The development of sustainable transports through the right logistics strategy – a system dynamics approach

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Abstract
As sustainable and efficient freight transport operations become more and more a crucial part within securing the competitiveness and success of a company or the whole supply chain the “right” logistics strategy is one main crucial part and plays a key role within realization of efficient transportation movements lowering environmental impacts. Freight transport is affected by different parameters determined within a logistics strategy. This research approach models interdependencies between logistics strategies and transportation movements through a systemic point of view.

Keywords: logistics strategy, sustainable transport operations, system dynamics

Introduction
Globalization, European integration, and the liberalization of transport markets have created conditions of production and distribution which have led firms to profoundly change their logistics concepts. This has major repercussions on demand behavior in freight transport (Bolis et al., 2003). Transport is a second order activity which is generated by other economic activities. As such, the demand for transport depends heavily on economic activities and consumption and changes both of these. When the economy is growing, both production and consumption will grow, hence leading to an increase in the demand for transport and vice versa. Nevertheless, transport has grown faster than GDP in recent years (Ruijgrok 2001). The restructuring of logistical systems (production and distribution systems) has influenced freight transport much more than changes in the physical mass of goods in the economy or in the allocation of freight between transport modes (McKinnon, 1998).

This research is motivated by the need for the development of methodological tools that would assist to analyze the impacts of logistic strategies on freight transport operations. A logistics strategy must take into account a variety of parameters including order size, frequency, transport flexibility, global or local sourcing, etc. After the definition of the logistical parameters, transport key performance indicators like utilization, transport mode have to be resolved under two main competing objectives (i) low transport costs and (ii) maximum of sustainability within the transport operation.

We apply a system dynamics approach for modeling systems behavior. There are already few models using SD for interrelationships between logistics and freight transport. A review of studies that applied SD methodology to different transport related issues showed that the methodology is well suited to catering to the needs of several analytical problems in transportation.
Nevertheless, the outputs of such models is often limited to being good enough to show policy impacts, behavioral trends and levels of change across time in a highly aggregate way. There is plenty of scope to extend SD modeling towards micro analytic models for

various transport issues as such models could provide more specific answers as aggregate models do which tend to be rather simple, general and abstract (Abbas et al., 1994). The advantages of SD models for freight transport models are limited data requirements, possibility of usage of land use interaction and the option of inclusion of external and policy effects variables. Disadvantages are the lack of statistical tests on parameter values (Jong et al., 2004).

The proposed model concentrates more on operative parameters but it is kept as generic as possible to facilitate its implementation on a wide spectrum of real-world cases. The next section defines the problem and outlines the study. The necessary elements for the developed SD methodology including model variables, the causal loop diagram and the Stock and Flow model are presented afterwards.

Problem definition and literature review

The dependence of logistics on efficient and well organized transport infrastructure and technology is well documented. The implications of logistics for transport are, however, much less researched (Homann et al., 2004). It is still difficult to determine the actual relationship between logistical structures and transport as it is seen on the one hand as an integrated part of the logistical system and on the other hand as an activity embedded in its own systemic logic in transport chains. The relationship between logistic organization and transport is not straightforwardly established.

Nevertheless, being able to link strategies of logistical organization with changes in transport would be of importance as it could support industries development of more environmentally sustainable supply chains (Drewes Nielsen et al., 2003).

Freight transport is affected by a broad range of corporate decisions. These decisions influence the transport operation in different ways. Logistical decisions affecting freight transport operations are made at four levels (McKinnon et al. 1996): Strategic, commercial, operational and tactical decisions. The growth of freight traffic is the result of a complex interaction between decisions made at different company levels. Generally the influence direction can be described as a top down (from strategic level to the operational level).

One explanation for the growth in freight transportation relates to the change in the logistically induced demand for transport, especially the increase in flexibility of the production and distribution structures. There can be found two reasons for this development, first the increased purchasing power (income growth) to choose from a large variety of consumption goods (economies of scope) and second the logistics within the production process like economies of scale, locational advantages and reduced costs for warehousing (Bleijenberg, 2003). Drewes Nielsen et al. (2003) illustrate, that the relationship between logistic organization and transport is not straightforwardly established because of the following reasons: (i) logistical organization is not only the dominant variable – it is also connected with other factors of supply chain management (ii) logistical principles are not well defined over the whole processes, (iii) surveys about logistics and transport suffer from very few response rates and (iv) whether the causes of changes in transportation growth rates are related to logistical organization or to changes in the market cannot be deducted so far.

