INTEGRATION OF ECOLOGICAL CRITERIA INTO THE DYNAMIC ASSESSMENT OF ORDER PENETRATION POINTS IN LOGISTICS NETWORKS

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ABSTRACT

By recognizing the necessity of climate protection, the demand for approaches to advance the efficient use of energy is growing. Logistics bears great potential regarding energy consumption and emissions; major improvements can be achieved by careful strategic planning or process re-organization. One key decision within this supply chain design task is the placement of the *order penetration point* (OPP) which influences both cost and service levels in a supply chain strongly.

In order to position and assess decoupling points in global supply chains, we present a methodology which takes product, process and market dynamics into account by combining an early analytical approach with a detailed simulation-based assessment. Within this methodology we distinguish between drivers, i.e. parameters, on the one hand and assessment criteria on the other hand. Consequently, we present the integration of ecological objectives and simulation-compatible indicators into the assessment criteria and exemplarily the according application-based on an industry use case to demonstrate interdependencies between logistics performance, costs and ecological considerations.

MOTIVATION AND INTRODUCTION

As the climate change is meanwhile widely acknowledged, people's attention is increasingly drawn to environmental protection. This aspect affects particularly both (1) the consumption of resources such as *energy* and (2) climate-harming *emissions* called greenhouse gases (GHG) that occur during the burning of fossil fuels. As these objectives always have to be related to the achieved benefit, the focus is put on efficiency, for example *energy efficiency*, which is described as the ratio of gained benefit and the necessary energy input (Müller et al. 2009).

Great potential for ecological improvements can be achieved within the field of *logistics*. It offers the lever to control the flow of goods and traffic. Today's low – and prospectively further decreasing – vertical integration leads to a greater number of production stages and, thus, to a higher demand for transports (Hellingrath et al. 2008). The energy consumption of the in- and out-plant production environment (freight haulage), for example, amounts to 16 % of the total German demand, which was 9,126 peta joule in 2008 (N.N. 2008). Additionally, the transport sector accounts for 14 % of the world-wide greenhouse gas (GHG) emissions (Stern 2008) or 30 % of those in OECD countries (International Transport Forum 2008). Although this great share offers a high potential for energy and GHG savings, the transport sector – in contrary to energy-intensive industries – has not contributed to energy reduction, but enlarged its quota (European Environment Agency 2006). Thus, the necessity of acting and the required potential for changes in the sector controlled by logistics is obvious.

So a major improvement regarding energy consumption and GHG emissions can be achieved by re-organization activities such as process optimization. In order to influence the planning of logistics networks in an early stage and, therefore, to maximize the potential for improvements, these activities have to start at the long-term design level, the *Supply Chain Design* (SCD).

The SCD has a multiple-year focus and is the highest level in Supply Chain Management (SCM). This level receives specifications from the company policy and is responsible for the cross-company design of a production and the logistics network. Typical questions being encountered on the design level include (Kuhn and Hellingrath 2002; Klingebiel 2009)

- the long-term decision of the spatial distribution of nodes such as production facilities or warehouses,
- the number of the network echelons,
- the selection of partner companies as well as
- the process and product design.

The *spatial nodes distribution* is closely related to the *number of echelons* in a logistics network and has a decisive influence on transport distances. Therefore, these important decisions determine the freedom of action for subsequent operations and their potential for optimization. Also the selection of *partner companies* represents a key factor for both the load of a network and the load distribution as these companies have pre-

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set locations. After all, the *process and product design* require certain productions steps in a defined order.
In order to ensure the optimal configuration of logistics networks, it is necessary to *assess* every considerable configuration. Conventional assessment criteria are the logistics performance, such as delivery service or delivery time, as well as costs, for example for production, transport and inventory. Nevertheless, due to the growing relevance of ecological effects, "green" criteria have to be integrated into existing performance measurement systems.
One key decision with strong interdependencies to other objectives of the supply chain design is the placement of the *order penetration point* (OPP) (Winkler 2009; Freiwald 2005). The proper placement of the OPP is important as the product will be differentiated according to the customers' requirements after the OPP and both cost and service levels in a supply chain are strongly influenced by the OPP placement (Schönsleben 2007). Therefore, our work focused on the according assessment methodology for supply chain design and the enhancement by ecological criteria.

