Tactical planning of sustainable transportation by logistics service providers for the automotive industry

M. Preuss[1], B. Hellingrath[2]

[1] Schenker AG, Alfredstr. 81, 45130 Essen, Germany

[2] Westfälische Wilhelms-Universität Münster, Lehrstuhl für Wirtschaftsinformatik und Logistik, Leonardo-Campus 3, 48149 Münster, Germany

Abstract

The paper presents a planning process, a decision support system and an optimization model designed for the tactical planning of transportation by a logistics service provider (LSP) for customers from the automotive industry focusing on the primary target of sustainable transportation. Therefore a rolling to-be planning process has been designed which covers the planning activities for different modes of transportation enabling the planning of shared trains consisting of freight wagons for parts and for finished vehicles by simultaneously taking into account the inbound as well as the outbound activities. A decision support system which allows for the collaborative planning of one LSP and several original equipment manufacturers (OEM) has been designed and implemented to support the future planning process. Main component is a new optimization model which is an extension of the service network design problem using the path formulation. Central features are the consideration of cost and carbon dioxide emission and of multiple freight wagon fleets which is important for the planning of shared trains. Several scenarios have been investigated to show the ecological and economical benefit of process, decision support system and model.

Keywords:

Sustainable logistics; Decision support; Optimization

1 INTRODUCTION

Consumers and governments increasingly strive for a **sustainable development**. This directly or indirectly affects companies and their activities. For example, decision makers in the automotive industry are convinced that sustainable development has a significant effect on the company value [1]. The basic demand of sustainable development is to ‘meet the needs of the present without compromising the ability of future generations to meet their own needs' [2]. A sustainable transportation system 'limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and, uses non-renewable resources at or below the rates of development of renewable substitutes' [3].

In terms of emission carbon dioxide is most discussed due to its impact on climate change. As the transport sector is responsible for more than 25% of carbon dioxide emissions in the EU-27 [4] an important objective of the European policy is the environmental sustainability of transport [5]. *InTer-Trans* is a European research project that has been initiated to improve the environmental impact of freight transportation under consideration of economic aspects using the example of the automotive industry. This paper deals with one major aspect of *InTerTrans*: The rolling adjustment of the tactical transportation plan from the point of view of an LSP according to the production plans of several OEMs.

2 STATE OF THE ART

There are three ways one can follow to improve the environmental effect of transportation by means of planning [6]: A decrease in the (average) haul distance, an increase in transport utilization and a shift to more sustainable modes of transport. A recent review reveals that **environmental** concerns are under-represented in the transportation choice literature. None of the 48 articles, that Meixell et al. reviewed, addresses environmental and energy concerns [7]. In most cases the traditional objectives cost and customer service are focused.

To describe trade-offs between cost and environmental impact that are not dominated by other solutions the idea of a 'frontier' for **eco-efficiency** was first presented by Huppes and Ishikawa [8]. Based on Pareto-optimality a solution is eco-efficient if it is not possible to improve the environmental quality without decreasing the economic value and vice versa.

A **process analysis** of the tactical planning of an automotive OEM focusing on production was carried out by Meyr [9]. A process analysis of an LSP in the automotive industry is not known to the authors. An adequate **decision support system** in the form of a Logistic Assistance System [10] that can be used for the tactical planning of sustainable transportation by an LSP for the automotive industry does not exist. Hellingrath [11] classifies two types of systems for production and logistics: On one hand tools for the calculation of a carbon footprint such as *EcoTransit* exist, that estimate emissions for pre-defined transport scenarios without generating optimized transport alternatives. Especially in complex transportation networks with a countless number of transport alternatives like in the automotive industry this may not be sufficient. On the other hand optimization tools exist, that mostly optimize environmental aspects only indirectly, e.g. by optimizing route length.

Transportation is among the successful application areas of **operations research**. According to Crainic [12] typical tactical decisions concern the design of the service network which includes the following issues.

1. *Service selection*: The routes on which regular transport services will be offered and their characteristics, e.g. frequency or mode of transport. This issue affects the means of transport.
2. *Traffic distribution*: The service routes used to move the traffic of each transport demand to its destination. This issue affects the cargo.
3. *General empty balancing:* Rules on how to reposition empty vehicles to meet the future needs of the next planning period in case of unbalanced traffic flows between regions.