Therefore we present a SD model trying to answer the main research question: How do transport logistics operations and their parameters interrelate?

The aim of this paper is to picture the interdependencies through a systemic point of view with the overall goal of more efficient transport operations. Efficiency is defined by a higher utilization of trucks and modal shift to rail if possible.

In this research we focus mainly on operative parameters of a logistics strategy and transport key performance indicators. A major assumption is that strategic parameters (e.g. production plants, warehouse location) have a long term character as well as are not part of daily business operations. This research tries to analyze interrelationships between operative parameters and their impact on freight transport operations in a systemic way. We extract the parameters of logistics strategy by a huge literature study which is explained in detail in Aschauer et al. (2011). Drewes Nielsen et al. (2003) developed four transport indicators which are showing the impact of changes in logistics on transport. In their research they analyzed the impact of changes in logistical organization on these parameters; nevertheless these developed indicators are also functional describing the impacts on transport when changes in operational parameters of logistics strategy occur: transport mode, transport distance, transport efficiency and transport content. These parameters will be explained in more detail in the following section.

Thus it is evident that the modeling methodology that is employed needs to be able to capture the transient effects of internal and external indicators and relates each other in an overall system. SD has this capacity and moreover allows creating experiments and scenarios within the developed system.

Parameter selection

Based on the findings from literature and expert interviews a model boundary chart was developed for the classification of the observed parameters (Sterman, 2000). In total, 25 parameters were identified which are relevant within the system of logistics strategy and freight transport operations. For the development of the causal diagram in the following step, these parameters were classified into endogenous (influenced and influencing parameters), exogenous (influencing endogenous parameters but not influenced by another parameter) and excluded (not included in the SD model yet) parameters.

Table 1 – Model boundary diagram

Endogenous	Exogenous	Excluded
amount per order cycle	logistics concept	product design
order cycle frequency	transport flexibility	outsourcing
shipment amount	production amount	Centralised/decentralised production
utilization of trucks	infrastructure capacity	Centralised/decentralised distribution
road kilometres travelled	transport distance	
number of transports	order cycle frequency	
pressure to consolidate	transport capacity truck	
road infrastructure utilization		
rail kilometres		
modal shift		
congestion possibility		
transport emissions		
fossil fuel consumption		
transport costs		
transportation lead time		

After the boundary clarification process, the causal diagram was developed. For the formal logic of the diagram, the developed parameters and key performance indicators have been concretized to some extent. For example instead of transport efficiency we talk of utilization of trucks, or transport mode is changed into modal split.

The causal loop diagram represents the major feedback mechanisms and serves as a simplified representation of the model. The first step of our analysis is to capture the relationships among the system operations in a SD manner and to construct the appropriate causal loop diagram. Figure 1 depicts the causal loop diagram of the system:

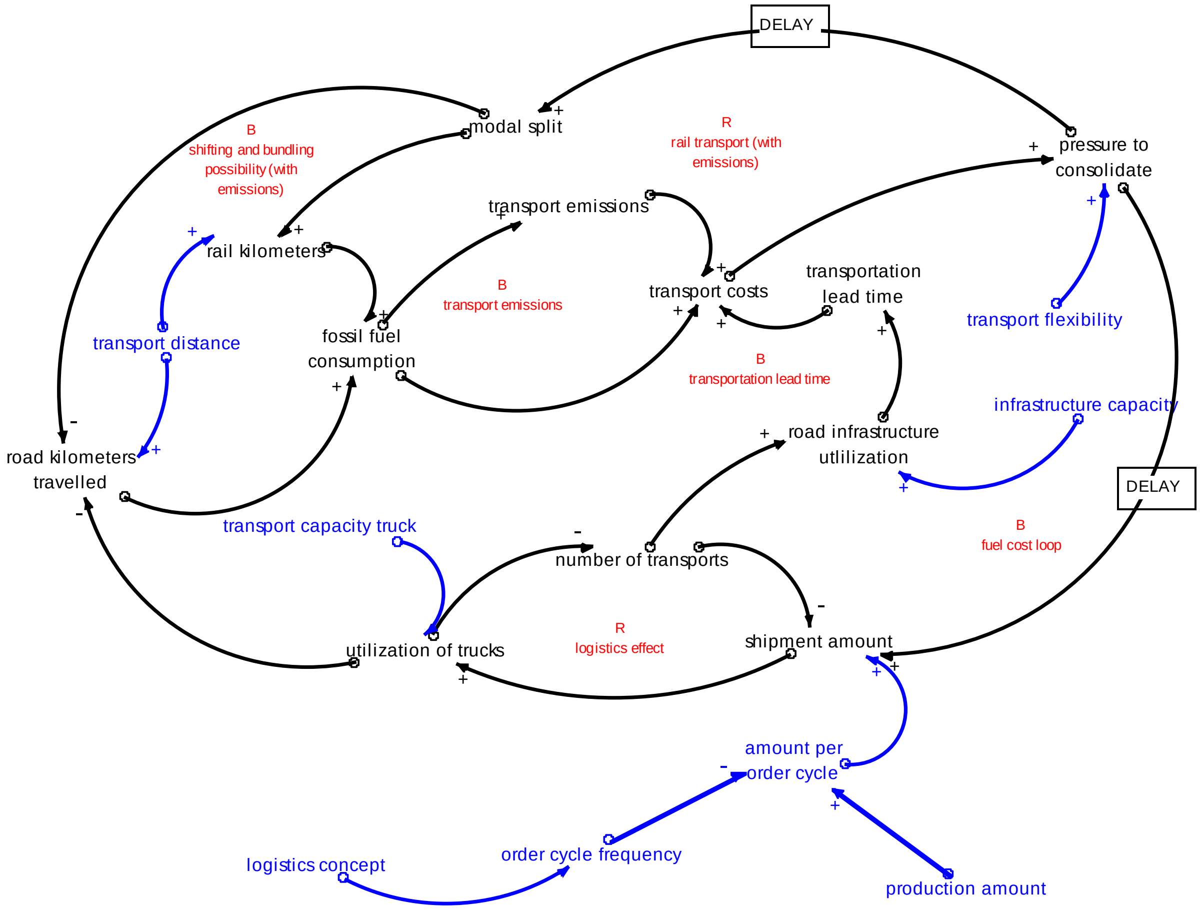

Figure 1 –Causal Loop Diagram

The first loop, called logistics effect is a reinforcing loop. The three parameters are shipment amount, transports and utilization of trucks. The shipment amount is influenced by the operated logistics concept (e.g. Just in Time, Vendor Managed Inventory, Just in Sequence) which influences the order cycle frequency and amount per order cycle which is determined also by the production amount of the company or supply chain. The shipment amount is influenced by the amount per order cycle and depends on the released orders within a certain time period. High numbers of order releases implicate a smaller shipment amount and vice versa. Small shipment amounts mean a low utilization of trucks whereas high shipment amounts have a positive impact on the utilization of trucks. This loop has two positive and one negative link. The parameter utilization of trucks is also influenced by the external parameter of truck load capacity. This factor can generally be fixed between 7.5 t and 44 t. As there is also a debate within the European Union about the permission of gigaliners, experiments and scenarios with 60 t of capacity can also be realized. This described reinforcing loop is the facilitated picture of what we have experienced in road freight transportation within the last 20 years through the introduction of inventory reducing logistics concepts.

Nevertheless, transportation and industry face now several new challenges and this reinforcing loop is influenced by the five other loops.
The first balancing loop is called the “fuel cost” loop and has the following parameters and influences. The percentage of utilization influences the transport distances travelled. This parameter is also influenced by the physical distance between the company and the supplier or costumer. If we have a distance of e.g. 100 km and a utilization of 100% only 100 km are traveled. If utilization is reduced to 50%, 200 km have to be travelled, 10% mean that 1000 km have to be travelled in sum and so on. The higher the amount of distance travelled, the more the fuel consumption is. This raises the transportation costs (especially if fuel price rises through crises or introduction of new taxes etc.). If transportation costs increase the pressure to consolidate also rises. If this consolidation pressure increases the shipment amount will also be increased through e.g. bundling. This bundling effect needs some time within the system as companies have to identify consolidation potentials and bundle them.

