Development of a Simulation Model for Multimodal, Cross-Company Logistics Networks

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Abstract. Continuous cost pressure causes companies to move production sites to low cost countries. Although production costs decline, logistics costs are negatively affected. Individual companies with limited shipment volumes do not have access to cost efficient and highly productive transport networks. Multimodal, cross-company logistics models are one approach to open up the potentials of transport networks for companies. This paper deals with the conceptual design and evaluation of cross-company logistics models. A new, holistic simulation and evaluation model was designed for development support of multimodal logistics concepts and potentials are validated instancing an example region.

Keywords: Logistics, Simulation, Evaluation.

1 Introduction

Progressive globalization and rising cost pressure in the automotive industry are increasingly forcing car manufacturers and component suppliers to set up new production sites in or move existing locations to low-wage region [1], [2]. It is for this reason that Central and Eastern Europe (known as CEE) became a popular target for relocation. These new production sites often just assume the supplier and customer structures of the parent plants. Approximately two thirds of suppliers as well as customers of Eastern European Tier 1 suppliers are still situated in Western Europe (Figure 1), [3].

However, benefits tend to fall short of predicted cost advantages, due to rising wage costs (in particular in industrial regions). The automotive industry in particular is thus focusing on the costs of transport logistics arising from intense transportation between Eastern and Western Europe.

The trend towards relocation has shown that the exchange of goods leads to new demands and challenges for transportation and logistics [4]. Business networking

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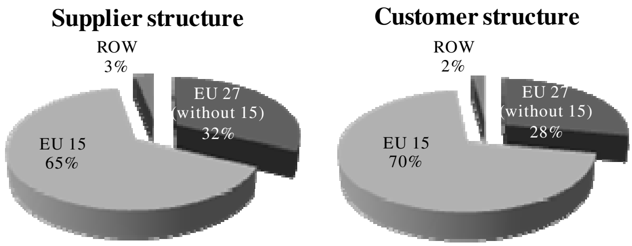

Fig. 1. Demonstration of supplier and customer structure of suppliers in the CEE region[1]

strategies and especially cross-company co-operation is one of the key factors to improve in production issues as well as in logistics and hence to survive in competitive markets [1], [5].

Based on this situation, a new simulation and evaluation model, which supports the development and evaluation of new logistics concepts, was developed. It is used for the validation and evaluation of cross-company logistics models. Due to the new, holistic evaluation approach potentials for optimization in the areas emissions, costs and logistical competitiveness are targeted on developing new sustainable and energy-efficient logistics models.

2 Cross-Company Logistics Models

The currently applied logistics processes, especially for the specific needs of individual enterprises in automotive industry do not appear optimal from a holistic point of view[2]. Deficits might emerge from direct transport running far beyond capacity, use of small transport carriers, less-than container load (LCL) with long running times or multiple handling steps as well as bad transportation tariffs due to small quantities. High stocks and capital tied up are results of this inefficiency. Since many companies have a similar source-target-behavior the potential of cross-company bundling to optimize transport efficiency is high.

2.1 Logistics Networks

There are various approaches for cross-company logistics models that conform to the general network model of logistics. These models represent networks transporting rights, goods, finance and information where spatial, quantitative, informational and temporal differences as well as company boundaries are crossed [6]. Parameters defining the structure of a logistics network are paramount [7]:

- Number, locations and functions of source points (= loading locations, making goods available),

[1] EU 15: member countries of the European Union prior to May 2004, EU27: current member countries of the European Union.

[2] This is part of the result of a questionnaire of 7 automotive enterprises in the near region of Timis in Romania in the course of the research project Trans Austria.

- Number, locations and functions of target points (= unloading locations, points of reception),
- Number, locations, functions of connections or nodes between sources and targets.

The network nodes are called transshipment terminals. This implies that only transshipment but not storage in general (no inventory) is foreseen at these locations. Transshipment terminals serve as consolidation terminals where the flows of goods are collected and/or as break-bulk terminals where the flows are in turn distributed [7]. The **basic structure** of transportation links can be represented either as **direct connection** ("point-to-point" transport) in its simplest form (single-stage, uninterrupted transport chain) or as a **multi-stage system** with preliminary leg, main leg and subsequent leg with transshipment terminals where the network nodes serve as consolidation terminals where the flows of goods are collected and/or as break-bulk terminals where the flows are in turn distributed.