A comparative analysis of 6 different service network design problem (SNDP) models was published by Wieberneit [13]. The models have very different characteristics and 'focus on a specific part of the whole tactical planning problem' [13]. None of the models can be used to solve the tactical planning problem of this paper.

In summary, no specific approach for the tactical planning of sustainable transportation of LSPs for customers from the automotive industry exists. Nevertheless it may be built on several ideas and concepts.

3 SUPPLY CHAIN STRUCTURE

The physical structure of an automotive supply chain can be classified into a production and a transportation network. The production network represents the view of an OEM. Customers, e.g. retailers and importers, have to be supplied with finished vehicles which are manufactured in car factories. Car factories are supplied with purchase parts by external suppliers (supplier traffic) and with original parts by internal suppliers, so-called component factories (inter-factory traffic). Component factories are supplied with parts by external suppliers. Suppliers and component factories are supplied with empty containers from car and component factories. Further nodes like supplier parks, transhipment points or warehouses may appear. The LSP's view is an extension of the production network by the transportation network which in this paper is considered in two layers: A road network and a rail network which are connected via road/rail-terminals. These networks are used to forward freight between origins and destinations of the production network. Shipments may be transhipped from road to road, from rail to rail, from road to rail or vice versa using adequate facilities. The relationship between LSPs and OEMs is n:m. LSPs have several automotive customers and use synergies by consolidating shipments and by optimizing empty runs.

4 ANALYSIS OF AS-IS STATE AND TO-BE-PLANNING PROCESS

From an LSP's point of view two **processes** within the tactical planning horizon are relevant. The planning of already contracted transports according to a forecast of an OEM and of new transports that are tendered by OEMs. Those two as-is process are modelled (see figure 1) using the Dortmund Process Chain paradigm [15]. It has to be remarked that the content of 'shared' process steps differs depending on whether they are part of the tender or the forecast-induced process.

