INTEGRATED OPTIMIZATION OF TRANSPORTATION AND SUPPLY CONCEPTS IN THE AUTOMOTIVE INDUSTRY

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KEYWORDS

Inbound logistics; supply concept; transportation concepts; cost optimization; CO2 emissions

ABSTRACT

A growing cost pressure due to increasing transportation costs and a changing environment call for a flexible adaptability of the inbound logistics processes in the automotive industry. Therefore, these processes need to be continuously reviewed for efficiency potentials. This paper provides an optimization model that allows for the integrated cost assessment of supply and transportation concepts. Additionally, the idea of green logistics is addressed by including the costs for carbon dioxide (CO2) emissions in the optimization model. The model is applied to an industrial case of a commercial vehicle manufacturer. The results show that delivery frequencies and the consideration of the entire material flow of a transport relation are main influence factors. The integration of CO2 emissions shows that the emissions can be reduced while only slightly increasing logistics costs.

MOTIVATION

Globalization, expansion of new markets, and fast changing environments are core challenges in the automotive industry leading to increasing logistics costs (Göpfert, 2013). Inbound logistics, which is the link between suppliers and manufacturers, is particularly concerned by these developments. This is because the inbound logistics embraces transportation and the respective costs. These transportation costs encompass a high share of the total logistics costs (Bravo and Vidal, 2013). Besides increasing transportation costs, progressive environmental pollution is a prominent issue nowadays. Larger transport distances are one main driver for environmental pollution. Thus, a continuous improvement of the inbound processes is required. Consequently, inbound logistics should be configured cost efficiently and at low emissions using different transport and supply concepts. Literature shows that these objectives are mainly addressed exclusively. Hoen *et al.* (2014) integrate CO2 emissions in the selection process of transport concepts. This is also one of many approaches for the quantitative selection of transportation concepts. For supply concepts, very few quantitative approaches exist and focus rather on the in-house logistics costs than on the inbound costs (see e.g. Wagner and Silveira-Camargos, 2011). The available qualitative approaches in literature for selecting those concepts focus either on supply or transportation, and do not address costs or emissions. Supply concepts are often chosen based on the parts' characteristics, such as the value or fluctuations in consumption (see e.g. Wagner and Silveira-Camargos, 2011). A qualitative approach to selecting the transportation concept is a decision tree using different criteria, such as delivery frequency or supplier location (see e.g. VDA-5010). To meet the gap in research we have provided an approach that combines the selection of transportation and supply concepts into one quantitative model based on costs and emissions.

MODEL STRUCTURE AND ELEMENTS

Model Framework

Inbound logistics is defined as "Activities associated with receiving, storing, and disseminating inputs to the product, such as material handling, warehousing, inventory control, vehicle scheduling, and returns to suppliers" (Porter, 2004, 39f.). To conduct the described activities, different concepts for each activity are needed, such as transportation concepts and supply concepts (see Figure 1).

A supply concept defines the configuration of the logistics process from the supplier to the manufacturer. Supply concepts include direct delivery and in-stock delivery. The latter implies that there is at least one warehousing stage included in the process. Direct delivery concepts embrace Just-in-Time (JIT) and Just-in-

Sequence (JIS) (VDA-5010). JIT means the delivery of homogenous parts just in time they are needed at the assembly line. JIS additionally orders the parts corresponding to the production sequence (Wagner and Silveira-Camargos, 2011).

A transportation concept includes the description of the transport process and the necessary logistics service. We distinguish between three different concepts: Direct relation, milk run, and hub and spoke. Direct relation is a single-stage transport chain. Thus, the material is delivered directly from the supplier to the recipient. A milk run is used for smaller delivery volumes, because partial loads from different suppliers are consolidated into a full load. The hub and spoke concept contains three stages: In the pre-run the goods are transported to a hub; in the hub the goods are re-sorted; and in the main-run the re-sorted goods are directly delivered to the recipient. In the automotive industry, hub and spoke concepts are often implemented using area forwarding. The area forwarder is instructed to collect all part loads from a certain supplier area, to combine these loads and to forward them to the OEM. How the area forwarder is exactly combining the part loads and which tours are taken is not transparent to the OEM. Therefore area forwarding represents a black box for the OEM in terms of operating processes. The difference between hub and spoke and area forwarding lies in the occurring expenses and the process transparency (Schulte, 2009).

