The Extended Generalized Cost Concept and its application in Freight Transport and General Equilibrium Modeling

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Abstract

The integration of Spatial Equilibrium models and Freight transport network models is important to produce consistent scenarios for future freight transport demand. At various spatial scales, we see the changes in production, trade, logistics networking and transportation, being driven by mass-individualization and changes in factor costs.
In this paper we focus on the latter driver for changes in freight transport. The cost of interaction plays an important role in many modeling frameworks that try to describe spatial processes. Whether it is international trade modeling, general equilibrium modeling, logistics network modeling, freight transport modeling: they all use a definition of cost for describing the distance between 2 points in space.

This paper tries to extend and standardize this Generalized Cost Concept, in order to obtain a more realistic description of the phenomena that are described by these models and also to obtain consistency between these models. We argue that, especially for the purpose of harmonizing the various partial approaches for freight transport modelling, the Generalized Cost concept is indispensable. Generalized Cost includes all costs that are involved in overcoming time and space that are taken into account in companies that try to minimize these costs while maintaining certain service levels, as required by their customers. The Generalized Cost concept is extended because it takes into account a number of circumstances, which sometimes have been neglected by other researchers. These circumstances involve a. o. shipment size, speed, value density, demand uncertainty, scale economies and network synchronization.

We describe in detail the concept of Generalized Cost from a logistics perspective, give a review of the way the Generalized Cost concept is presently used in modelling spatial processes, and give some recommendations for incorporating the proposed Generalized Cost concept.

1. Introduction and paper outline

The development of the economies all over the World is depending on the production and demand of products and services. Both the supply and demand of products relies, amongst other aspects, on the accessibility of countries and regions. The relaxation of trade barriers since the Second World War has given a great stimulus to the development of World Trade (Rodrigue, 2006 ab), but also the decrease of transport costs in real terms as well as the reduction of total logistics costs have contributed to this phenomenon in a significant way.

The development of world trade is directly linked to the demand for international freight transport, maritime transport and air freight in particular. Although the share of transport costs in total logistic costs for expensive products is much less than for low value bulk products, also for these products considerable cost savings have been reached, both because of economies of scale and improved supply chain management. In this paper we will describe each of these phenomena in more detail and with a systems perspective. We will focus our attention to intercontinental transport flows.

First we will describe the process of globalization as it has emerged and its relationship with integrated logistic cost. This integrated logistic cost concept is an extension of the concept normally used in modelling international trade and freight transport, because it also takes into account the cost due to unreliable demand and supply, the costs of passing boundaries (including administrative burdens) as well as the possibilities to create cost reductions through efficient logistics using economies of scale and hybrid networks. In the second part of this paper the utilization of this extended generalized cost concept in spatial equilibrium modeling and freight transport modeling is described in a conceptual way.

2. Globalisation and Logistics Costs

The globalization of the world economy has emerged from a period with a high degree of protection and isolation towards the present state that is characterized mainly by free trade (see Figure 1).

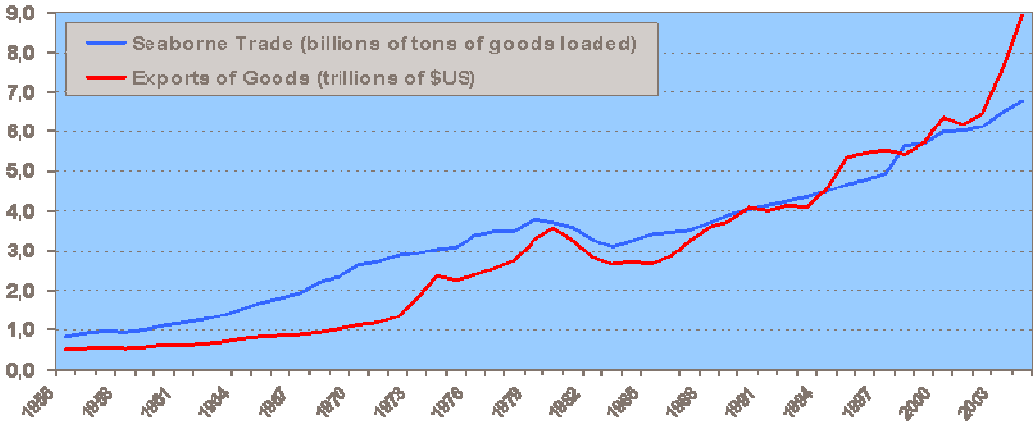

Figure 1. Development of Seaborne Trade and Export of Goods (Rodrigue, 2006a)

One of the main drivers behind this growth of international trade has been the differences in cost of producing the same type of product in different places of the world, which are due to difference in factor costs, availability of natural resources. Together with the cost of overcoming the distance one can determine whether it is more attractive to import the products from elsewhere and to carry the burden of transporting goods over large distances, or to avoid the costs involved in transporting these goods and produce them locally. Both the organization of production and transport economies of scale play an important role in the choice of production and sourcing solutions.

An example is given below for the production of automobiles. In general one can say that the assembly of automobiles takes place not too far from the final customer, but some of the parts are produced by assembly plants that distribute their products to worldwide spread customers.. This can lead to complicated supply chains as in visualized in Figure 2. The location of production plants normally is a long term investment decision, and thus

the geographic spread of production patterns used to be rather stable over time. Nowadays, as a result of the economic crisis, the location of factories is re-evaluated and those that are not ideally located or do have a lack of governmental support are under the threat of being closed down. Assembly plants, however, are more footloose and their location can change, influenced by regulatory measures (subsidies, regulation on the share of local content), the relative importance of transport costs in the cost of final products, congestion and other capacity restrictions.