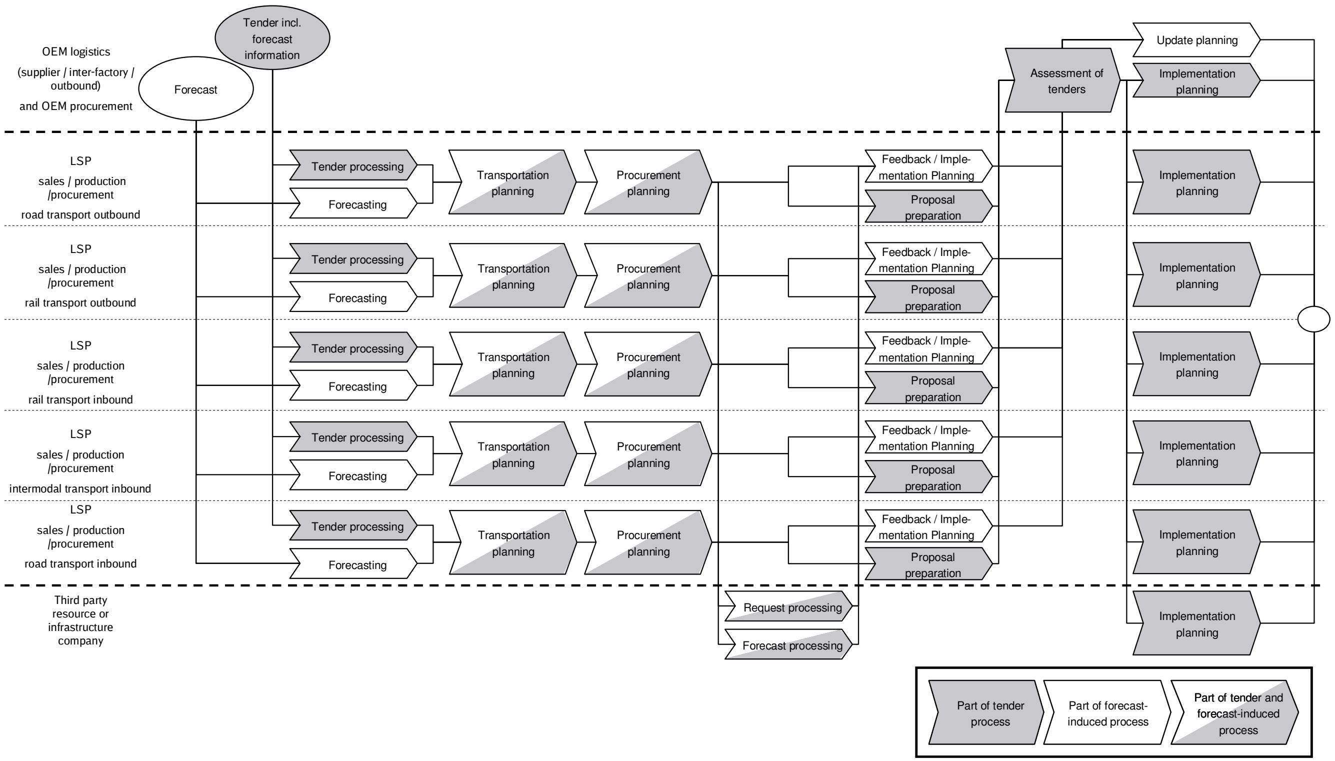

Figure 1: As-is planning process

The analysis of the processes especially leads to the following **findings and requirements for the to-be process**:

a. Separate planning of supplier, inter-factory and finished vehicle distribution transportation by the OEM and the LSP disregards synergy effects: Although the means of transportation for finished vehicles and parts are different, the planning of shared trains consisting of full and/or empty freight wagons for parts and for finished vehicles in one planning process is possible in principle and may lead to a shift from road to rail. For example wagons containing empties for parts could be merged with wagons containing finished vehicles, at least for a part of the haul. A complete trip in this train is mostly not possible due to different destinations. As a consequence the to-be process should enable the planning of shared trains to realize economies of scope. Therefore a planning process has to be established that spans organizational units for inbound (supplier and inter-factory) and outbound transports (see figure 2). The new process should not only cover one mode of transport but several: Rail, road and intermodal transport should be considered simultaneously, e.g. to anticipate how changes in the rail transport plan would impact on road transportation and vice versa. Ideally, the planning of the OEM would cover inbound and outbound transportation as well. Further, a planning process of the OEM should be established that takes place simultaneously to the transportation planning of the LSP and enables a collaborative planning.

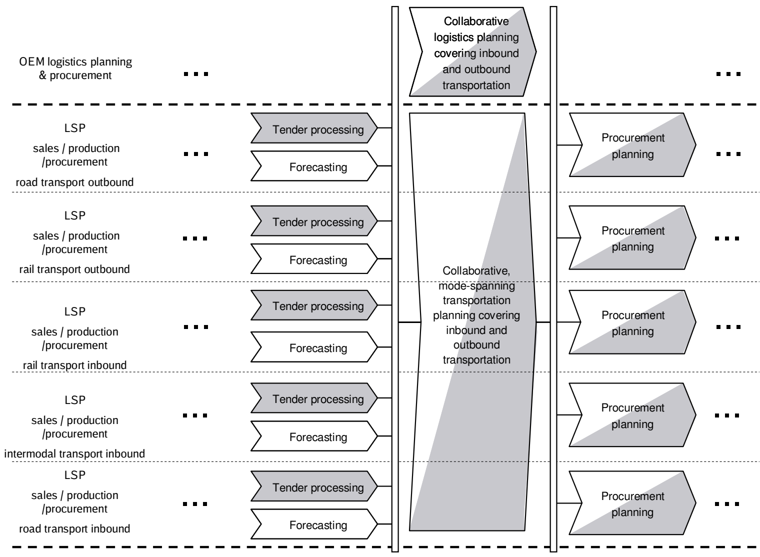

Figure 2: Structurally modified part of the to-be process

b. The specification of carbon dioxide emission for a planned transport scenario is often requested by the OEMs. But as for an LSP the influence of emission on the acceptance of a transport plan is not transparent, it would increase the competitiveness of the LSP to generate and offer several alternative eco-efficient transport plans from which the