For a consistent understanding, we briefly explain the used terminologies and the considered inbound process: The combination of a part and a charge carrier is defined as a shipping unit. A packing batch is the number of parts the respective charge carrier contains. Thereby the volumetric weight can be determined, which is needed to calculate the freight rates. A shipping unit is transported from the supplier to the manufacturer by means of transport using a transportation concept. A transport relation is defined by the combination of a supplier and the receiving manufacturer plant. The parameters of the material planning, such as lead times, safety stocks, etc., represent restrictions that need to be met. Each part is delivered by a combination of supply and transportation concepts described above. This combination determines the subsequent in-house processes.

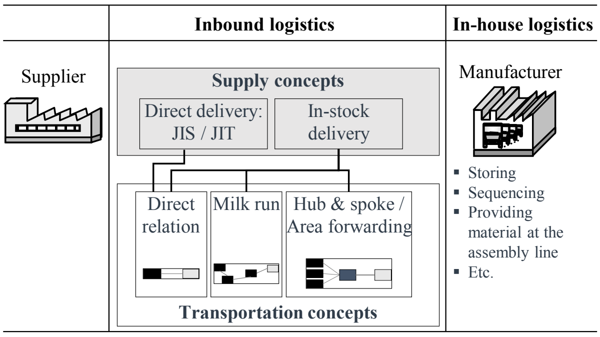

Figure 1: Combinations of Transportation and Supply Concepts

Optimization Approach

The objective of this work is to identify saving potentials within the inbound process by selecting appropriate supply and transportation concepts. Additionally, CO2 emissions should be minimized. We only consider combinations of the most common supply and transportation concepts described before (see Figure 1). A JIS or JIT delivery only works with the transportation concept direct relation. In-stock delivery, however, is combinable with each of the four transportation concepts (hub and spoke and area forwarding are two different concepts in terms of occurring costs). Thus, there are three main optimization scenarios possible: First, the switch from direct delivery to in-stock delivery and vice versa. To compare both supply concepts adequately, in-stock delivery is always combined with the cost optimal transportation concept. The second scenario addresses the optimization of the transportation concept within in-stock delivery. The third scenario refers to the choice of the optimal delivery frequencies for area forwarding and hub and spoke.

To identify the most economic inbound concept, the described model framework must be transferred into a cost model. The main challenge is assigning the arising expenses to the different logistics activities. One appropriate approach addressing this issue is activity-based costing. The approach deals with the assignment of overhead costs to upstream and downstream activities from production, such as storing, transportation, etc. (Weber, 2012). Hence, the entire process described in the model framework is modelled by the relevant cost types. The selection of the cost types is geared toward the material flow process (Wagner and Silveira-Camargos, 2011). Although we focus on inbound concepts, in-house logistics is still taken into account. This is because the subsequent processes from inbound logistics have an impact on the cost calculation. We include all costs that are crucial to distinguish between the different concepts. Furthermore, depending on each logistics concept, the derived cost functions differ (Wagner and Silveira-Camargos, 2011). Table 1 displays these different compositions and the considered cost types.

Cost Types

In the following, we explain the different cost types listed in Table 1. The sum of these costs we call inbound logistics costs. The transportation costs depend on the used transportation concept. For all transport concepts, one cost part is defined by the full load. It is calculated by the transportation cost rate multiplied by the distance to the supplier and the number of transports. The transportation cost rate, however, varies between the concepts, due to different tariff arrangements. To calculate the costs for a milk run, we add stopping costs. The distance is based on the defined tour of the milk run. For area forwarding, the transportation costs are either calculated by full load or partial load. This depends on the volumetric weight of the respective load. The partial load is calculated by multiplying the weight of a shipping unit, the cost rate per kilogram and the number of shipping units. The cost rates per kilogram depend on the distance to the supplier and the transported kilograms per delivery, which leads to a highly complex problem description. The transportation costs for hub and spoke consist of the pre-run and the main-run. For the pre-run, the same costs as for the area forwarding are assumed. The main-run can either be calculated like the partial load or the full load (i.e. direct collection). Empty container deliveries to the supplier are executed through the network of main supplier plants. To estimate the costs for the return of empties, inbound transportation costs are multiplied by the convertible ratio of the containers.