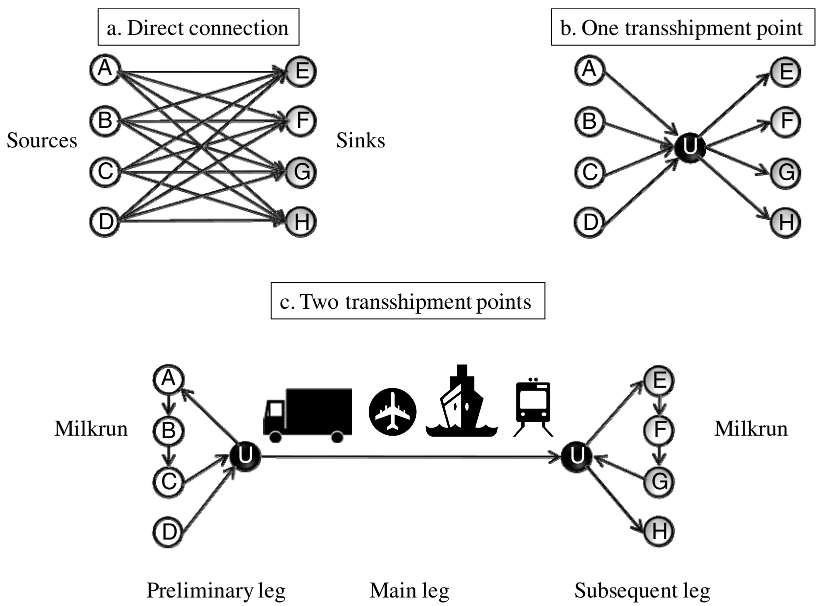

Fig. 2. Illustration of consolidation by means of transshipment points [8]

The mixture of logistics systems made up from the given basic structures is decided in the logistical network structure. The processes are designed when the logistical capacities are superimposed on this. The logistical capacity can be subdivided into transport capacity, warehousing capacity and information capacity. In addition to the basic structure of the systems, the speed of traffic flowing between the individual points in the system must be taken into account [9]. The network strategy is also based on geo-economic considerations such as the long-term development of customer demand or the development of the required delivery time.

Summing up, the criteria logistics costs, supply service, adaptability, susceptibility to interference, transparency and time for planning and establishment of the system are important in the moment of developing and evaluation logistics models [9].

2.2 Consolidation of Shipments

As described in the initial situation, optimization of transports for individual businesses does not appear ideal; therefore companies can align with partners to a logistical cooperation and bundle transport volumes. Bundling, also referred to as consolidation, happens when transport volumes are combined to form larger transport batches in order to allow more efficient and more frequent shipping by concentrating large flows onto relatively few links between terminals, thus lowering transport unit costs and the unit costs of incoming or outgoing goods at their starting or target points. The starting points for the scenarios for transport bundling are the individual parameters of the logistical network structure. The following forms may thus be used:

- Source-point bundling often following the principle of the "milk run" (the shipments intended for a particular destination are collected from several places of shipment, from neighboring places of shipment or from a shipment region and processed together)
- Target-point bundling, where shipments from one place of shipment intended for several destinations or for a delivery region are processed jointly and transported together and
- Transport bundling, where shipments are collected and delivered in one tour

Further forms of bundling can be inventory bundling or temporal bundling, and vehicle bundling and transshipment point or transit terminal bundling as forms of spatial bundling (Figure 2). The number of transports between sources and targets can be reduced by the setup of transshipment points from m x n to m + n, m and n being the number of source and target points [10], [11].

Bundled transport over the long run between 2 transshipment points can raise high potentials due to low transport costs and efficient use of transport capacities [12]. Logistics performance is improved by the raised frequency of transports. Overall every bundling type must meet the requirements of savings through consolidation of synergy effects to cover higher transport costs, operation costs of handling points or longer distances of time frames in comparison with direct relations.

