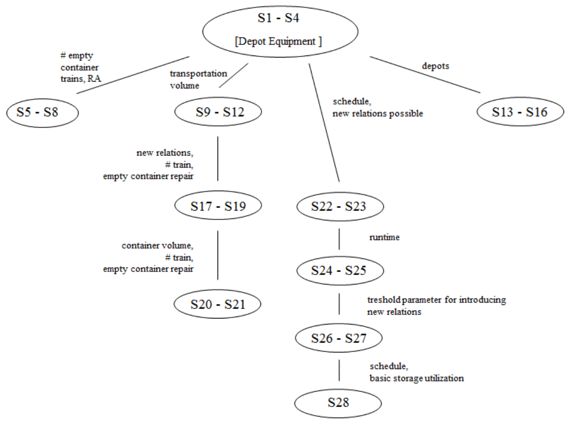

Figure 5: Scenario tree

Scenario S1-S4 start with (LZ1, TM1, see Table 1) and consider different Depot Equipment. In S5-S8 the number of trains in residual areas are changed. The path S9 – S12, S17-19 and S 20-S21 investigates an increase in transportation volume, introduction of new relations and a rise in container volume. In the other path (S22 – S28) we are changing the train schedule and thereby forcing new relations. In Figure 6 we compare the average utilization of a relation to the overall number of operated relations. Transportation volume TM2 is used for S9 and S11 and TM3 for S10 and S 12 rsp. We can observe that due to an increase in transportation volume the average utilization of relations is decreasing, because we need more relations to cope with the transportation volume. Obviously this is an important management parameter to figure out the appropriate supply of transport relations.

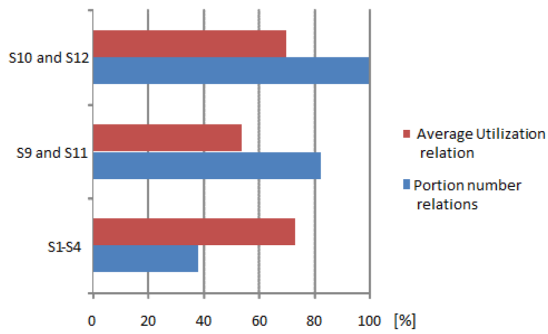

Figure 6: Relation utilization and operated relations

CONCLUSION

We can state that the developed approach is very well suited to cope with the complexity of modeling and simulation an intermodal freight network. The results generated are very robust and show the potential of agent based simulation in this domain. During further developments will work on a better aligned basic train schedule and we will elaborate the network attributes.

Also the class diagram can be adapted in order to facilitate the introduction of wagons for train formation.

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REFERENCES

Abacoumkin, C. und Ballis, A. (2004). Development of an expert system for the evaluation of conventional and innovative technologies in the intermodal transport area. European Journal of Operational Research 152, 410-419.

Alumur, S. und Kara, Y. (2008). Network hub location problems: The state of the art. European Journal of Operational Research 190, 1-21.

Andersen, J., Crainic, T.G. und Christiansen, M. (2009). Service network design with management and coordination of multiple fleets. European Journal of Operational Research 193, 377-389.

Anghinolfi, D., Paolucci, M., Sacone, S. und Siri, S. (2011). Freight transportation in railway networks with automated terminals: A mathematical model and MIP heuristic approaches. European Journal of Operational Research 214, 588-594.

Ballis, A. und Golias, J. (2002). Comparative evaluation of existing and innovative rail-road freight transport terminals. Transportation Research Part A 36, 593-611.

Ballis, A. und Golias, J. (2004). Towards the improvement of a combined transport chain performance. European Journal of Operational Research 152, 420-436.

Bierwirth, C., Kirschstein, T., Meisel, F. (2012). On Transport Service Selection in Intermodal Rail/Road Distribution Networks. Business Research Journal 5 (2), 198-219.

Boschian, V., Dotoli, M., Fanti, M.P., Iacobellis, G. und Ukovich, W. (2011). A Metamodeling Approach to the Management of Intermodal Transportation Networks. IEEE Transactions on Automation Science and Engineering 8 (3), 457 - 469.

CAPMAN (2004). Summary Report Capacity Management Project (Capman Phase 3). UIC – International Union of Railways (Hrsg.).

Crainic, T.G., Florian, M. und Leal, J.U. (1990). A Model for the Strategic Planning of National Freight Transportation by Rail, Transportation Science 24 (1), 1-24.