The inventory and storage costs can both be divided into fix and variable costs. In this case, fix costs depend on the safety time and variable costs on the daily inventory. The inventory fix costs are calculated by multiplying the price of a shipping unit by the interest rate per day, the number of days the shipping units are in circulation, and the number of shipping units. The variable inventory costs are defined by the price of the shipping unit multiplied by the interest rate per day and the daily inventory. The daily inventory arises from the delivery and the occurring demands. Note that only the inventories of the manufacturer are included, that is transit and in-house inventories. The storage costs are only relevant for in-stock deliveries. The fix storage costs are calculated by the price for warehouse space, the space of a charge carrier adapted by the stacking ratio, the safety time, the costs for storing and un-storing, as well as the number of shipping units. For the variable storage costs, the daily cost rate based on the space utilization is multiplied by the daily inventory.

The miscellaneous costs include trailer and container rental fees, sequencing costs, and costs for service providers. Trailer rental fees depend on two aspects: The buffer time and the trailer range. The buffer time is the time a trailer spends on average on the trailer yard which is coupled with the number of transports. The trailer range is measured in days and is determined by the trailer content (i.e. the number of shipping units) and the consumption of the respective part. The trailer rental fees only incur for direct deliveries. For the container rental fees, we calculate the cost rate for a charge carrier multiplied by the time the charge carriers are in circulation and the number of shipping units. The circulation time is two times the transit time from supplier to manufacturer plus the time the charge carrier is standing at the supplier's plant. Sequencing costs are composed by the sequencing price per part, the batch size, and the number of shipping units. For in-stock delivery it has to be checked whether the parts need to be provided homogeneously or sequentially at the assembly line. The costs for service providers occur in in-house logistics when a trailer has to be moved from the trailer yard to the dock and vice versa. They depend on the number of internal transports (counted twice for forwarding and returning) and the cost rate of the service provider. These costs only occur for direct deliveries.

Table 1: Inbound Concepts with Assigned Cost Types

	JIT	JIS	In-stock delivery			
	Direct relation	Direct relation	Direct relation	Milk run	Hub and spoke	Area forwarding
Transportation costs						
Full load (direct collection)	X	X	X	X	(X)	X
Partial load						X
Pre-run					X	
Main-run					X	
Stopping costs				X		
Empty returns	X	X	X	X	X	X
Inventory and storage costs						
Inventory (fix)	X	X	X	X	X	X
Inventory (variable)	X	X	X	X	X	X
Storage (fix)			X	X	X	X
Storage (variable)			X	X	X	X
Miscellaneous costs						
Trailer rental fees	X	X				
Container rental fees	X	X	X	X	X	X
Sequencing costs		X	(X)	(X)	(X)	(X)
Service provider costs	X	X				

X Cost type is relevant for this inbound concept
(X) Cost type is not always relevant for this inbound concept

CO2 Emissions

The calculation of CO2 emissions follows the consumption-based approach according to the European Standard EN 16258, i.e. a "well-to-wheel" approach. Greenhouse gas emissions are expressed by CO2 equivalents (CO2e), which is a standardized "measurement against which the impacts of releasing (or avoiding the release of) different greenhouse gases can be evaluated" (Kontovas and Psaraftis, 2016, p. 45). In the calculation, one can distinguish between an empty run and a full run. The emissions of an empty run are constant per kilometer because they depend on the tare weight of the freight vehicle. We assume a linear development of the emissions from an empty to a full run. To determine the CO2e emissions realistically, the calculation is done separately per transportation concept. For area forwarding we assume an average capacity utilization of the transports for each area to calculate the emissions.

To include CO2e emissions in the cost optimization, we multiply the CO2e emissions by a cost rate (Euro per ton of CO2e emission). Since there are no taxes on CO2 emissions in Germany so far, we assumed the highest tax rate for transport fuels within Europe, which is the tax rate of Finland with US$ 66 per ton CO2e (World Bank Group and ECOFYS, 2016). Including CO2e emissions in the optimization model is optional. Nevertheless, CO2e emissions are included for two reasons: First, to demonstrate the consideration of a non-monetary objective, and second to comprise green logistics due to its importance.

OPTIMIZATION MODEL

Requirements, Assumptions, Boundaries

By analyzing the different cost and CO2e emission functions, it became obvious that there are three main drivers: The number of executed transports, the number of shipping units, and the sum of daily stock. In a wider sense, the trailer rental fees can be regarded as inventory costs for direct deliveries and the costs for service providers can be considered as an extended transportation within the manufacturer's plant. Hence, the objective dimensions of the optimization model consist of inventory and storage costs, transportation costs, and CO2e emissions. The objective is to reduce each value, taking into account the correlated trade-offs.