The goal to reduce logistics costs while keeping logistics quality at the same level or raising the quality (delivery times, adherence to delivery schedule) is the main focus when designing the transport network. An iterative method is needed to evaluate the impacts of modifications in logistics models regarding ecology, economy or logistic competitiveness.

Transport bundling or cross-company logistics networks are originally based on the idea of good distribution in urban centers. The different approaches can be summed up with the term city logistics [13]. Other known developments of transport bundling of different suppliers are area contract freight forwarders, bundling and delivering goods for one plant conjointly. Collaborative approaches and the logistics models in this case are mainly based on the following premises:

- Identification of route sections where transport volumes can be handled with efficient transport carriers
- Availability of adequate partner for transport bundling on route sections (legs)
- Possibility of individual businesses to efficient usage of carriers
- Distance from source to target of possible nodes considering impacts of variance from ideal path
- Prioritization from transport volumes given limited capacities of one carrier in the main run as a result of different impacts on target categories
- Possibility to change transport frequency

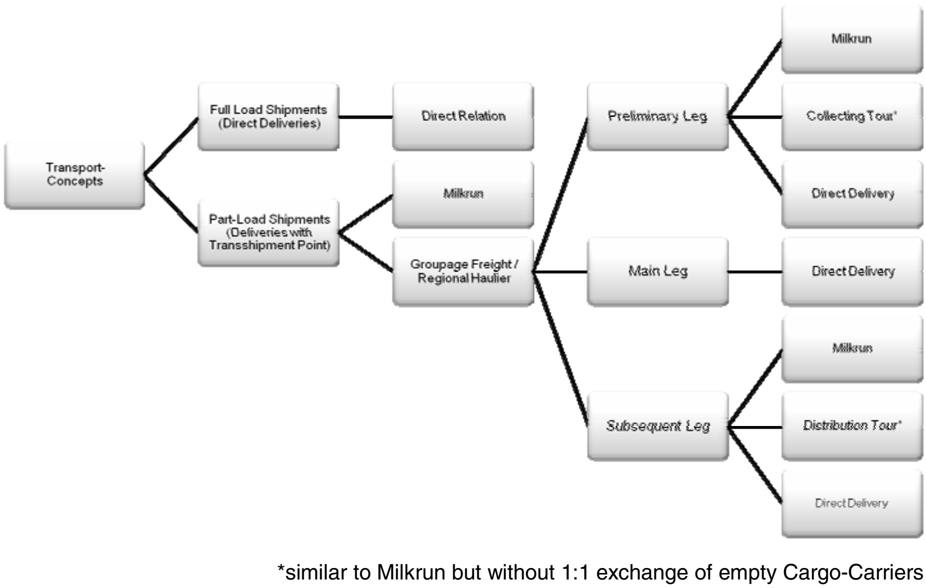

Fig. 3. Overview of logistics models considered

3 The Evaluation Model and the Simulation

The control variables required to achieve the objectives (minimize emissions, reduce costs of logistics and increase logistical competitiveness) are the following:

- Traffic avoidance: organize transport more efficiently (improve vehicle utilization, cut down on transport capacity)
- Bundling of goods flows: consolidate in order to optimize the substitution relationship between transport and inventory costs
- Switching freight transport to other means of transport: inter-modal transport

In the long run, it is also necessary to validate the results of the model's conceptual design. This should be performed in accordance with the main target dimensions - emissions, costs, and competitiveness.

It is in particular the intermodality aimed for in the models that plays an important role in the evaluation of this target dimension. In this point, only a selection of the most harmful emissions - CO_2, NO_X, and amounts of particulates - is analyzed; they are mainly accounted for in the dominant means of transport - road haulage. The emission levels are mainly dependent on the journey, i.e., distance covered by the predefined journey profile and on the allocated transport resource. Diesel or electrical power consumption also plays a decisive role in the output of emissions.