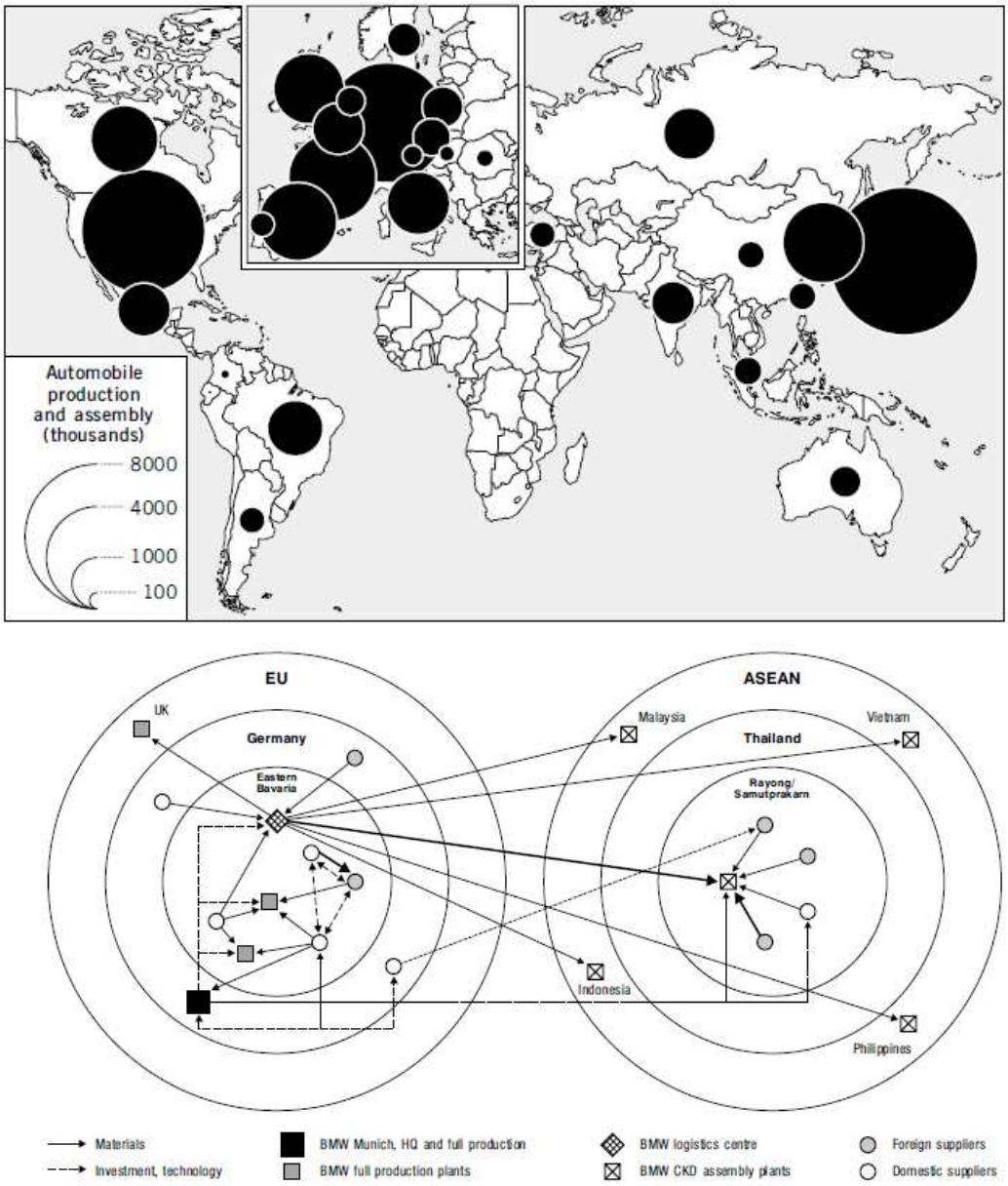

Figure 2. Location of Production of automobiles worldwide and an example of the supply chain of BMW. Source Dicken (2003)

When we try to explain these developments in order to better understand the worldwide flows of goods and trade patterns, the main explanatory variables are the GDP on both sides of the relation, the amount of population and potential customers, as well as the distance of the relation under research.

However, when these main drivers are used to explain international trade in gravity type models, it appears that some structural over- and underestimating takes place, due to the fact that the regulatory frameworks and logistics organisation have a large impact on the possibilities to realize trade if the potential for that trade does exist. Hausman et al (2004) have extended the traditional gravity type model with indicators that describe the attractiveness of establishing bilateral trade, given the volume of consumption and production on both side of the relations and also given the distance to be covered to transport the products. These indicators involve the time indicators (also including hinterland transport to and from the main ports), costs (including product cost, transport (shipping) cost, and especially emphasize the effect of total cost of trade document procedures and border control cost and inventory cost) and indicators related to risk factors such as the complexity of customs documents and the frequency of services between ports).

They have estimated a gravity model to test the relative importance of these variables and found that the indicators reflecting the logistics efficiency have an important explanatory power to explain the variations in international trade. Also they use this fact to stress the importance of logistic efficiency and to avoid cumbersome procedures that hamper reliable deliveries. Earlier, Hummels has performed an analysis that shows that each day of increased ocean transit time between two countries reduces the probability of trade by 1 percent (all goods) to 1.5 percent (manufactured products) (Hummels, 2001).

We start from the results from Hummels and Hausman et al. and try to explore the nature of logistics cost a bit more in order to achieve even more accuracy in the explaining power of our freight transport models and SCGE models that describe word trade relations. We extend the concept of Generalized Logistics Cost by including also variables that try to capture the effects of economies of scale and the impact of improved transparency, because it is recognized that these are important variables to include in the analysis (van Nunen et al, 2008).