Furthermore, we want to point out some dependencies: The trailer rental fee, which depends on the trailer range, cannot be assigned to only one specific cost driver. It is rather a combination of the number of transports and the respective transported quantities interacting with the predominant demands. Area forwarding and hub and spoke do not apply a fix cost rate, but costs depend on how much is shipped in each run (i.e. the transportation costs for each transport of a transport relation can differ). Furthermore, the stocks depend on the time-based and quantity-based shipments. Consequently, the inbound costs per supply and transportation concept do not rely on a single shipment. Thus, a multi-period consideration is necessary.

Additionally, we assume the following: All process flows behave ideally; the network of suppliers is given; a shipping unit is the smallest indivisible unit; a year is defined by 48 weeks and 5 working days; the used freight vehicle corresponds to a mega trailer.

The following aspects are not part of the optimization: Emergency concepts or extra tours; quality issues; a lack of delivery reliability; network optimization; operative control; upfront investments allowing for the use of alternative inbound concepts; the definition of possible milk run tours. To include milk runs in the optimization, each tour must be defined separately in advance.

Minimization Problem

The objective of the model is the identification of optimization potentials within the inbound logistics process based on a monetary valuation. The developed cost accounting shows that two aspects are mainly relevant for determining the costs: Firstly, the chosen type of inbound concept and, secondly, the order quantity. The order quantity is not only crucial for the respective transportation tariff, but also indirectly for the inventories. Hence, the model to be developed corresponds to a lot sizing problem. In literature, several approaches exist that address this decision. In this paper, we apply a mathematical optimization model that minimizes the logistics costs. We used a decomposition approach to solve the problem efficiently. First, we optimize each combination of supply and transportation concept separately. The objective function includes all cost types that depend on the order quantity. This excludes fix storage and inventory costs, as well as container rental fees and sequencing costs. Fix storage and inventory costs and sequencing costs depend on the process and occur per shipping unit. Container rental fees depend on the frequency for return of empties – figuratively and according to the assumptions, these costs are also process-related. Second, we compare the logistics costs of the different partial solutions (including all cost types) and choose the most cost-efficient concept combination.

Before formulating the optimization problem, we want to stress that the staggered transportation tariffs lead to a non-linear problem. Since linear optimization problems are easier to solve, linearity is defined as a requirement. To obtain a linear model, the decision model is adapted to the determination of the order quantity at a certain point in time for each staggered tariff. For a better understanding of the mathematical formulation, see the notation overview in Table 2.

Table 2: Notation Overview

Decision variables			
$q_{T,i,k}$	Number of transports in period *i* using tariff *k*		
$q_{U,i,k}$	Number of shipping units in period *i* using tariff *k*		
Specific weights for the different supply and transportation concepts			
λ_S	Weighting by which the sum of the daily inventory is included in the objective function; varies per supply and transportation concept		
$\lambda_{T,i,k}$	Weighting by which the number of transports in period *i* with tariff *k* is included in the objective function; varies per supply and transportation concept		
$\lambda_{U,i,k}$	Weighting by which the number of shipping units in period *i* with tariff *k* is included in the objective function; varies per supply and transportation concept		
Parameters			
$d_{U,i}$	Demand for a shipping unit in period *i*		
lb_k	Lower bound of a tariff *k* (in volumetric weight)		
ub_k	Upper bound of a tariff *k* (in volumetric weight)		
$p_{T,k}$	Transport cost rate for a transport (including stopping costs) using the corresponding transport tariff *k*		
$q_{MIN,U}$	Minimum order quantity of a shipping unit		
$q_{SS,U}$	Safety stock of a shipping unit		
$v_{U,k}$	The value of a shipping unit that is used as assessment basis for the transport tariff *k* (in volumetric weight)		
w_{FV}	Load capacity of a freight vehicle (in volumetric weight)		
w_U	Volumetric weight of a shipping unit		
Indices and abbreviations			
i	Index for the period	*S*	Inventory / stock
j	Indexvariable iterating the periods	*SS*	Safety stock
k	Index for the transport tariff	*T*	Transport
FV	Freight vehicle	*U*	Shipping unit
MIN	Minimum		