The cost calculation model is somewhat more extensive and can be subdivided into three different categories (Transport costs, transshipment costs, and inventory costs). When it comes to transport costs, it is important that the model is based on the actual costs incurred, i.e., the overhead costs, road charges, customs clearance, and wage costs, and not on the transport tariffs charged by shipping companies. The road charges are particularly difficult to determine due to differing systems in the individual countries, and they play a considerable role in determining the route.

$$C_{Total} = C_{Transport} + C_{Handling} + C_{Inventory} \tag{1}$$

$$C_{Transport} = C_{Transport\ Truck} + C_{Transport\ Train} + C_{Transport\ Plane} + C_{Transport\ Ship} \tag{2}$$

$$C_{Handling} = \sum_{i=1}^{n} Quantities_{Change\ of\ Resource} \cdot C_{Transshipment\ (Change\ of\ Resource)} \tag{3}$$

$$C_{Inventory} = C_{Capital} \cdot C_{Warehousing} \tag{4}$$

The third criterion in evaluating optimization models is logistic competitiveness, which is made up of the ability to deliver (a measure of the extent to which the company can guarantee the logistical service requested by the customer - short delivery times compared to the competition are especially important for a high ability to deliver) and delivery reliability (delivery reliability rates the service provision of the logistics process - it indicates the proportion of the complete and punctual deliveries compared to all delivery orders) [14].

Against this background, it becomes apparent that the cooperative planning of multimodal transport is affected by a multiplicity of factors. Numerous interdependencies between these parameters and the goal criteria such as costs, emissions, or flexibility exist. The evaluation model thus has to solve the conflict of goals like the trade-off between costs and guaranteeing competitiveness by applying stocks.

Beyond that, the identified parameters are in reality very often afflicted with uncertainty. These affects frequently influence the quality of material planning decisions and transport planning considerably.

Owing to dynamic interactions and taking stochastic phenomena into account, a static estimation of the behavior is difficult or almost impossible. Simulation has satisfactorily demonstrated its ability to illustrate and evaluate systems with dynamic behavior.

In order to provide a simulation model for logistics operators, the system-specific characteristics in a suitable simulation environment have to be illustrated. To achieve flexibility in planning regarding changes of logistics models or changes of the basic conditions, it is useful to provide a generic and easily adaptable model. For this purpose, the models of intermodal transport were illustrated within an application platform for simulation. This simulation environment permits the illustration of various technical models in a modeling environment adaptable to the planning domain. Furthermore, the environment permits an automatic derivation of simulation models and a return of the results to an economic or ecological level. In this section, the fundamental methods of the application platform simulation and the development of a simulation model for the planning of multimodal transport are described.

3.1 Application Platform for Simulation

Depending on which simulation tool is chosen from the set of tools with different universal validities and application references, the simulation expert can access more or less preconfigured building blocks. Special simulators contain solutions matched to the specific area of the domain of application, thus simplifying handling. The higher the degree of universality, the more varied the possibility of creating and depositing own functional building blocks becomes; however, the necessity of a simulation-specified training increases as well. The application environment developed by V-Research deals with simulation models in production and logistics.

To execute a conventional simulation study, a substantial amount of time and money has to be invested, which still prevents small and medium-sized businesses to apply those. To prevent a planner, who is usually well trained in his respective systems domain, from dealing with the simulation expertise itself, it is helpful to develop an instrument that lets him answer upcoming questions without specific simulation know-how in an accessible amount of time. Thus, the planner is able to define planning tasks, generate models, analyze results, and optimize those results by comparing different scenarios.

The core of the platform represent application related and technically oriented components that base on the utilization of open industry standards (.Net Framework 2008) and reliable, well-tested simulation software. The concept embraces the idea that each simulation study needs certain key functions and procedures; contains customer and project specific characteristics and requirements; should be expandable concerning detailing, functionality, and system boundaries; and lets other users (e.g. customers) enhance the model.

The separation between task specific and resource specific components is reflected in the structure of the application environment. Task specific components summarize all aspects concerning process logic of an application that are illustratable by a (production and/or logistic) system. Examples would be the definition of manufacturing technologies used for processing orders, process outcomes, product structure etc.; logistical sequencing strategies (push, pull, KANBAN, …); organizational classifications (employees assigned to department and resources, shift schedules, …); as well as an architecture for administering simulation runs, result data, and shift schedule data.