Also McCann (2004) has already indicated that reliability; transparency and frequency have an important impact on the necessary levels of safety stocks and should be included in the analysis. Other important cost components of a realistic integrated cost concept are:

1. pipe line costs (including inventory costs for products in the pipe line)
2. value density (***vd*** = ***V / Vol*** in m3), where ***V*** stands for value: for products with a higher value density inventory costs are more important than for other products
3. shipment size ***P*** : the higher the shipment size the lower the transport and handling cost per unit
4. frequency ***f*** : higher frequencies lead to lower waiting costs, and therefore more reliable lead times, lower safety stocks and also to network synergies

5. variance in demand, the higher this variance the higher the demand for responsive and therefore expensive services that can meet this demand, or require to bear bigger amounts of stocks: if the demand is stable goods can be forecasted accurately and goods can be shipped far before the actual demand is realized and use a cheap mode of transport.

The definition of Generalized Logistic Costs we propose that takes into account all of the drivers mentioned above for product i out of the set of all products, is:

$C_i = I_i + H_i + T_i$, i = 1, … , I

$I_i = I_i^{safety} + I_i^{pipeline}$

I_i^{safety} = f (frequency, ordersize ***o***, σ^{demand} variance, σ^{supply} lead time variance)

$I_i^{pipeline}$ = f (***TT*** **,** ***r, V***)
TT = Transport time,
r = interest rate also reflecting the risk for obsolescence of unsold products,
V = value of goods transported

H_i = handling costs (depending on the packageing density:
pd = # colli per m3)

T_i = transport costs = f (***d, P, f, vd, m, s, b***)

d = distance ,
P = shipment size
f = frequency = ***Vol*** / ***o*** ,
vd = value density,
m = mode
s = speed (depending on the mode of transport)
b = reliability of the mode used:

We assume that rationalistic supply chain managers try to minimize their logistic costs while maintaining a certain service level that is required for their customers. These service levels are very much correlated with the value density of the products involved (Christopher, 1992, Simchi-Levi et al, 2000) so the supply chain optimization problem can de reduced to a generalized cost minimization problem per product type. This optimization problem involves the choice of production and storage locations, the frequency of replenishment shipments, the choice of mode and the inventory policy used. In many cases the mode choice decision is not a free choice, and normal choice models that assume an extensive set of alternatives cannot be used. We propose to use Generalized cost curves that take into account the most likely choice for mode of transport.

Lammers et al (2006) have found out that 95% of the transport mode choice is determined by the product characteristics and the 'as the crow flies' distance, that for most transport flows are given and cannot be influenced. In Figure 3 below the shipment sizes and transport costs of some modes of transport are visualized. From this picture it becomes clear that huge differences between the respective modes of transport exist, both in shipment size and in average transport charges.

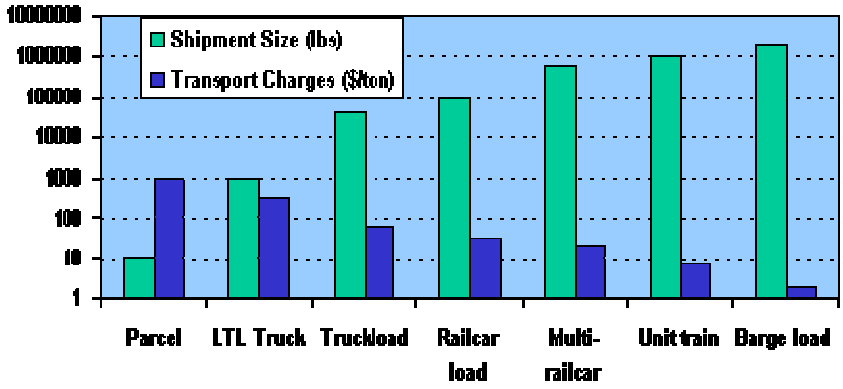

Figure 3 Differences in shipment size and transport charges for different modes of transport (source: Rodrigue 2006a)

Because of these large differences and the limited choice flexibility, it is possible, given a limited number of exogenous factors, to specify an a-modal or mode abstract generalized logistics cost function, such as the one visualized in Figure 4 below:

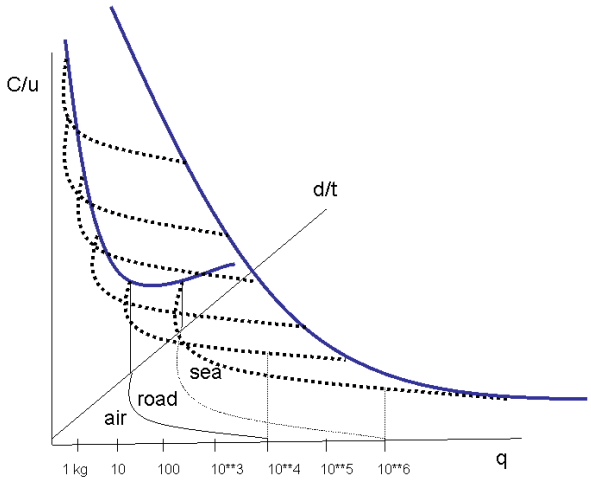

Figure 4 Transport cost per unit, as a function of speed (distance per time unit) and shipment size

This figure shows the areas for which the modes air, road and sea transport are dominant. By specifying the weight of the shipment and the required speed the mode choice and the transport cost per unit can be derived easily. 100.000 tons of crude oil are transported by

ship, a box of diamonds is shipped by air, unless the distance is less then 1000 km's, when road transport or express parcel transport will be used. There will be no discussions on the mode choice decision in these circumstances.