ASSESSMENT OF THE ORDER PENETRATION POINT POSITIONS

The Order Penetration Point

The positioning of the order penetration point is gaining relevance in strategic logistics planning (Olhager 2003). In Anglophone literature, the expressions "Customer Order Decoupling Point", "Order Decoupling Point" or simply "Decoupling Point" are used as synonyms (Winkler 2009). The OPP is defined as a point in time at which a product is reserved for a certain customer order and marks the transition between two production strategies that are typically practiced in contemporary production and logistics networks (Parry and Graves 2008; Wagenitz 2007): on the one hand, there is the forecast-driven, customer-anonymous production, also referred to as push logistics or *build-to-stock* (BTS) production since commodities are "pushed" forward without being assigned to a customer order and buffered in stock. On the other hand, *build-to-order* (BTO) activities or pull logistics describe the order-driven and customer-specific production, where – metaphorically speaking – the customer "pulls" a product out of the supply chain (Kuhn and Hellingrath 2002; Lee 2002). Shifting the OPP up- or downstream in the supply chain to a certain position affects various parameters of a logistics network such as delivery time, stock level, inventory costs or variant diversity being discussed in detail further down (cf. next section).
Depending on the OPP position, different *product delivery strategies* can be defined and differentiated. For example, Olhager differentiates between four strategies (Olhager 2003): (1) make-to-stock with an OPP before shipment, (2) assemble-to-order with an OPP between procurement and final assembly, (3) make-to-order leading to an OPP after the product design and (4) engineer-to-order implying an OPP before the design.

As the determination of the optimal OPP position underlies a complex set of influence factors, an appropriate assessment method is required.

Assessment of the OPP Position

In order to position and assess decoupling points in global supply chains, we have developed an according *methodology* within the German-Brazilian BRAGECRIM project "Highly Extensible Life-Cycle Oriented Placement of the Order Penetration Point" (HeliOPP) (Klingebiel et al. 2011; Winkler 2009) which takes specific dynamic products, processes and market situations into account by combining an analytical approach with dynamic assessment. The procedure is divided into three main phases: feasibility selection, static assessment and dynamic assessment. During the first phase, design options are developed based on a selection of supply chain segments (e.g. product segments, market segments) and the specification of targeted key performance indicators. Subsequently, a static analysis reduces the large number of possible solutions to a smaller number of economically reasonable ones. From this set of possible supply chain configurations, scenarios for a detailed analysis are derived. The supply chain simulation of these scenarios ensures the consideration of dynamic effects. Within several projects, the application of this basic procedure has proven its efficiency (Klingebiel and Seidel 2007; Saroemba et al. 2005; Schwede et al. 2011).

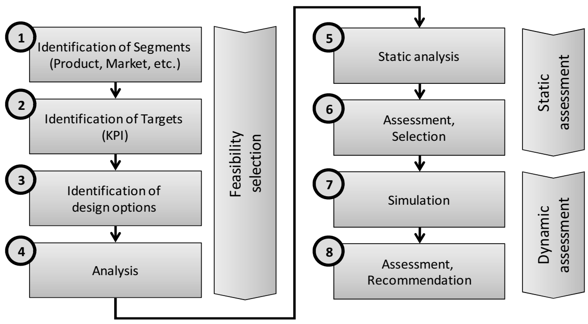

Figure 1: Methodology for the assessment of the order penetration point positioning (Winkler 2009)