OEM may choose one. To keep the number of alternatives limited, the sales department should define a target corridor for the transportation planning of a tender. Concluded contracts would include maximum levels of emission having to be kept during the forecast-induced adjustment process.

c. The consolidation operations of the dedicated rail service network for OEMs are reviewed very rarely although changes in demand could lead to inefficiencies regarding utilization and haul distance. Thus adjustments to the consolidation concept should be checked regularly, preferably in accordance to the rolling planning cycles of the railway companies. In Germany a completely new rail schedule is generated each year with the schedule being adjusted five times a year.

d. Lack of an adequate optimization tool for the complex multimodal transportation planning task especially taking into account ecological aspects and the operation of shared trains. Thus a decision support system shall be designed that generates parts of the eco-efficient frontier of solutions, considers shared trains and can be used for a collaborative planning (cp. figure 2).

5 DECISION SUPPORT SYSTEM

An adequate decision support system shall not replace but supplement existing sophisticated IT-tools for more detailed, specific planning tasks, such as a tool for the scheduling of locomotives. Due to its comprehensive application area that spans several transportation planning units it should be deployed upstream of those tools and be used by a team covering the relevant transportation planning units.

For this purpose a JAVA-based decision support system for ecological sustainable transportation planning (*EcoTraP*) has been developed. Its Input comprises transport demand, parameters for the objective function and for constraints. The future demand of different OEMs contains supplier and inter-factory demand measured in cubic meters and outbound demand measured in number of cars. The demand includes tender and forecast data which may already contain or later be given attributes that restrict its transport options. This may for example be used to set a mandatory mode for an order that is already contracted. The parameters for the objective function comprise information on cost and emission of the transport alternatives. Constraints include capacity restrictions of the means of transportation and the network infrastructure, which is represented by a graph $G=(N,A)$, being provided with a set of nodes N and a set of arcs A.

Core component is an optimization model that is solved by an IBM ILOG CPLEX optimizer. Result is a tactical transport plan that includes the decision on mode choice for rail, road and intermodal transport. Regarding rail different transportation concepts are considered (single car traffic (SCT), block trains, hub concept) including repositioning activities. Repositioning of road resources is also covered whereas road consolidation operations, e.g. pre-haul, are only considered approximately.

6 OPTIMIZATION MODEL

Main component of *EcoTraP* is a mixed integer optimization model that minimizes cost and emission of carbon dioxide (see figure 3). The model is an extension of the SNDP in path formulation. In this formulation, several arcs of the transport network are put together to paths *p* for commodities and to service routes *r* for means of transportation. The means of transport being represented in the model are trains, freight cars, trucks and intermodal transport units (ITUs). Concerning train transport the two main forms *m* are modelled: Dedicated block trains (direct or indirect) and single car transport. The decision variables z_r^b represent the frequency of dedicated trains on route *r* per planning bucket. Block trains are restricted to contain cargo of a single OEM or a group of cooperating OEMs *b*. At every stop of its route a number of wagons may be exchanged between trains. Simplifying and according to the supply chain segments and their characteristics three fleet types *f* of freight wagons y_r^{bfmq} are assumed: Vehicle transport wagons for car distribution, wagons with sliding sides mainly for inter-factory transport, and carrying wagons for intermodal transport units (ITU) w_r^b mainly for supplier transport. Each of the freight car types has a maximum capacity g^{fq} that limits the number of services in the planning horizon. The index *q* indicates if a transport is intermodal or not. x_r^{bfq} is the number of trucks that is used to haul the percentage v_p^{bkf} of the total volume of commodity *k* from origin *o(k)* to its destination *d(k)*. η^{kf} is a factor used to convert v_p^{bkf} into a capacity need. Unit of measure for parts is cubic meters and for finished vehicles is their number. α_{ij}^r indicate whether arc *(i,j)* is part of the route *r* (α_{ij}^r=1) or not (α_{ij}^r=0). ε_{ij}^p specify whether arc *(i,j)* is part of the path *p* (ε_{ij}^p=1) or not (ε_{ij}^p=0). β_i^r indicate whether route r starts from i (β_i^r=1) or not (β_i^r=-1).