Besides shipment side and speed there are 2 other determining factors that really do have a strong influence on the modal choice and other logistic decisions, and that is the value density of the product and the level of demand uncertainty. When taking into account the value of the product and the volatility of demand also the effect of inventory costs via increased safety stocks and the effect of pipeline costs can be visualized, as is done in Figure 5.

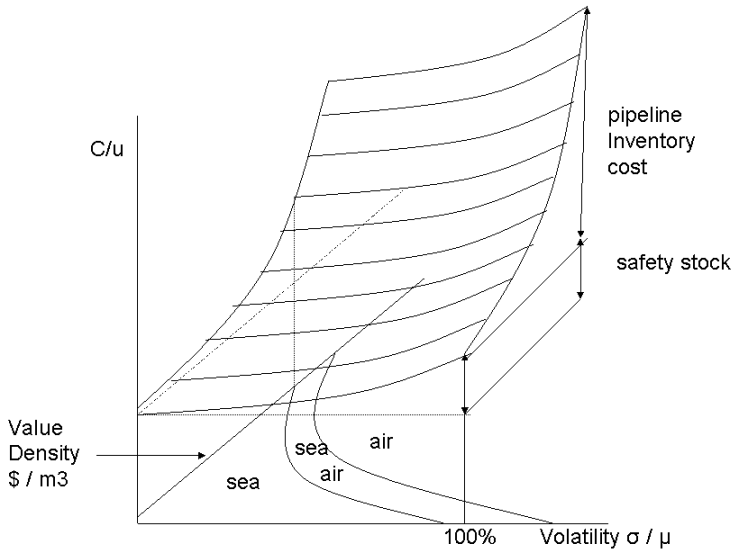

Figure 5. Logistics cost per unit as a function of value density (value per m3) and volatility (standard deviation of demand/ mean demand)

When the value density is low, pipeline costs (the inventory costs during transport) will be negligible. When the value density becomes larger (for instance a shipment on 1 container with 1000 laptops (20 pallets of 50 laptops) with a production value of $500 per laptop, each container will have a pipeline cost of $5000 for a trip of 36 days and a capital cost of 10%. The average transport rate of this container from Asia to Europe is $ 1500, so the pipeline cost for this shipment will exceed the sea transport cost with a factor 3 and this integrated costs would be roughly the same when these products would have used the air mode (3kgs per laptop at 2$ per kg). So, although transport costs differ a lot per mode of transport; generalized costs show less variation, taking into account other logistic cost factors.

When the volatility is high, retailers and distributors do need safety stocks in order to avoid empty shelves if the demand for a product is higher then the stock and the demand during the reorder period. Safety stocks can be avoided for a great deal if fast and reliable transport options exist that can guarantee the delivery of products within the customer service requirements. So, trade off's exist between inventory costs and transport costs and the Generalized cost concept should take these trade off's into account.

Thus it can be concluded, that by taking into account a few important product and demand characteristics into account a large variation in generalized cost can be explained already quite well. There is one variable however that requires special attention and that is the level of reliability of the supply. Congestion, lack of adequate planning and sudden events (earthquakes, strikes) can have a strong impact on the reliability of supply chains and ask for resilience strategies (Sheffi, 2005).

Through the use of hybrid networks a flexible way of quickly adapting from one supply source to another can be created as is clarified in Figure 6. The volatile part of the demand is supplied by a fast (and more expensive) network, while the stable part of demand is being delivered through the slow but cheap hub network that makes maximum use of economies of scale.

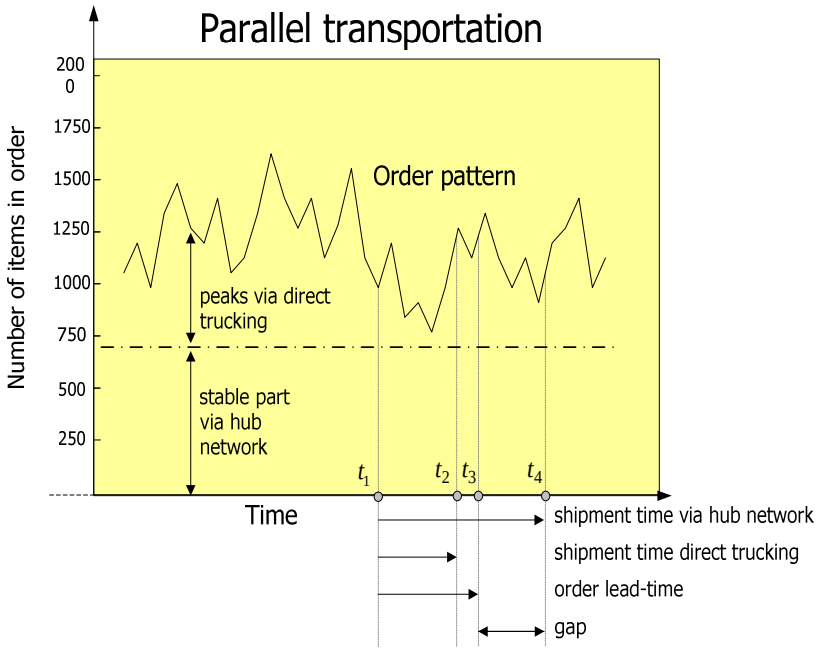

Figure 6. Being responsive by combining different networks (Groothedde, 2005)

3. Evolution of freight models as partial systems

The classical transport modelling framework consists of four modelling steps: trip production, trip distribution, mode choice and route choice. This structure has been in use for both passenger and freight models for decades. Freight models have been slowly moving away from this framework, following three lines of improvement: (1) a consistent description of trade-economy linkages, (2) the introduction of inventories as determinants of geographical demand patterns and (3) a consistent treatment of transport mode and route choices (Tavasszy, 2006). As we will argue in this section, these

directions have developed in parallel and in separation. Also we will explore to what degree generalized logistics costs have been used in these models.