A significant aspect of this methodology is the identification of substantial drivers for the selection of feasible OPP supply chain scenarios (Winkler 2009). Among the total number of 18 drivers, factors such as the article value and weight, supplier reliability, accepted delivery time, cycle time or aspects of underlying network topology have been integrated. A static, excel-based analysis integrates a subset of non-dynamic drivers to assess and exclude supply chain configurations on basis of predefined acceptable performance and cost levels. The remaining scenarios are evaluated thoroughly by help of supply chain simulation which integrates dynamic aspects and provides high granularity KPIs.
Yet, in order to assess the influence of the selected drivers on the OPP position, a suitable *target and*

indicator system for the static as well as the dynamic assessment is required whereby "suitable" indicators are those that represent the effects of OPP drivers on a certain objective. Common target systems offer indictors that can be assigned to one of the two categories "supply chain costs" with the objective of costs reduction and the "supply chain performance" representing logistics performance. Figure 2 explicitly shows the targets of each category:

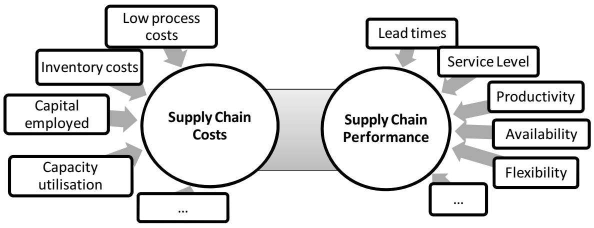

Figure 2: Classic criteria for logistics assessment

Production, transport or any other activities cause supply chain costs that are to be lowered. Inventories do not only lead to increasing costs by capital commitment, but also require additional stock capacities and reduce flexibility, e.g. in case an article turns obsolete. The capital employed exceeds the amount of capital commitment for inventories and covers the total assets (minus current liabilities), such as production facilities. In contrast to that, one is concerned about the *supply chain performance* which is composed of productivity, availability and a (preferably high) service level which may cover functionalities such as "track and trace". Shorter lead times (e.g. for replenishment) imply short reaction time on the customer's needs and, thus, also lead to higher flexibility.

Various performance measurement systems follow this distinction between costs and performance, e.g. the *German industrial guidelines* 4400 are well-established in industrial practice and include such a KPI system. It is divided into the three parts "procurement", "production" and "distribution" and, thus, covers the entire supply chain. The "logistic indicators" presented in these guidelines aggregate the objectives of *high performance* and *low costs* to a ratio called high *logistics efficiency* (Verein Deutscher Ingenieure 2002). Logistics performance comprises the categories availability, throughput time, productivity and delivery service whereas logistics costs are divided into the two groups inventory and process costs. Each category is represented by exactly-defined indicators.

Besides the common two dimensions, *ecology* as a third criterion is becoming increasingly relevant: According to a survey conducted by the German Logistics Association (BVL) (Straube and Pfohl 2008), approx. 90 % of the polled enterprises expect ecology to be a sustainable, but not a fashion issue. Today, 36 % of the corporations and 40 % of the SME intend to integrate environmental and resource protection into their logistics strategy. Three exemplary enterprises which have already developed ecological initiatives with specific saving objectives are the logistics provider DHL ("GoGreen", http://www.dpdhl-gogreen.com), the sports goods producer Puma ("PUMAVision", http://vision.puma.com) and the electronics company Sony Ericsson ("GreenHeart", http://www.sonyericsson.com/greenheart/). As the relevance of ecological subjects increases, the drivers and assessment criteria of the OPP methodology have to be enhanced accordingly in order to make use of its ecological potential.

Ecological Potential of the OPP Placement

Like all strategic planning options, the positioning of the OPP offers great potential for ecological improvements in logistics networks.

Yang et al. conclude that in distribution logistics the missing ecological objective leads to more frequent transports with smaller volume over long distances (Yang et al. 2005). As a driver, they have identified the growth of e-commerce combined with the customer's attitude towards product delivery: the KPI is the delivery time, which leads to a hand-over of an order as fast as possible, often within 24 hours. A similar effect can be observed for production replenishment: intending to reduce expenses for capital commitment, replenishment concepts such as "just in time" (JIT) and "just in sequence" (JIS) over long transport distances do not only cause the risk of expensive stock-outs, but also require a high frequency of transports (Das and Handfield 1997).