The objective function is displayed in formula (1). We call it a general model for the case of a single part. The objective function holds for each combination of the inbound concepts. We differentiate between the alternative concept combinations, compounded by the cost types, with the three weights λ_S, $\lambda_{T,i,k}$ and $\lambda_{U,i,k}$.

$$\begin{aligned}\min_{q_{T,i,k};q_{U,i,k}} \sum_{i\in\mathbb{R}^I}\sum_{k\in\mathbb{R}^K} \lambda_{T,i,k}\cdot q_{T,i,k} + \lambda_S \\ \cdot \sum_{i\in\mathbb{R}^I}\left[\sum_{j=1}^{i}\left[\sum_{k\in\mathbb{R}^K} q_{U,j,k} - d_{U,j}\right] + \frac{1}{2}\cdot d_{U,i}\right] \\ + \sum_{i\in\mathbb{R}^I}\sum_{k\in\mathbb{R}^K} \lambda_{U,i,k}\cdot q_{U,i,k}\end{aligned} \tag{1}$$

Subject to the constraints:

$$\sum_{j=1}^{i}\left(\sum_{k\in\mathbb{R}^K} q_{U,j,k} - d_{U,j}\right) \geq q_{SS,U} \qquad \forall\, i \in \mathbb{R}^I \tag{2}$$

$$q_{U,i,k} \leq \left\lfloor \frac{ub_k}{v_{U,k}} \right\rfloor \cdot q_{T,i,k} \qquad \forall\, i \in \mathbb{R}^I, k \in \mathbb{R}^K \tag{3}$$

$$q_{U,i,k} \geq \left\lceil \frac{lb_k}{v_{U,k}} \right\rceil \cdot q_{T,i,k} \qquad \forall\, i \in \mathbb{R}^I, k \in \mathbb{R}^K \tag{4}$$

$$\sum_{k\in\mathbb{R}^K} q_{U,i,k} > \left\lfloor \frac{w_{FV}}{w_U} \right\rfloor \cdot \left(\sum_{k\in\mathbb{R}^K} q_{T,i,k} - 1\right) \qquad \forall\, i \in \mathbb{R}^I \tag{5}$$

$$\sum_{k\in\mathbb{R}^K} q_{U,i,k} \geq q_{MIN,U} \qquad \forall\, i \in \mathbb{R}^I \tag{6}$$

$$q_{U,i,k} \geq 0 \qquad \forall\, i \in \mathbb{R}^I, k \in \mathbb{R}^K \tag{7}$$

$$q_{T,i,k} \geq 0 \qquad \forall\, i \in \mathbb{R}^I, k \in \mathbb{R}^K \tag{8}$$

$$q_{U,i,k} \in \mathbb{Z} \qquad \forall\, i \in \mathbb{R}^I, k \in \mathbb{R}^K \tag{9}$$

$$q_{T,i,k} \in \mathbb{Z} \qquad \forall\, i \in \mathbb{R}^I, k \in \mathbb{R}^K \tag{10}$$

Constraint (2) ensures that the inventory does not fall below the safety stock. Constraints (3) and (4) guarantee that the specific tariff is only applied when the upper or lower bound is not exceeded or undercut, respectively. The boundaries are specified per area and OEM individually. For a case study these boundaries are provided by the OEM. The available tariffs and the corresponding boundaries are defined in a way that the maximum capacity utilization of the freight vehicle is implicitly included. Constraint (5) ensures that for each period a new transport is only triggered when the previous transport is completely full. Constraint (6) states that each order quantity of every period has to correspond to at least the minimum order quantity. Constraints (7) to (10) describe the non-negativity and integer conditions.

Model Extensions

For the application to an industrial case, some adaptions need to be made. These adaptions are implemented by adding further constraints and additional decision variables. Thereby the model's complexity is increased, but still the linear character of the model has not changed.

So far the model does not include restrictions for warehouse capacities. This could lead to the fact that the model accepts high inventories in favor of transportation costs savings. In practice, the data of warehouse capacities are often not available or at least difficult to obtain. Hence, we decided to include delivery frequencies in the model that are often used to control order quantities and inventories. To implement delivery frequencies, additional restrictions are added to the model. These restrictions are the following: The delivered quantity should not exceed the sum of demands until the next delivery point. The maximum quantity of a delivery of one week should not exceed the sum of demands of this week. A delivery is only permitted if the delivery frequency admits it. And the delivery frequencies for the considered period are equal for each week. The mathematical formulation of these restrictions goes beyond the scope of this paper. Furthermore, for direct deliveries, a minimum capacity utilization of each transport is defined, since there are no pre-defined numbers of deliveries per period for those supply concepts. Thereby, we eliminate the case when a full load is exceeded by only one shipping unit and thus an additional full load is billed because of this single shipping unit.