An additional aspect, which all of the loops connected to “pressure to consolidate” have in common is, the positive relation between transport flexibility and the pressure to consolidate. A growth in flexibility leads to a growth of the pressure as companies want to realize their transports efficient regarding costs and utilization.

A very similar effect is the second balancing loop “transport emissions”. As described in the last loop the higher the amount of travelled distances, the higher is the fuel consumption, the higher are emissions of the trucks, depending on the standard and age of the truck. Within this model we assume that a growth in emissions results in a growth within transport costs. We can say that emissions are internalized. If transportation costs rise, we can find the same effects as described above, the pressure to consolidate will also rise and therefore measurements to increase shipment amount should be implemented.

The fourth loop of the causal loop diagram is the balancing loop “transportation lead time”. If the number of transports (truck on the road) is high the risk of being affected by congestion, accidents etc. is evident. As road infrastructure has a certain amount of capacity and influences the level of service (from free, undisturbed flow to congestion) of the road within a day. This means a potential loss of time and planning uncertainty. Loss of time also has a huge effect on transportation costs. The bottlenecks and infrastructure constraints on road are an important issue in the future and definitely have to be considered. Having a lot of low utilized trucks running on road infrastructure will also increase the transportation costs and leads to an increase of pressure to consolidate and to increase shipment amounts.

The next two loops will be described together as they are very similar. They are named as “shifting and bundling possibility (with emissions)”. Through a growth within pressure to consolidate, besides bundling and increasing truck utilization there also is a possibility to shift from road to rail. The realization of such a shift needs a certain amount of time and cannot be realized immediately. A shift reduces travelled kilometers by truck and as a consequence fuel consumption and emissions are reduced. This decreases transport costs and reduces the pressure to consolidate. Both are balancing loops.

Having also a lot in common, the last two loops are also described together. They are named as “rail transport” and “rail transport with emission”. If the pressure to consolidate is high enough, and some other restrictions are fulfilled, a shift is realized after a certain period of time. This changes the modal split and increases transport kilometers by rail whereas transport kilometers by truck are reduced. Rail also needs energy (underling in the model that rail needs fewer fuel energy as well as produces less emissions than trucks do) and thus has an effect on transport costs and emissions which also increases in a next step transport costs. This increases the pressure to consolidate. The loops are reinforcing.

The described causal loop diagram was developed iteratively by a literature study and expert interviews. Within the model, some assumptions have been taken to reduce complexity. The comprehensive diagram serves now as a basis for the transformation into the quantitative stock and flow model.

The next step of SD methodology includes the development of the mathematical model presented as the stock and flow diagram that captures the model structure and the interrelationships among the variables. The stock flow diagram is easily translated to a system of differential equations, which is then solved via simulation. The stock flow diagram of our model has been developed using Stella software and is exhibited in Figure 2. The stock and flow diagram is a graphical representation of the mathematical model.