These two strategies of reducing costs by fewer inventories and of increasing logistics performance (e.g. shorter delivery times and higher customer service levels) result in a lower degree of capacity usage of transportation means. Therefore, the total number of transports and – by that – the sum of emissions increase as well as the rate of emissions per product.

As a counteraction, higher stock levels offer potential for ecological relief as they reduce the number of necessary transports. The strategy of decoupling is quite common in production processes. This is known as "load leveling", or "heijunka" in Japanese automotive industry (Womack et al. 2006). The load level is controlled by "order releases" (Herrmann 2000). Herrmann describes its effect on the production process as follows:

"Proper order release reduces the inventory and cycle time within the shop and reduces the variability of these measures. However, they may increase the total manufacturing lead time because orders have to wait in the order release pool."

Linking this comparison to transportation processes, the order pool accords to outbound stock levels. By that, means of transportation (or "shop" in terms of production) can be loaded more evenly, also if a sudden deviation from the schedule occurs. However, the total lead time of an item from its production end to the arrival at the customer may increase as articles have usually been buffered before transportation. In this sense, the identification of an optimal OPP position

leads to both the right level as well as the right place of stock. The increased capacity usage of transportation lowers not only the number of transports but also transportation costs, *energy demand* and *emissions*.
The ecological potential of the OPP positioning described above leads to the conclusion that the two-dimensional relation between business and customer has to be enhanced by a third dimension, namely ecology (cf. Figure 3).

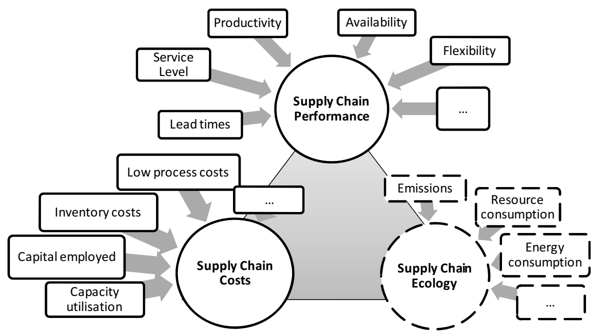

Figure 3: Targets of logistics assessment enhanced by the ecological dimension

In order to grant the acceptance of ecological objectives, it is necessary to integrate them into the conventional two-dimensional target system equally. Within such a target system, ecological indicators play a similar role as the costumer targets: For a business or supply chain manager, the interests of a customer are only relevant, because failing in this category implies costs or lost sales. As a matter of principle, environmental aspects only gain relevance for the business executive since energy consumption and pollution are growing cost drivers (for example due to price, taxes or emission certificates). Therefore, companies have to consider ecological objectives and seek according assessment targets in order to measure cost and performance implications.
This integration has to be fulfilled on two levels: First, performance measurement systems must be complemented with ecological indicators and, therefore, be empowered to cope with ecological objectives. Secondly, the applied *assessment methodology* has to be enabled to deal with these factors in each evaluation step.

AN ECOLOGICAL KPI SYSTEM

To enable OPP-focused logistics planning that takes all three dimensions into account, a target system with a suitable measurement system for each category is needed. Regarding the classic two dimensions, a well-established indicator system such as the German industrial guidelines 4400 is applicable for an OPP-related KPI derivation. The integration of ecological aspects requires (a) the identification of assessment targets and then (b) exactly defined KPI.
Environmental damage is caused by emission occurring in logistics networks. The probably best-known undesired output is carbon dioxide (CO_2) which is mainly responsible for the climate change. However, there exists a great variety of relevant emissions as well as inevitable input (such as energy) that appear to be suitable indicators. Therefore, we accomplished a classification of relevant ecological KPI regarding the peripheral area of automotive production sites (Reeker et al. 2010). As the OPP positioning affects – in matters of environment – predominantly transport processes, this classification is suitable for an adaption to the OPP positioning assessment. The *ecology* branch of our existing classification can be split into (1) energy consumption, (2) pollutant emissions and (3) noise emissions. This is in line with the common categorization of ecological evaluation parameters, e.g. from OECD or EEA. The derived structured list of highly ecology-relevant indicators is shown in Figure 4:

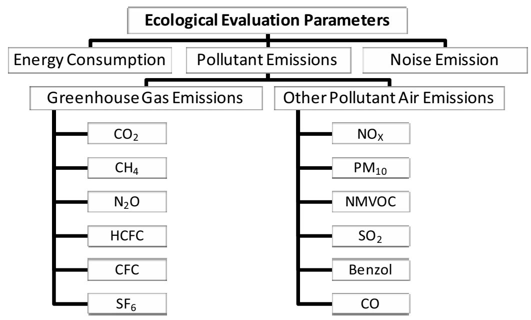

Figure 4: Ecological evaluation parameters (Reeker et al. 2010)

This taxonomy is suitable as basis for a KPI framework for the OPP positioning assessment. However, dimensions and calculation directions are required to serve as a target system.
As the unit for each measure is an absolute one, it cannot stand for itself, but should be related to a certain context, e.g. a logistics system, a process or an article. The unit of the SI system for *energy* is Joule which equals the dimensions $kg \cdot m^2/s^2$. A frequently used unit is watt hour, which measures work and derives from Joule. Within the class of transport-relevant pollutant emissions, we discuss six *greenhouse gas* (GHG) emissions: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrochlorofluorocarbon (HCFC), chlorofluorocarbon (CFC) and sulfur hexafluoride (SF_6). To quantify gas emissions, the mass (weight) is measured, preferably in metric tons or kilograms (United Nations 2010). GHG are gases in the atmosphere that absorb and emit radiation within the thermal infrared range. This causes the warming of the earth and is called "greenhouse effect" (Pachauri and Reisinger 2007). The other group of pollutant emissions, *other pollutant air emissions*, consists of other nitrogen oxides (NO_X), non methane volatile organic compounds (NMVOC), sulfur dioxide (SO_2), benzol and carbon monoxide. These emissions do not support the greenhouse effect but cause other environmental damage (e.g. smog). Another air

emission is "*particulate matter*" (PM) which can be differentiated by its size. Then, PM_{10} describes particles of 10 micrometers or less. A high concentration of PM in the air is held responsible for health hazards such as lung cancer or heart diseases (Bhatnagar 2006). The common unit for PM measurement is – just like gases – kg or tons. Finally, *noise* can be listed as a strongly burdening emission. The attention of politics and society on this emission was crowded out by air pollution, but is now drawn back. The appropriate quantification of noise is probably the most difficult among the emissions described above: indeed, sound volume can be measured in decibel (db) or in relation to the perception of a human ear (db(A), decibel per area) (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2008). However, firstly, this value depends on the distance from the noise source which is highly dynamic in case of a vehicle passing by. Secondly, the impact varies significantly depending on the time of the day. Traffic noise is considered to be much more disturbing at night time. In 2002, the European Union defined noise indicators – L_{den} and L_{night} – which take these challenges into account. "L_{night} is the annual long-term average noise level during the night (23.00–07.00). L_{den} is the annual long-term average noise level over 24 hours, combining the L_{day}, $L_{evening}$ […] and L_{night} […] levels. L_{day} and $L_{evening}$ are the annual long-term averages noise levels during the day (07.00–19.00) and evening (19.00–23.00)" (European Environment Agency 2009). These measure techniques standardize and simplify the handling with noise emissions. Nevertheless, it is still to be criticized that these measured results are not objective data but have already been aggregated and weighted.