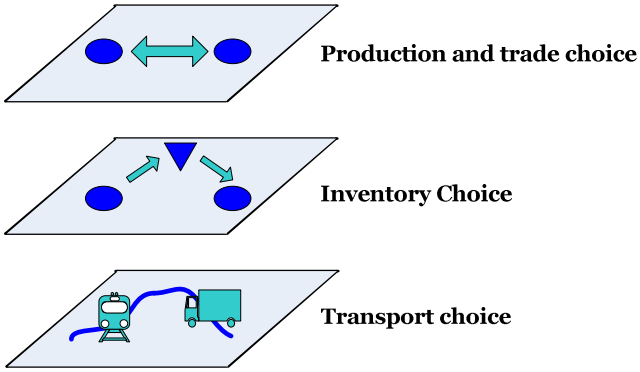

Figure 7: Freight modelling problems divided in three layers

We briefly describe the literature according to these lines, concentrating on the leading operational freight forecasting models and recent research developments in the field.

Trade-economy linkages
The trade-economy models deal with calculation of production and consumption volumes per region and per commodity (economy models). The output of economy models is further used in trade or distribution models, which produce data on trade and goods flows between regions. This class of problems is often solved by the spatial computable general equilibrium (SCGE) models. Bröcker (1998) proposed to use SCGE models for operational, interregional intersectoral models, overcoming the perception that the general equilibrium models cannot be made operational.

Currently the SCGE class of models is the main tool for estimation of transport-related and financial-economic impacts (Tavasszy, 2006). Prior to the advent of the SCGE models in the 90's spatial price equilibrium models (Harker, 1985) and gravity models (Chisholm & O'Sullivan, 1972) were the main methods by which trade was modelled. In Europe there are SCGE models covering the whole EU, as well as Dutch, Italian, Norwegian models. Among the models mentioned, the Harker model, extended with a freight network, is perhaps the most integrative in its attempt to combine different levels of our framework.

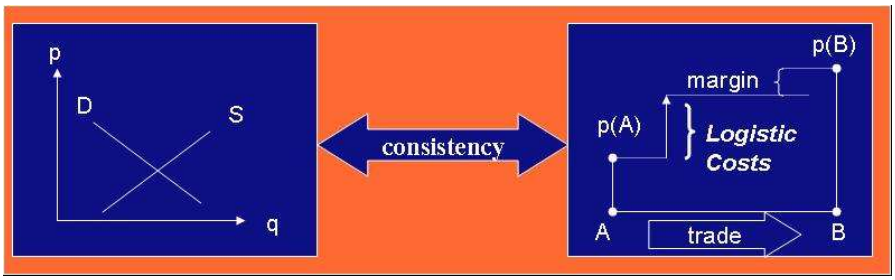

Figure 8 : Key elements of the spatial equilibrium problem in product markets: demand/supply functions and their interaction with trade between regions

Research into spatial gravity models augmented with additional variables such as logistics friction and quantitative metrics of logistics performance shows a statistically significant relationship between quality of logistics and the level of bilateral trade, (Hausman et.al, 2005). The research implications of this report are that the gravity model with a single generalized logistics cost function can be applied to determine trade flow between world regions. The model does not attempt to explain the interaction between trade and prices and volumes of production and consumption. As can be seen from Figure 8, logistics costs play an important role in the equilibration process that is described in SCGE models. It also shows the importance of a good calculation of these costs. In general they are not exogenously given but are endogenously determined, and a.o. being influenced by (dis)economies of scale in logistics processes.

Inventory Choice

The output of the freight economy linkages models is materialized in the form of interregional freight flows. However, these flows do not in itself form a sufficient basis for the estimation of the actual path and infrastructure claim that these flows cause. The class of logistics behaviour models solves this problem by modelling actual goods flow between the trading regions, including intermediary transhipments and stock points. The output of logistics models is in the form of Origin-Destination matrices (O/D matrix), which take into account intermediary flows between the stock or transhipment points. Logistics models can also generate information on mode and vehicle type used, as the choice for inventory location will be closely related to the choice of shipment sizes and modes of transport within the different legs of the chain. An abstract mode approach, as suggested earlier in our paper, can also be applied here.