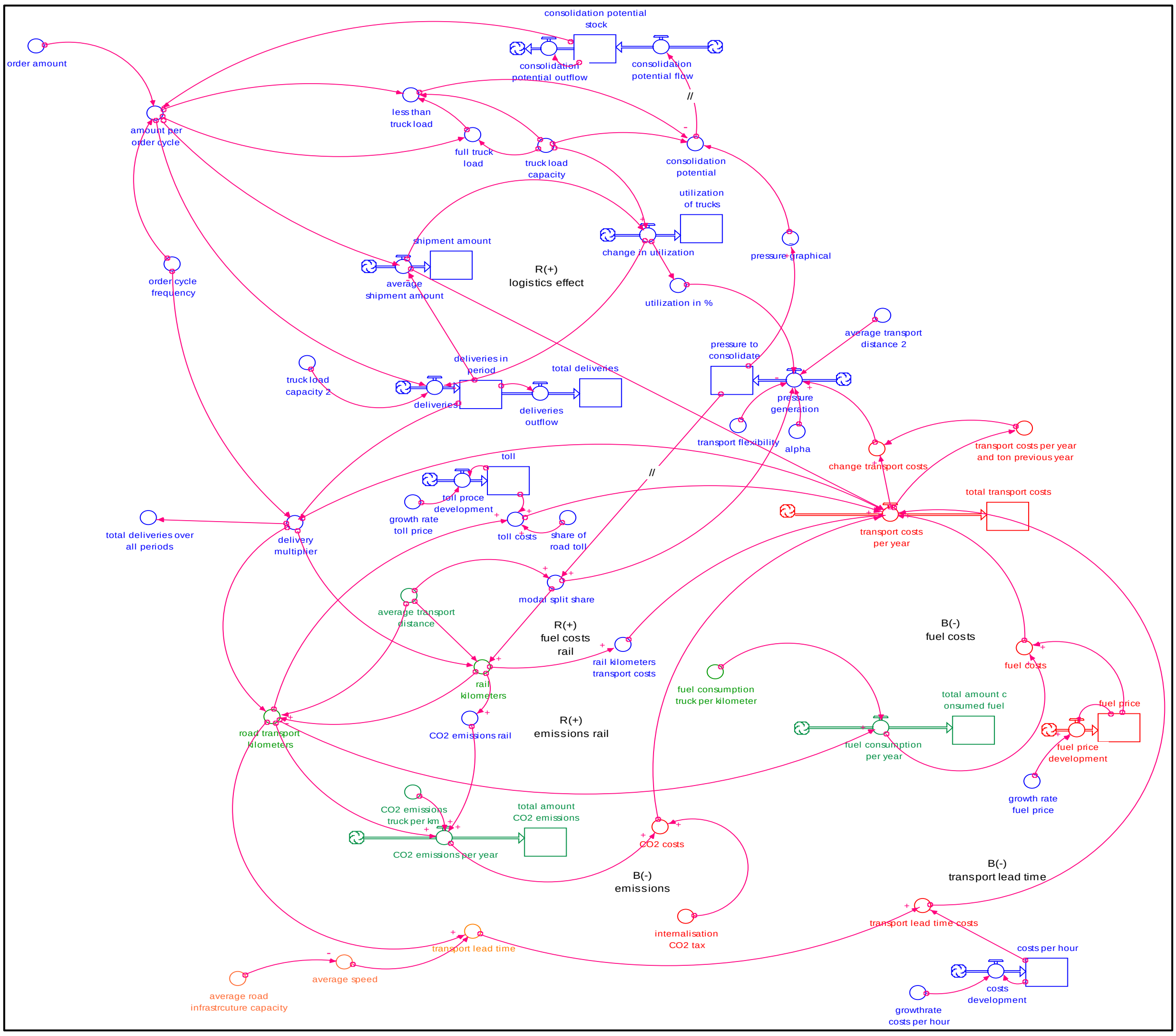

Figure 2 – Stock & Flow Model

Sterman (2000) suggests for a structured validation of a model the following tests: dimensional consistency, extreme conditions, parameter assessment etc. For the detection of structural flaws in system dynamics models, direct and indirect structure tests are used.

For the latter, especially extreme condition and behavioral sensitivity tests are the most significant ones (Barlas, 1996). After these tests, a validation, based on real company data was also realized to proof the models applicability.

As leverage points (Meadows, 1999) the following parameters have been determined within the model*: order frequency, truck load capacity, transport flexibility, consolidation coefficient (alpha), toll costs, fuel costs, CO2 internalization costs, road infrastructure capacity and truck costs per hour*.

All operated validation test exhibited a meaningful plausible behavior of the model regarding to consistency tests, extreme conditions tests, behavioral sensitivity tests and tests with real company data . The model's behavior is consistent with empirical and theoretical evidence. Therefore its applicability for modeling different numerical investigations is given.

Conclusions

We presented a system dynamics model for the interdependencies between logistics strategies and freight transport. The developed model allows the comprehensive description and analysis of the system operations (parameters of logistics strategy) and taking also transport relevant factors (toll, CO2 internalization, infrastructure capacity) into account.

We first validated the SD model employing e.g. extreme condition and behavioral sensitivity tests and then proceeded with the realization of numerical investigations or scenarios. The latter provides insights about the influence of the different leverage points within this dynamic system. Through experiments with these possible leverage points, the following have shown a high influence on the system: order frequency, *truck load capacity, transport flexibility, alpha and the cost parameters* (toll, fuel and truck per hour). The model can be used to analyze various scenarios thus identifying efficient policies and further to answer questions about long term behavior of the complex interactions between logistics activities and transport movements.

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