We now expand the two-objective indicator system for distribution by the third objective "low ecological burden". The terminology avoids knowingly the expression "ecological impact" since the described indicators offer only measures, not impacts on the environment or creatures. Ecological burdens are comparable to costs: they are not desired, but under given technological restrictions inevitable for providing logistics performance. We, thus, conclude that the lesser ecological burdens occur as the higher logistics efficiency emerges. We integrate this ecological objective into the existing definition of logistics efficiency

$$\frac{logistics\ performance}{costs}, \qquad (1)$$

whereas the main objective remains "high logistics efficiency". However, the enhanced ratio is now determined by a second denominator, i.e. we define the *ecological logistics efficiency* as

$$\frac{logistics\ performance}{costs + ecological\ burden}. \qquad (2)$$

So logistics efficiency can be improved by (a) increasing logistics performance, (b) decreasing costs and (c) lowering ecological burdens. The according target and indicator system is presented in Figure 5. As we developed an appropriate indicator system available so far, we are now able to extend our entire methodology.

ENHANCEMENT OF OUR METHODOLOGY AND EXEMPLARY APPLICATION

With the developed target system for ecological logistics efficiency, relevant targets and KPI have been identified to extend step 2 ("identification of targets (KPI)") of our methodology (cf. Figure 1) by ecological criteria. Further decisive steps for the ecological assessment of the supply chain are the steps of the static and the dynamic assessment (steps 5 to 8). The selected targets are used in each analysis and assessment step (identification of design options → static analysis → simulation) and, thus, each of these steps must be enabled to handle ecological evaluation parameters. For both the static and dynamic phases, a suitable *dataset* for the ecological assessment is required. This ecological assessment dataset or method had to fulfill certain requirements.

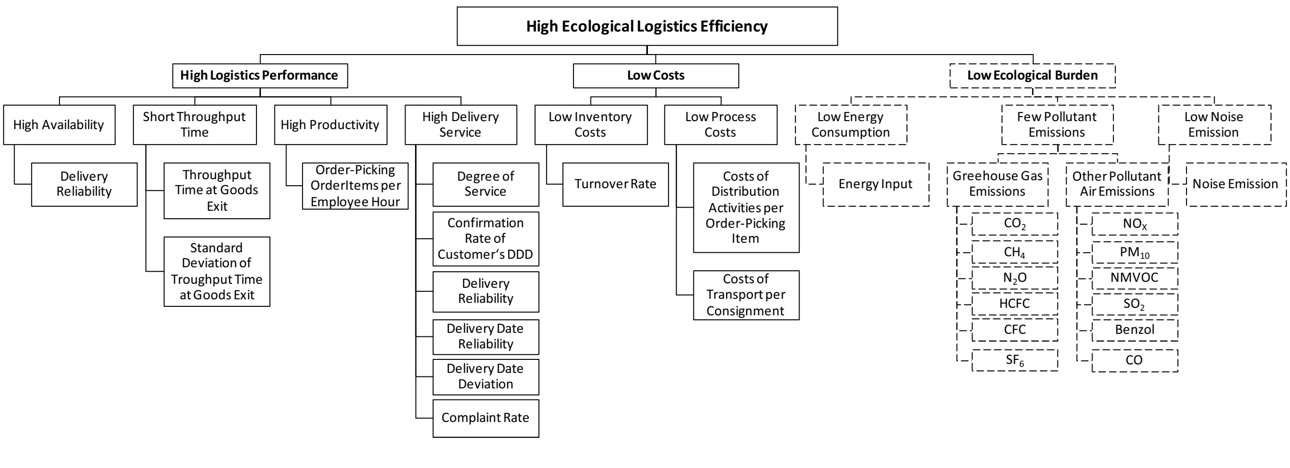

Figure 5: Overall target system of the Ecological Logistics Efficiency (own illustration) in dependence on the German industrial guidelines 4400 (Verein Deutscher Ingenieure 2002)

These requirements are: (1) comprising the indicators described above, (2) attachable to existing results of our analysis and assessment methods, (3) approved by well-accepted institutions and (4) affordable access.