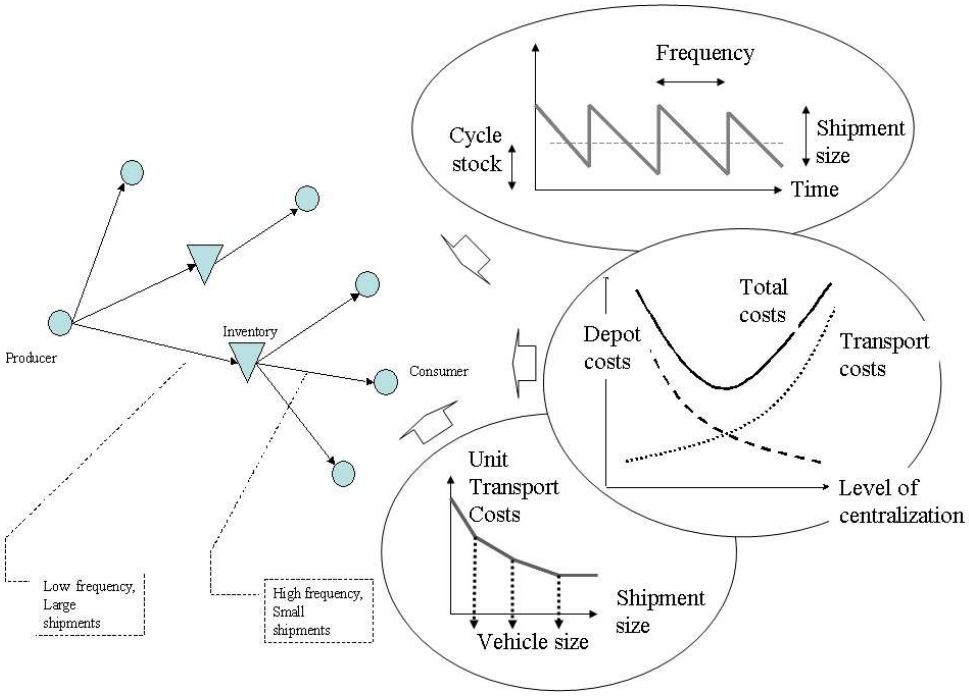

Figure 9: Key elements of the intermediate inventory choice modelling problem: endpoint and pipeline inventories (A), spatial logistics trade-offs (B) and economies of scale in transport (C)

There have been a number of experimental initiatives worldwide to develop spatial logistics models (Tavasszy, 2006). The Los Angeles County freight model includes a comprehensive, innovative, multimodal modelling framework to support freight transportation decision making in Los Angeles County (Fisher, 2005). The modelling approach combines freight modelling techniques: logistics chain modelling and tour-based truck modelling.

The SMILE model has been constructed in order to enhance understanding of the developments and policy options regarding freight transport in the Netherlands. The model developed in 1990^{s} in the Netherlands and was the first aggregate freight transport model, which accounts for routing of flows through distribution centres. It explicitly takes into account logistics developments and translates logistics tendencies, such as centralization of warehouses, higher frequencies and consolidation into freight demand characteristics (Tavasszy, 1998). The SMILE model extends 4-layer classical freight modelling framework with an extra logistics layer. The decision to use intermediate inventories in SMILE was constructed as a discrete choice model, disregarding mode and route choice but following a mode abstract approach and employing transport cost curves where costs vary by shipment size (see Tavasszy, 1998, 2001 for applications).

The GOODTRIP model has been developed at Delft University in the Netherlands. The GOODTRIP model estimates goods flows, urban freight traffic and its impacts (Boerkamps, 1999). Based on consumer demand, the GOODTRIP model calculates the volume per goods type in m^3 in every spatial zone. The goods attraction constraint calculation starts with consumers and ends at the producers or at the city borders. Next, the goods flows of each goods type are combined by using groupage probabilities. The model not only builds a distribution O/D matrix, but also produces vehicle tours, thus spinning into the realm of the freight trips and networks class of models. The tours per mode are assigned to corresponding infrastructure networks, resulting in network loads, per mode on each network. The modelling process is sequential; there are no feedbacks to previous phases in the process.

The SLAM model (Spatial Logistics Appended Module) evaluates the impacts of changes in the logistic and transport systems within the whole Europe on the spatial patterns of freight transport flows (Tavasszy, 2001). The model takes into account changes in distribution structure, i.e. the number and location of intermediate warehouses for the distribution of goods. This model spawned the SCENES model, which has been incorporated into the EU modelling suite TRANSTOOLS.

Apart from the state-of-the-art models, there is an ongoing research in the field of logistics behaviour models. Burmeister (2000) looks at Just In Time (JIT) production environments with complex logistic systems and intensive use of technologies such as information and communication. Such complex systems are believed to replace the traditional manufacturing practices in future. The article identifies "4 worlds" which have distinct organization of transport and production. The JIT concept has been tested for

each of the four worlds. One of the ideas the article is that transport serves as production coordination means and the synchronisation of both processes is essential.

In the United Kingdom work has been done on the EUNET 2.0 model, which is an integrated regional economic and logistics freight transport model, Jin (2005). It has been designed using SCGE and SCENES modelling principles and serves the purpose of forecasting future levels of goods transport demand as a function of economic transactions and freight logistics. The model represents logistic movements and integrates this representation in a Spatial Input-Output (SIO) Model, while explicitly treating logistic stages (echelons) and associated transport costs. The model reaches trip and network modelling levels, taking into account different modalities and vehicle sizes.

Groothedde et al(2005) have elaborated quantification of economies of scale in logistics networks. Consolidation of logistics networks allows more efficient and more frequent shipping by concentrating large flows onto relatively few links between hubs. The authors propose a formulation of total logistics costs in a logistics network, which takes into account density of the flow and location of inventories. The paper showed on an application example in the Netherlands that collaborative consolidation of flow between key points (hubs) provides substantial advantages for collaborating parties.

Transport choices

The freight trips and network models normally treat mode split and, simultaneously or subsequently, assign vehicle trips to the transport network using route choice models. Some national level models (Belgium, the Netherlands, United Kingdom, Finland and Sweden) treat modal split and network assignment simultaneously Beuthe (2001), Swahn (2001). Recently, models of worldwide, multi-modal transport chains have been introduced (see Pattanamekar et al, 2008 and Tavasszy et al, 2007).