The objective function (1) minimizes cost and emissions simultaneously. This comprises costs h and emissions l for moving empty means of transportation over a service route. θ^b is the weighting factor for emissions. Further, shipment flow cost c_p^{kf} and shipment flow emissions q_p^k are considered. As the main driver for shipment flow cost and emission is weight, v_p^{bkf} is converted into tons by a factor υ^k. Restrictions (2) ensure the maximum capacity of trains κ is not exceeded by the accumulated length of the freight wagons ρ^f. Constraints (3), (4) and (5) make sure that the capacity λ^f, ν, μ^f per freight wagon, ITU and truck is held. (6) and (7) restrict the number of ITUs λ and μ per freight wagon and truck. Restrictions (8) ensure that the demand of each commodity d^{kf} is satisfied. (9), (10) and (11) represent the balancing of freight wagons, trucks and ITUs. In this case other assets like railway locomotives or personnel are procured 'one way' and thus do not have to be repositioned by the LSP. (12) restrict the accumulated, weighted distances δ^{fm} of freight wagons by their fleet capacity g^{fq}; other assets are assumed to be available unrestrained. Restrictions (13) offer the opportunity to set minimum or maximum volume levels per path, e.g. to set contracted volumes fix for a certain path or to eliminate paths due to the preference of an OEM. Constraints (14) - (18) ensure the variables are nonnegative and that the most important design variables z_r^b are integer and offer a minimum service level (number of departures ω_f^b) to the OEM. As the required level of detail regarding other assets is lower and the model would not be solvable due to their large number, the other variables are modelled continuously.

$$\min \sum_{b\in B}\sum_{r\in R^z} h_r^z z_r^b + \sum_{f\in F}\sum_{m\in M}\sum_{q\in Q}\sum_{r\in R^y}\sum_{b\in B} h_r^{yfmq} y_r^{bfmq} + \sum_{f\in F}\sum_{q\in Q}\sum_{b\in B}\sum_{r\in R^x} h_r^{xf} x_r^{bfq} + \sum_{b\in B}\sum_{r\in R^w} h_r^w w_r^b$$
$$+ \sum_{f\in F}\sum_{k\in K}\sum_{b\in B}\sum_{p\in P^k} c_p^{kf} \upsilon^k v_p^{bkf} + \sum_{b\in B}\sum_{r\in R^z} \theta^b l_r^z z_r^b + \sum_{f\in F}\sum_{m\in M}\sum_{q\in Q}\sum_{r\in R^y}\sum_{b\in B} \theta^b l_r^{yfmq} y_r^{bfmq}$$
$$+ \sum_{f\in F}\sum_{q\in Q}\sum_{b\in B}\sum_{r\in R^x} \theta^b l_r^{xf} x_r^{bfq} + \sum_{b\in B}\sum_{r\in R^w} \theta^b l_r^w w_r^b + \sum_{f\in F}\sum_{k\in K}\sum_{b\in B}\sum_{p\in P^k} \theta^b q_p^k \upsilon^k v_p^{bkf} \quad (1)$$

$$\sum_{r\in R^{ym}}\sum_{f\in F} \rho^f y_r^{bmfq} \alpha_{ij}^r \le \sum_{r\in R^z} \kappa z_r^b \alpha_{ij}^r \qquad \forall (i,j)\in A, b\in B, m\ne SCT, q\in Q \quad (2)$$

$$\sum_{k\in K}\sum_{p\in P^{ky}} \eta^{kf} v_p^{bkf} \varepsilon_{ij}^p \le \sum_{m\in M}\sum_{r\in R^{ym}} \lambda^f y_r^{bfmq} \alpha_{ij}^r \qquad \forall (i,j)\in A, b\in B, f\in F, q\ne \text{intermodal} \quad (3)$$

$$\sum_{k\in K}\sum_{p\in P^{kw}} \eta^{kf} v_p^{bkf} \varepsilon_{ij}^p \le \sum_{r\in R^w} \nu w_r^b \alpha_{ij}^r \qquad \forall (i,j)\in A, b\in B, f\in F \quad (4)$$