Based on a literature and market survey (Reeker et al. 2011), we selected the *ELCD – European Life Cycle Database* (European Commission 2010). This dataset is offered by the Joint Research Centre of the European Commission. Each formula for the assessment is open-source and can be parameterized by means of transportation, capacity usage and other influence factors. The enormous number of emissions calculated by ELCD formula comprises the consumed energy, particles as well as all the gas emissions listed above. Therefore, the ELCD is well-qualified for the application in our method.

We performed the upgrade of the static as well as of the *dynamic analysis*. By transforming the ELCD calculation sets into Excel formulas, we were able to ecologically post-assess analytical and simulation results ecologically. ELCD formulae for the calculation of transport emissions require certain input factors depending on the means of transport utilized on the examined relation. In our example study, we concentrated on a transport by lorries with 7.5 t of total weight. The according ELCD formula performs the following calculation steps involving the presented variable and given input factors:

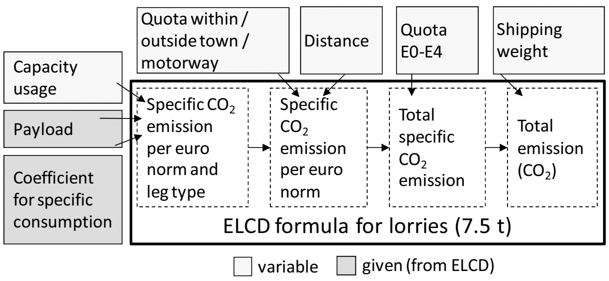

Figure 6: ELCD formula schematic for 7.5 t lorries

In our *case study* we assessed a supply chain providing distributors with automotive wearing parts. As process simulation software we applied OTD-NET ("order-to-delivery network simulation"), developed by Fraunhofer Institute for Material Flow and Logistics (Wagenitz 2007). OTD-NET introduces a holistic approach for modeling and simulation of complex production and logistics networks and delivers in-depth insights into information and material flows, stock levels, network stability and flexibility, boundary conditions and restrictions.

We focused on a cutout from a plant in Germany, via a nearby distribution center to a distributor in Munich, Germany. The shipping volume comprised one article weighting 55 kg with a mean demand of 30 parts per month. The transportation of about 600 km from Wolfsburg to Munich was performed by a truck of 7.5 t of total weight.

In this context, we developed six scenarios: We placed the OPP at the distributor, at the DC and at the plant and combined these OPP positions with two transportation strategies: At first, in the scenarios 1 to 3, the truck left 10 hours after call-off or if the capacity was exhausted. Then (scenarios 4 to 6) the truck left after 48 hours or on full charge. The configuration of the most important parameters as well as the results are presented in Table 1.

The case clearly demonstrates the interconnection between economical, ecological and performance-related objectives: An OPP position at the end of the supply chain (scenarios 1 and 4) results in an extremely short order-to-delivery time, but leads to high stock levels representing the economical dimension. Shifting the OPP upwards reduces the stock level in the supply chain (cf. Figure 7). However, the order-to-delivery time increases significantly.

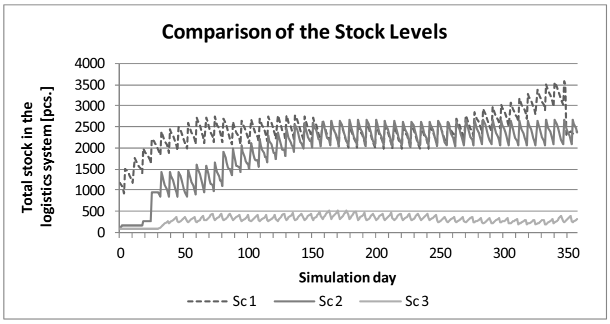

Figure 7: Comparison of the scenarios 1 to 3 by the stock level in the logistics system

Here, the *ecological effect* is indicated by the average CO_2 emission per part. As goods are consolidated by the lower transportation frequency (scenarios 4 to 6), the number of transports is decreased by up to 20 % compared to the scenarios 1 to 3 with a maximum waiting time of 10 hours. The improved capacity usage reduces the CO_2 emission per part by up to 17 %.