So far, the model considers the case of a single part on a transport relation. In reality though, the material flow of an entire transport relation is considered, i.e. all parts that a supplier delivers to the manufacturer. Thereby, more reliable cost statements can be drawn due to the weight staggered tariff systems. To integrate all parts of a transport relation, we suggest combining them into one reference shipping unit. This is done by acquiring the weighted averages of the part's characteristics for all parts of the transport relation. The reference shipping units are formed while pre-processing the available data. Moreover, safety stocks are set to zero. The process flows are ideal and thus the safety stock is never permitted to undercut (although in reality the safety stock serves in emergency cases). The order quantity decision does not depend on safety stocks. Delivery times and call-off orders are not explicitly regarded, since these are parameters for the operative planning. The presented model addresses a more tactical level, striving for a precise statement about the inbound logistics costs for each inbound concept combination – i.e. not solely average cost calculations. Parts with an order quantity smaller than the minimum order quantity, are monetarily not interesting and negligible. Therefore minimum order quantities are also set to zero.

The optimization problem is formulated in Microsoft Excel. The individual optimization problems are solved using the Gurobi Optimizer 6.5.1 via the open source plug-in "OpenSolver" (OpenSolver, 2017).

APPLICATION TO INDUSTRIAL PRACTICE

Case Description

We consider the case of a commercial vehicle manufacturer: The company decided to relocate the production of bus chassis from the initial plant to either plant A or B. Note that the data presented in this paper is completely anonymized. It is merely used to demonstrate the applicability of the model. From the company's perspective, the alternative plant A was favored.

The analysis uses the following data structure: All parts of the relevant production portfolio of the bus chassis are considered. The data basis is a production period of one month extrapolated to one year. It is assumed that the network of suppliers of those parts remains the same after relocating the production, as contracting new suppliers may take some time. Inter-plant transports are not included, i.e. deliveries of components from other production plants of the company. The analysis covers 452 in-stock delivered parts (i.e. the supply concept of the initial plant) from 142 different suppliers. Furthermore, uniformly distributed demands are assumed due to the data basis of one month. Fluctuating demands are generally applicable to the model, but only reasonable when considering a sufficiently large number of periods. The objective of the model is to reveal optimization potential instead of supporting operative control.

Case Results

The objective of the case study is twofold: First, the optimization model should be applied to a real practical problem. Second, one of the three optimization scenarios should be exemplified. To solve the relocation problem, the inbound logistics costs for all three plants need to be compared. For the cost calculation the most efficient combination of supply and transportation concept for each part and transport relation is used. Due to little quantities that are procured from each supplier, direct delivery is for none of the plants preferred over in-stock delivery. The first optimization scenario (i.e. the choice between supply concepts) is therefore neglected. The inbound logistics costs are always calculated with the optimal transportation concept for each reference shipping unit. Thus, the second optimization scenario is applied, but will not be discussed in detail for the different parts. Instead, this chapter stresses four aspects: The effect of reference shipping units, the effect of the optimization of delivery frequencies (i.e. the third optimization scenario), and the effect of included CO2e emissions in the optimization. The results of the first three analyses are illustrated in Figure 2. Since all parts are delivered in-stock, cost types related to direct delivery are not displayed in the results.

In analysis 1, the overall inbound logistics costs were calculated for all three plants. Reference shipping units are built per supplier over all 452 parts (i.e. only bus chassis parts). The transportation costs have the highest share with an average of 49%. Storage and inventory costs only have a share of 17% on average. For the initial production plant, the transportation costs' share was the lowest at 44%, which can be explained by smaller distances to the suppliers. From an inbound costs perspective, the company's tendency favoring plant A over B can be supported.