$$\sum_{k\in K}\sum_{p\in P^{kx}} \eta^{kf} v_p^{bkf} \varepsilon_{ij}^p \le \sum_{r\in R^x} \mu^f x_r^{bfq} \alpha_{ij}^r \qquad \forall (i,j)\in A, b\in B, f\in F, q\ne \text{intermodal} \quad (5)$$

$$\sum_{r\in R^{wy}} w_r^b \alpha_{ij}^r \le \sum_{r\in R^y} \lambda y_r^{bfmq} \alpha_{ij}^r \qquad \forall (i,j)\in A, b\in B, \; q=\text{intermodal}, f=\text{supplier transport} \quad (6)$$

$$\sum_{r\in R^{wx}} w_r^b \alpha_{ij}^r \le \sum_{r\in R^x} \mu x_r^{bfq} \alpha_{ij}^r \qquad \forall (i,j)\in A, b\in B, m\ne SCT, \; q=\text{intermodal}, f=\text{supplier transport} \quad (7)$$

$$\sum_{p\in P^k} v_p^{bkf} = 1 \qquad \forall k\in K, f\in F, b\in B \quad (8)$$

$$\sum_{b\in B}\sum_{q\in Q}\sum_{m\in M}\sum_{r\in R^m} \beta_i^r y_r^{bmfq} = 0 \qquad \forall i\in N, f\in F \quad (9)$$

$$\sum_{b\in B}\sum_{q\in Q}\sum_{r\in R^m} \beta_i^r x_r^{bfq} = 0 \qquad \forall i\in N, f\in F \quad (10)$$

$$\sum_{r\in R^m} \beta_i^r w_r^b = 0 \qquad \forall i\in N, b\in B \quad (11)$$

$$\sum_{b\in B}\sum_{m\in M}\sum_{r\in R}\sum_{q\in Q} \delta^{fm} y_r^{bfmq} \le g^{fq} \qquad \forall f\in F \quad (12)$$

$$\chi_p^{bkf} \le v_p^{bkf} \le \phi_p^{bkf} \qquad \forall p\in P, b\in B, k\in K, f\in F \quad (13)$$

$$z_r^b \ge \omega_r^b \text{ and integer} \qquad \forall r\in R^f, b\in B \quad (14)$$

$$y_r^{bfmq} \ge 0 \qquad \forall r\in R^m, b\in B, f\in F, m\in M, q\in Q \quad (15)$$

$$x_r^{bfq} \ge 0 \qquad \forall r\in R^m, b\in B, f\in F, q\in Q \quad (16)$$

$$w_r^b \ge 0, \qquad \forall r\in R^f, b\in B \quad (17)$$

$$v_p^{bkf} \ge 0 \qquad \forall p\in P^k, b\in B, k\in K, f\in F \quad (18)$$

Figure 3: Optimization model

7 COMPUTATIONAL STUDY

For testing purposes a scenario with two OEMs, 21 nodes, representing production and transportation facilities, and 31 transportation orders was built up. Each order contained the aggregated demand of cars, parts or empties of one week from origin to destination. Except for the inter-factory transport orders the respective amount of goods of each order was not sufficient for train transport. To examine in how far the to-be process and EcoTraP may support using synergies, three scenarios were compared regarding cost: In scenario one, each order is planned separately. In scenario two orders of inbound transportation (including inter-factory) and outbound transportation are planned separately. In scenario three inbound and outbound transportation are planned simultaneously. Compared to scenario one, the cost benefit of scenario two was 7,9% and of scenario three was 11,7%. Reason for the improvement were adequate consolidation operations plans. In scenario one the means of transport are limited to trucks except for inter-factory transport. In scenario two three further train services each for finished vehicles and for parts resulted. In scenario three another six shared train services are suggested by *EcoTraP*.

Further, the effect of the integration of carbon dioxide emission into the objective function was analyzed for the third scenario. Carbon dioxide was weighted with values between 0 and 10 € per ton. The relationship between cost and carbon dioxide emission is illustrated in figure 4. Due to the relatively small size of the transport network and little consolidation possibilities only three alternative transportation plans could be generated that could be offered to the OEMs. As expected, it may be observed that a reduction in emission would cause an increase in cost and vice versa. A slightly convex character of the set of examined solutions indicates that the solutions are eco-efficient.