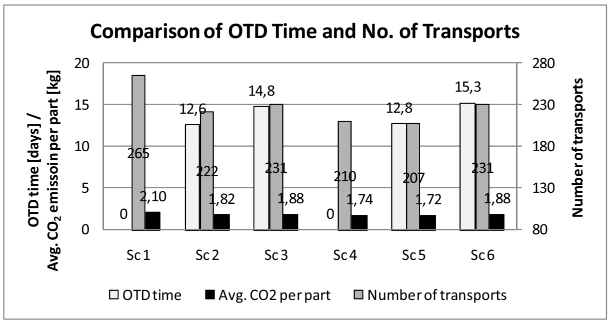

Figure 8: Comparison of scenarios by logistics performance, no. of transports and avg. CO_2 emissions

The experiments demonstrate the great effect of different OPP positions on the environment and the potential for ecological improvements if cutbacks in matters of performance and/or costs are accepted.

Table 1: Parameters and results of our case study

	Parameters varied		Performance	Economy			Ecology			
Scena-rio	**OPP at…**	**Transp. waiting time OEM→Dlr**	**OTD time [days]**	**Stock Dlr [pcs.]**	**Stock DC [pcs.]**	**Stock plant [pcs.]**	**Number of transports**	**Avg. Cap. Usage [%]**	**CO_2 per transport [kg]**	**CO2 per part [kg]**
Sc1	Dealer	10 h or full load	0,0	1354	157	974	265	0,667	83,81	2,10
Sc2	OEM	10 h or full load	12,6	0	88	1737	222	0,796	86,92	1,82
Sc3	Supplier	10 h or full load	14,8	0	87	213	231	0,765	86,17	1,88
Sc4	Dealer	48 h or full load	0,0	1351	157	974	210	0,841	88,01	1,74
Sc5	OEM	48 h or full load	12,8	0	88	1737	207	0,853	88,31	1,72
Sc6	Supplier	48 h or full load	15,3	0	87	213	231	0,765	86,17	1,88

CONCLUSION

In this paper, a target system combining *ecological objectives* with the established objectives of economy and logistics performance has been presented. In combination with the illustrated OPP methodology, which integrates a feasibility analysis of OPP supply chain scenarios followed by static and dynamic assessment, the three objectives may be pondered. The results of the case study presented above demonstrate that involving ecological objectives into the decision of the OPP placement can make a sizeable contribution to the reduction of emissions, such as CO_2, and energy demand. The case shows qualitatively that both a high logistics performance and an ecological transportation strategy are possible, if high stock levels (and costs) are accepted. On the other hand, costs and emissions can be reduced by lowering the logistics performance (in our case a longer OTD time).

Nevertheless, ecological OPP positioning should take additional steps forward. First, the aggregation of ecological indicators to a top key figure is necessary to allow for strategic balancing of the three objectives. However, the number of different units is challenging and complicating a combination of according values. A possible solution is the application of the standardized *Life-Cycle Assessment* (LCA) which offers a conclusion about ecological impact measured by a (non-dimensional) score value.

Second, ecological objectives are solely integrated as post-assessment criteria. The proposed solution lies in the integration of ecological drivers into the dynamic assessment phase, i.e. the integration of ecological parameters into *simulation itself*. As simulation requires a software tool, the necessary development step is enabling the supply chain simulator OTD-NET to deal with ecological parameters.

Third, it is obvious that, so far, ecological aspects do not drive the definition of OPP supply chain scenarios. This specification is typically based on heuristics and feasibility selections for which literature already offers many product-related, market-related or material-flow-related drivers (see for example Olhager 2003, Winkler 2009). Yet, ecological considerations are not mirrored and a systematic derivation of ecological OPP drivers is necessary. Simulation of OPP scenarios may give first indications and serves as validation platform.

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