The second analysis focuses on the effect of reference shipping units while comparing only the initial plant and plant A. Here the reference shipping units are extended by the entire material flow of each supplier (i.e. all parts of the suppliers and not only bus chassis parts are considered). The results in Figure 2 show the costs of the initial plant and plant A with reference shipping units considering either only bus chassis parts (1) or all parts of the suppliers (2). The costs difference of -1.9% of plant A is not as high as the cost difference of -21.8% of the initial plant. This can be explained by the fact that the suppliers are mainly new suppliers for plant A. In contrast, the initial plant can achieve synergies through higher transport volumes because the same suppliers deliver parts for other components. The transportation costs therefore even decrease by 28%. These numbers show the importance of sourcing suppliers in accordance with the production network.

In the third analysis, the effect of optimized delivery frequencies for plant A is examined. The upper bar shows the logistics costs when using the initial delivery frequencies. The lower bar displays the logistics costs with optimized delivery frequencies. The reference shipping units consider all parts of the suppliers. The optimized delivery frequencies result in 10.6% less logistics costs. 71% of these cost savings can be drawn from only ten of the considered suppliers. Three suppliers still comprise 37% of the cost savings. Note that the adaption of the delivery frequencies is not readily possible in practice, as smoothing effects for incoming goods and demand fluctuations also need be considered.

The last analysis focuses on the CO2e emissions. We run the optimization model for plant A once including CO2e emission in the objective function and then without emissions. We found that the CO2e emissions could be reduced by 1.14% per year, whereas logistics costs only increased by 0.03%. Pre-studies of other transport relations had shown that there is a lot of potential in reducing CO2e emissions while logistics costs increase hardly noticeably.

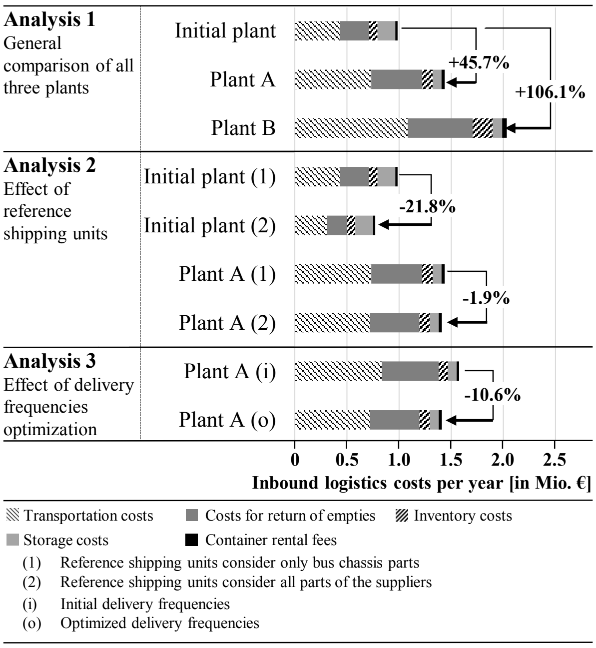

Figure 2: Results from Different Analyses

CONCLUSION AND OUTLOOK

This paper proposes an optimization model for evaluating the most efficient combination of supply and transportation concepts. Additionally, the idea of green logistics is included by adding CO2e emissions to the objective dimensions. The objective function of the model is cost oriented. We applied activity-based costing for the different processes to model the inbound concepts. The complexity of the model arises from the weight and distance staggered transport tariffs as well as the inclusion of delivery frequencies. The optimization model is a linear, multi-period, integer model that is able to use deterministic and dynamic demands with the objective of determining the optimal order quantity.

The use cases for the developed model are broad: Identifying saving potentials in existing inbound processes, selecting the inbound concept for new sourced parts, or supporting strategic management decisions. The latter complies with the case presented here. The main findings were the following: The idea of reference shipping units was identified as highly relevant, because the inbound logistics costs were calculated more precisely than with a single-part view. Delivery frequencies are equally relevant. The findings for CO2 emissions show that a reduction is possible without increasing logistics costs significantly. To summarize the innovation of this work, three aspects need to be stressed: The integrated combination of supply and transportation concepts; the implementation of staggered transportation tariffs; and the application of reference shipping units.

The presented model still leaves room for future investigations: The model should be extended by more capacity restrictions, such as available sequencing area or warehouse capacity, in order to gain more detailed results. In our optimization, the only means of transport is a mega trailer. To model more different inbound concepts, further means of transport should be considered. Additionally, modelling other combinations of supply and transportation concepts may be interesting, e.g. a JIS milk run. Although the model detects saving potentials within the inbound concepts, the final decision for changing the inbound process requires the evaluation of necessary investments and the future development of the concerned parts' characteristics.

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