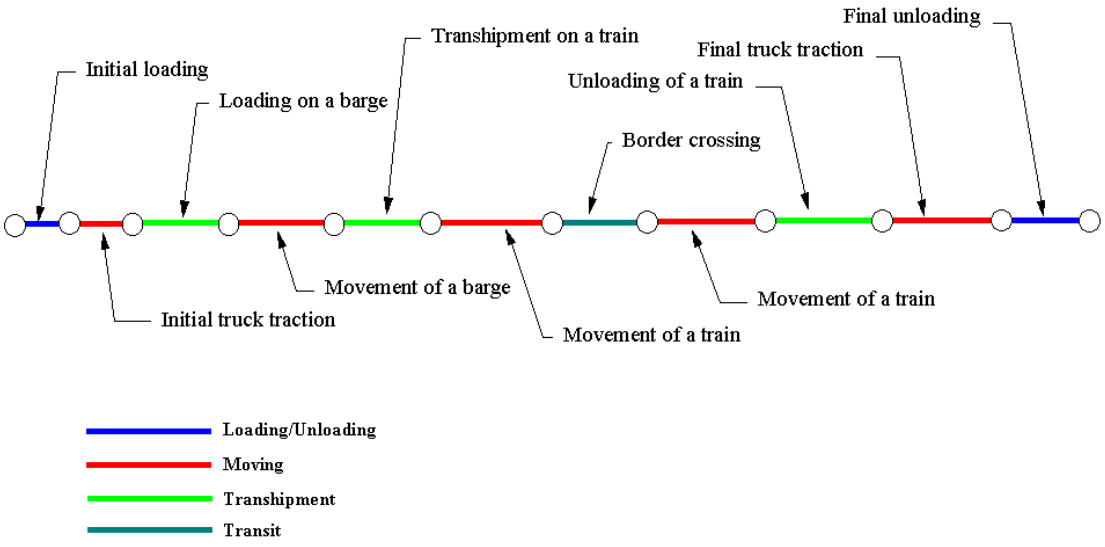

Figure 10 Illustration of the network architecture of the European multimodal network choice model NODUS (www.fucam.ac.be)

Modelling of empty trips present a big research challenge as there are not much empirical data over empty vehicle trips. The local urban freight models are currently not very different from regional or global ones. The urban freight modelling presents a promising research field.

Two innovations in models of transport service choice, that employ a form of logistics cost formulation, come from Liedtke (2005) and de Jong et al (2007). Both use micro level simulation of transport logistics choices. Liedtke (2005) develops an agent based microsimulation model for freight transport in Germany using a total logistics costs formulation for transport and trade decisions. Based on de Jong et al (2007), a logistics simulation model with deterministic cost minimisation has been constructed for both Norway and Sweden. De Jong's model uses a multimodal network, and also allows transshipment between modes of transport and different means of transport by mode (e.g. LTL-FTL). The number of links considered by the model allows aggregation to the national level. Both logistics models operates at the level of individual firm-to-firm (sender-to-receiver) relations and simulates the choice of shipment size and transport chain for all (several millions) of these relations within a country, export and import. The authors describe in detail transport logistics and the model's data requirements, although inventory costs are only treated for the goods in transit. Additionally the authors acknowledge difficulty in modelling vehicle empty trips.

Recent work of Holguín-Veras (2008) has considered enhanced formulations to model commercial vehicle empty trips at the networks level. Modelling of empty trips is important, since on the one hand empty trips load infrastructure and increase logistics costs, and are difficult to estimate from production/consumption statistics on the other hand.

4. Towards integrative freight equilibrium models using generalized costs

Freight models have to a great extent evolved separately along the 3 different layers of our framework presented above in figure 7, with few integrative attempts. As Liedtke et al (2009) point out, a risk of the traditional multi-step transportation modelling framework is the mismatch between the functional behaviour of the different sub-models making construction of comprehensive choice models problematic. Our objective in this section is to sketch a model in which functional behaviour is aligned between sub-models, by reaching consistency in demand volumes and costs of services between the 3 layers. Consistency in costs is reached by applying the generalized costs concept as described earlier in the paper. Consistency in demand volumes at different levels is reached by equilibrating the flows in the different layers.

The basic architecture for an integrative model that complements the classical 4 step modelling approach is one with a separate choice model for intermediate inventories, as described in the previous section. The approach of using logsums to aggregate costs over choice alternatives is already standard practice in discrete choice models for passenger transport. For freight models specifications using sequential discrete choice models and logsum approaches for consistency in costs, including an inventory model, were provided

for the SCENES and SAMGODS. The logistics choices and cost formulations were not as wide in scope, however, as described in this paper. Shipment sizes were exogenous, supply chain choice sets were limited to national and continental distribution centers and costs of unreliability were not included.

Models of spatial interaction
Ideally, models of spatially separated product markets should show prices and quantities that are consistent within and between regions. Although this is the case for SCGE models, accessibility is usually still represented by distance or transport costs alone, sometimes supplemented by trade barrier effects. The definition of accessibility in trade models can successfully be extended to include logistics variables, as Hausman et al (2004) show. In their model, however, logistics costs are exogenous. Linkages with models that explain changes in logistics costs as a function of network choices and supply chain design could increase the scope of applications of the model because of existing economies of scale. While the Hausman model deals with trade and assumes regional freight demand to be constant, a next step would be to include generalized logistics costs in SCGE models, or another model type in which regional freight demand is endogenous.

Choices concerning the location of intermediate inventories could potentially be integrated in models of spatial interaction as well. Applying the O/D estimation approach presented in Pattanamekar et al (2009), chains of movements can be synthesized starting from observations of individual origin-destination movements (as available in transport statistics) and thus reproducing a table of trade between regions of production and consumption.

One result of using generalized logistics costs is the natural inclusion of the choice of shipment size. To reflect the reality of decision making at firm level, models of supply chain choice, mode choice and routing should be in harmony from this perspective. For example, inventory optimization models should take into account synchronization between production and shipping schedules in a way that inventories are considered at those locations that determine the eventual route of the shipment. Finally, as many of these cost and service functions are non-linear or discontinuous, ideally, (dis)economies of scale need to be considered. Note that this presents additional difficulties for aggregate models, as (unlike in passenger transport networks) some of this non-linearity and discontinuity appears at the individual firm level, rather than at the collective level.