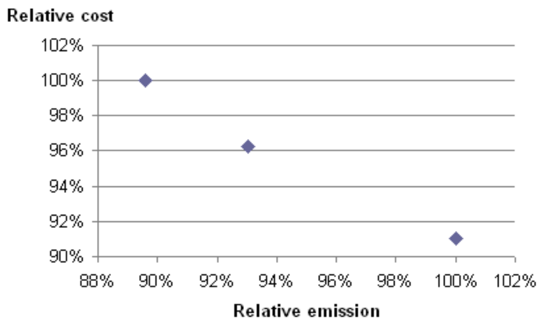

Figure 4: Cost-emission relationship of test scenario

8 SUMMARY

In this paper, an improved tactical planning process for sustainable transportation in the automotive industry by LSPs was presented. The process has a rolling character, covers the planning activities for different modes of transport, and enables the planning of shared trains consisting of freight wagons for parts and for cars by simultaneously taking into account the inbound as well as the outbound activities. To support decision making in the future process a decision support system was designed and implemented. The tool determines several positions on the eco-efficient border and allows for the collaborative planning of one LSP and several OEMs. Main component is an optimization model which is an extension of the SNDP. It considers cost and carbon dioxide emission as well as multiple freight wagon fleets which is important for the planning of shared trains.

Several test scenarios have been created to show the benefit of planning process and decision support system. It could be shown that the planning of transport consolidation in general and of shared trains have positive impact on the efficiency of this scenario. Further, the relationship between cost and emission in this scenario was examined. As only small scenarios were tested, further research should be directed to examine the solvability of larger instances and adequate solutions methods. This would be required for extending the model e.g. with uncertainty, more fleet types or a time dimension to catch demand fluctuations.

9 REFERENCES

[1] Brunner, M., 2006: Strategisches Nachhaltigkeits-Management in der Automobilindustrie – Eine empirische Untersuchung, DUV.

[2] United Nations World Commission on Environment and Development, 1987, Our Common Future, Oxford University Press, Oxford.

[3] European Council, 2001, 2340th Council Meeting – Transport/Telecommunications - Luxembourg, 4-5 April 2001. Belgium.

[4] European Commission Directorate-General for Energy and Transport, 2008, EU energy and transport in figures - Statistical pocketbook 2007/2008. Luxembourg.

[5] European Commission Directorate-General for Press and Communication, 2003, Europe at a crossroads. The need for sustainable transport, Belgium.

[6] Souren, R., 2000, Umweltorientierte Logistik, in: Dyckhoff, H., Umweltmanagement. Zehn Lektionen in umweltorientierter Unternehmensführung. Springer, Berlin, Heidelberg, New York.

[7] Meixell, M. J., Norbis, N., A review of the transportation mode choice and carrier selection literature, The International Journal of Logistics Management, 18(1), 2007, 125-150.

[8] Huppes, G., Ishikawa, M., 2005. A Framework for Quantified Eco-efficiency Analysis, Journal of Industrial Ecology 9 (4), 25–41.

[9] Meyr, H., 2002: Kurz- und mittelfristige Planung in der Automobilindustrie zwischen Heute und Morgen. Universität Augsburg, Lehrstuhl für Produktion und Logistik.

[10] Kuhn, A.; Hellingrath, B.; Hinrichs, H.: Logistische Assistenzsysteme. Huss-Verlag, München 2008.

[11] Hellingrath, B., Schürrer, S., 2009, Energieeffizienz und Umweltbilanz von Supply Chains, in: Ten Hompel, M., Software in der Logistik. München, Huss, Logistik Praxis, S.16-21.

[12] Crainic, T.G., 2000, Service network design in freight transportation, European Journal of Operations Research, 122, 272-288.

[13] Wieberneit, N.: Service network design for freight transportation: a review, OR Spectrum, 30(1), 77-112.

[14] Kuhn, A., 1995: Prozessketten in der Logistik: Entwicklungstrends und Umsetzungsstrategien, Verlag Dortmund, Praxiswissen.