These components signify the applied level. The technical level comprises the structure of a production and logistics system. The resources (machines, means of transportation, tools, …) are systematically described in predefined components. In order to create a complete model, these project specific resources are substantiated and incorporated into a basic model. The entire architecture thus differentiates between technical components, application oriented components, and the actual business application. The business application represents the simulation study, which can be made up of a number of simulation experiments. The component model is well suited for customer specific simulation applications within a short period of time.

3.2 Simulation Model for the Planning of Multimodal Transport

By describing the behavior and the possibility of providing process cycle time fluctuations using distribution functions, so-called confidence intervals can be determined through a number of replications (simulation runs with independent random variables) which allow a prediction to be made as to the bandwidths where the target dimensions are likely to be with a given level of probability.

The basis for the simulation model is formed by individual logistical building classes (factory, transshipment centre, etc) that can be combined with one another to represent any desired logistics concept (point-to-point transportation, consolidation terminals, milk run). These building classes are created in the simulation environment Flexsim®. Structural, procedural, and resource-related data are required in order to model with the simulation system. By modeling with building classes, it is possible to describe both the structure and the behavior of individual resources independently, as well as their interaction with other building classes. This inherent knowledge contained in the individual building classes is used and extended by configuring the building classes to form an overall model.

The central technical construct in the domain transport planning is the route, which represents a given start-destination-relation, for example between a loader in Eastern Europe and a Western European production facility. This route is either being served by a direct relation or by intermodal transport, which is usually conducted through certain hubs. In any case, the chosen domain model displays the relations from start to destination between Eastern and Western production locations. The actual routes taken were tracked via GPS and then contributed into the system's data. The information includes not only kilometers driven for the running time calculation, but also other data such as altitude profiles. These profiles further refine the simulation model leading to consumption and emission data of the transport resources to be implemented in the model.

The system load of the simulation model is determined by the output of products on the loader's side, which is being processed in form of a tabulated schedule. A profile of each originating plant is defined therein, stating which products are being put out in which amount at what time. The running time of the simulation is thus supplemented with the corresponding number of product objects that later undergo the defined transport process (stated below).

Transport resources are active parts when it comes to bridging regional distances within the domain model. In the case of the afterwards presented application various types of trucks and trains are displayed in the model. Transport resources are matched with certain routes and characterized by a number of attributes. Besides loading and unloading times for the transport resource, triggers have to be defined when a transport resource leaves a location (e.g. every Monday 8 a.m.). Furthermore, additional data can be added to the model, such as cost, consumption, emissions, or any local- or time-specific data. Therefore, the model is formed in a way that specifies consumption data for different types of trucks and diesel locomotives. In case of electrified railways, the proportionate emissions for the necessary power are included as ecologic target factors in the simulation for each country.

In the domain model, a plant can serve as a starting point or as a destination, or even as a hub to add products to or discharge items from the transport. Product objects are created in the course of simulation, beginning at the starting plant with a time-amount-profile, and they are dissolved after reaching the destination.

The handling point describes a special location along the route, with incoming transports being unloaded and leaving transports prepared for the next trigger with their inherent loading and idle times (see transport resource).

In contrast to the handling point, no change of transport resource and no transshipping take place at a processing point. This simulation block simply represents a location where the transport is halted for a certain handling time, calculated as a stochastic variable. This method enables the display and calculation of customs clearance at national borders. The handling itself is not directly calculated due to model simplification, and it is thus represented by idle time.

Beside of these simulation blocks, the transport process is an integral part of the simulation model. The later presented application includes a process that starts off with the production of products at a starting point and ends at the destination point, where the products are destroyed. On closer inspection, the transport starts, when a specified amount of products is available at a certain location and the starting trigger for a certain means of transportation is activated. Consecutively, the transport process is being planned according to the route; the products are loaded on the transport resource and then transported to the next stop on the route. If the next stop is a plant or handling point, the products are unloaded and, if needed, prepared for the next shipment. In case of the next stop being a handling point, the idle time is applied and the transport continues. Upon arrival and unloading of the transport, the respective products are destroyed in the simulation environment and the simulation run is ended.