Etlinger, K., Schindlbacher, E., und Gronalt, M. (2013). Modelling of intermodal networks. In: Proceedings of the International Conference on Harbor Maritime and Multimodal Logistics M&S 2013, 18-25, September 25-27, Athen.

Geerts, J.-F. und Jourquin, B. (2001). Freight Transportation Planning on the European Multimodal Network. European Journal of Transport and Infrastructure Research 1 (1), 91 - 106.

Guélat, J., Florian, M. und Crainic, T.G. (1990). A Multimodal Multiproduct Network Assignment Model for Strategic Planning of Freight Flows, Transportation Science 24 (1), 25-39.

Jourquin, B. und Beuthe, M. (1996). Transportation policy analysis with a geographic information system: The virtual network of freight transportation in Europe, Transportation Research Part C: Emerging Technologies 4 (6), 359-371.

Lindstrom Bandeira, D., Becker, J.L. und Borenstein, D. (2009). A DSS for integrated distribution of empty and full containers. Decision Support Systems 47, 383–397.

Macharis, C., Caris, A., Jourquin, B. und Pekin, E., (2011). A decision support framework for intermodal transport policy. European Transport Research Review 3, 167-178.

Mahmassani, H.S., Zhang, K., Dong, J., Lu, Ch.-Ch., Charan Arcot, V. und Miller-Hooks, E. (2007). Dynamic Network Simulation–Assignment Platform for Multiproduct Intermodal Freight Transportation Analysis. Transportation Research Record: Journal of the Transportation Research Board, No. 2032, Transportation Research Board of the National Academies, Washington, D.C., 9–16.

Miller-Hooks, E., Mahmassani, H.S., Nair, R., Zhang, K., Charan Arcot, V., Kuo, A., Lu, Ch.-Ch., Dong, J. und Kozuki, A. (2007). Assessing service design options and strategies for overcoming barriers in the Reorient intermodal freight transport corridor. Proceedings of the European Transport Conference (ETC) 2007, Oktober 17-19, Leiden.

Nash, A. und Hürlimann, D. (2004). Railroad Simulation using OpenTrack, In: Proceedings of the Ninth International Conference on Computer in Railways (Comprail IX), eds. J. Allan, C.A. Brebbia, R.J. Hill, G. Sciutto & S. Sone, 45-54, Dresden.

Nossack, J. und Pesch, E. (2010). A truck scheduling problem arising in intermodal container transportation. European Journal of Operational Research 230, 666-680.

Opentrack (2010). OpenTrack – Simulation of Railway Networks. Entnommen von http://www.opentrack.ch/ am 27.11.2010.

Posset, M., Gierlinger, D., Gronalt, M., Peherstorfer, H., Pripfl, H. und Starkl, F. (2014). Intermodaler Verkehr Europa. 1. Auflage, Eigenverlag der FH OÖ Forschungs & Entwicklungs GmbH - Logistikum Steyr.

Puettmann, C. und Stadtler, H. (2010). A collaborative planning approach for intermodal freight transportation. OR Spectrum 32, 809-830.

Schneider, W. (2003). The German National Freight Transport Model. Paper präsentiert bei: Conference on National and International Freight Transport Models, Helsingør, Denmark.

Schindlbacher, E. (2014). Agentenbasierte Simulation intermodaler Gütertransportnetzwerke, Dissertation, University of Natural Resources and Life Sciences, Vienna.

Schindlbacher, E. und Gronalt, M. (2010). Using Auction Mechanisms for Coordinating Container Flows in Intermodal Freight Transport Networks. In: Janssens, G.K., Ramaekers, K. and Caris, A. (Hrsg.), The 2010 European Simulation and Modelling Conference, S. 317-321, EUROSIS-ETI Publication.

SteadieSeifi, M., Dellaert, N.P., Nuijten, W., Van Woensel, T. und Raoufi, R. (2014). Multimodal freight transportation planning: A literature review. European Journal of Operational Research 233, 1-15.

Wieberneit, N. (2008). Service network design for freight transportation: a review. OR Spectrum 30, 77-112.

Yamada, T., Frazila Russ, B., Castro, J. und Taniguchi, E. (2009). Designing Multimodal Freight Transport Networks: A Heuristic Approach and Applications. Transportation Science 43 (2), 129-143.

Zehendner, E. und Feillet, D. (2014). Benefits of a truck appointment system on the service quality of inland transport modes at a multimodal container terminal. European Journal of Operational Research 235, 461–469.

Zhang, R., Yun, W.Y. und Kopfer, H. (2010). Heuristic-based truck scheduling for inland container transportation. OR Spectrum 32, 787–808.