Throughout this process, the running time and its contributing factors of each process entity, such as time needed for loading procedures, handling activities, driving times, and emissions depending on the road profile (distance, incline, street conditions), are logged. After the simulation, this logged data supplements the results analysis. A historiography of the granulated simulation data in a database enables detailed and flexible analyses and a deduction of key performance indicators. The (logistic) results drawn from the simulation can consequently be applied to calculations with data sources concerning emission behavior, for cost analyses, and for comparisons whether logistics targets have been met. The model structure simplifies changes made to the parameters (e.g. varied transport cycles, use of various traffic resources and carriers etc.), and a comparison of the effects on the three target areas economy, ecology, and competitiveness is enabled. Based on the opposed target dimensions, a decision can only be made through comparing different scenarios and considering the pros and cons of all compromises.

4 Application of the Modeling Approach to a Romanian Automotive Cluster

In a research project funded by the Federal Ministry for Transport, Innovation and Technology (BMVIT) as well as the Austrian Research Promotion Agency (FFG) the developed logistics models are demonstrated by means of the region Timis in Romania. Focusing on 7 automotive companies volumes of outgoing transports were analyzed. Starting from the current state of individual transports, different scenarios were defined. The scenarios are aimed at cost reduction and sustainability in using modes of transport for high volumes like rail traffic.

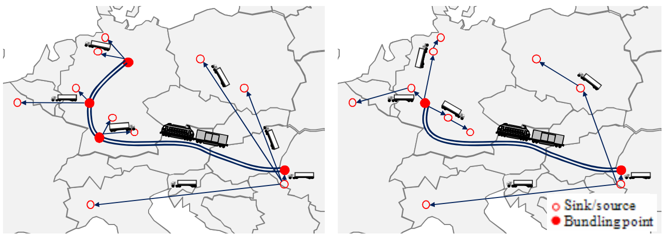

Fig. 4. Scenarios 1 and 2 [15]

Figure 4 shows 2 defined scenarios of transport bundling for the Timis Region. Scenarios 1 using block train with 3 stops and direct relations from the end of the train not considering locations in Poland and Italy that cannot profit from consolidation with the block train. Scenario 2 limits the block train to one stop but bundles transports further leaving the train to their final destinations. Destinations not considered in the main leg bundling where consolidated as well. Shifting the main leg to railway and optimizing the collection and distribution of goods from and to transshipment points logistics costs could be reduced by 15 % in the given case. The ecological impact in reduction of CO2 emissions by 40 %, cutting fuel consumption in half, shows the success in more than one target dimension. The main deficit of the models is overcoming the doubled lead time coming from the ceteris paribus inspection of transports.

In addition to the simulation and evaluation of scenarios a sensitivity analysis was executed to cover the ecological and economical results. Therefore the evaluated scenarios indicated were simulated with lower basic loads keeping all other factors stable. At a level of 70% of the load, block train concepts as well as the transfer of 66% of transports to railroad could be maintained. Negative effects of the change in basic loads were determined in the capacity utilization of transport capacities and the flexibility especially for block trains. Nevertheless the developed transport concepts and cross-company models can stand up to the actual transport handling. Economic considerations show lower costs of scenarios compared to the actual situation. Therefore the model indicated shows full functionality even with fluctuation of volumes and prices.

5 Concluding Remarks

This paper visualized models to simulate and evaluate potentials of transport bundling for cross-company logistics networks to identify those potentials given a specific case. The research project Trans Austria demonstrated the similar source-sink-behavior for companies and thus the potential of cross-company transport bundling.

The empirical analysis showed the great complexity of the problem that was built in a simulation framework and therefore the challenge for possible implementations which constitute further research developments. Optimization of the given set of problems would be a possible expansion keeping in mind the time and cost needed to set up the base and ensuring the transferability of an optimization model.

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