Integrating logistics considerations into transport choices using network models
Inventory decisions can be modeled as part of a hypernetwork choice problem, where different layers of the network represent segments of the chain upstream and downstream from distribution centers. The route choice process can be carried out using deterministic or probabilistic network choice methods. Figure11 illustrates a bi-level hypernetwork with 2 routes: direct shipping (route I) and indirect shipping (route II). The top network in the figure has high shipment sizes, and the goods have to switch to lower shipment sizes via storage in a DC. A direct routing alternative is available, although at higher shipping costs. Note that this differs from the supernetwork approaches for transport mode choice. In these approaches the choice for inventory location is not included or the alternative

routes constitute only transport service related network choices and not, like in this case, the choice of supply chain configuration.

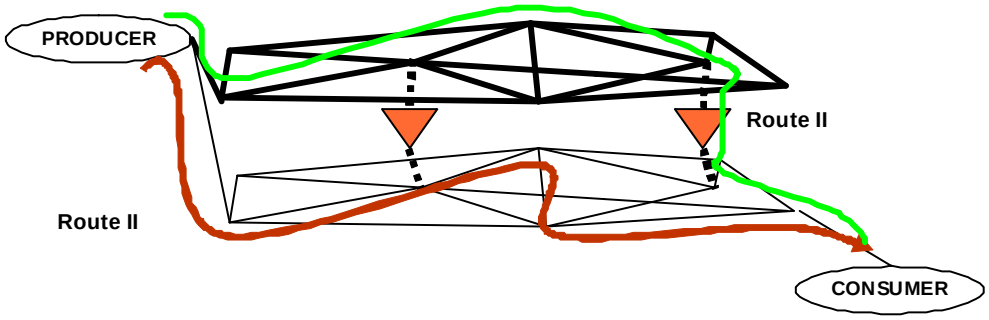

Figure 11 A hypernetwork model for inventory location choice

Note also that in order to show hybrid structures, a probabilistic choice model, allowing the simultaneous use of different alternatives, will be needed. Where supply chain structures interact with routing and mode choice, models need to be developed such as SMILE that describe the choice of vehicle type (including light goods vehicles) and the choice of transshipment terminals (see also the NODUS and SAMGODS models). An important extension of routing models is the aggregate representation of roundtrips (Holguin Veras, 2008). The inclusion of inventory costs in itself can also be relevant to increase the accuracy of mode choice models, even if inventory locations are not the subject of choice (de Jong, 2007).

The modelling work of Nagurney (2002) already represents an important step in this direction. She proposed a novel multilevel network framework that allows capturing distinct flows, in particular, logistical, informational, and financial flows within the same network system, while retaining the spatial nature of the network decision-makers. The authors interlink three networks that facilitate movements of goods from producers to consumers: logistical, informational and financial networks. Calculation of prices belongs to the financial networks and is done dynamically using input from logistical and informational networks.

A specific point in the above sections concerns the multitude of possible supply chain architectures. More complex forms of supply chains, where different manufacturing systems interact with inventory configurations (e.g. “built to order” connected to a rapid fulfillment depot instead of supply chains driven by “built to stock” manufacturing, see Tavasszy, 2003) are a further expansion of these hypernetwork type models.

Alternative architectures for integrative models

In this section we have presented different ways to integrate logistics considerations in freight models. These extend the possibilities to model freight movements. The figure below provides an overview of alternative configurations of models. There are two dominant, overarching configurations which support all main clusters of choices in the aggregate freight models. Other configurations can be derived from these two.

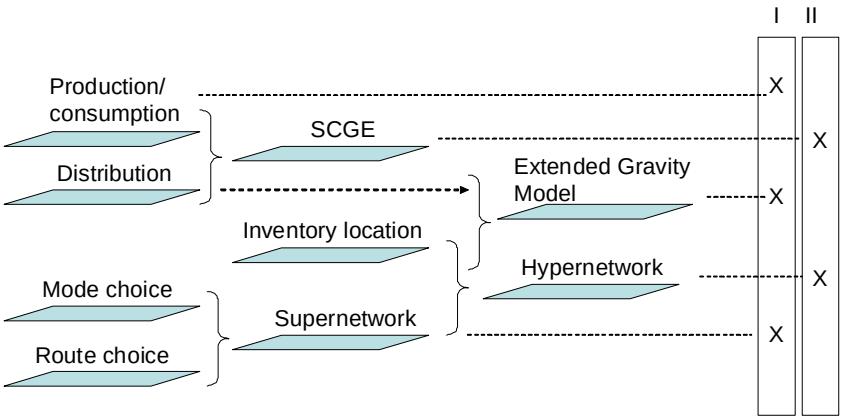

Figure 12: Alternative configurations for an integrative freight model

Consequences for data acquisition
Note that freight model databases need to be extended in terms of the structural elements of logistics activities. Data are needed on the various logistics infrastructures (size, location of inventories, terminals), the quality of logistics services (speed, reliability) and the costs of services. Also the demand for logistics structures and services needs to be monitored. Finally data that characterizes logistical requirements (i.e. behavioural preferences) of shippers and carriers is needed. This data can be obtained through estimation of behavioural models, but will require some form of observation of (intended or realized) logistics choice behaviour.

5. Conclusion

Freight models have progressed beyond the 4 step framework in several ways. Both on the area of spatial interaction models, inventory choice and logistical choice models, as well as network models improvements in modeling techniques, and improvements in model structure and explaining variables have been introduced that have led to a better description of each of these different layers of freight modelling.

These model innovations have been developed rather independently, and although each improvement can be justified on its own account, they all are lacking a framework in which the specific characteristics of freight flows are taking into account consistently. This means that they have to reflect the fact that there is always direct linkage between freight flows and the way the world and regional economies develop, but also there needs to be a link with the development of logistics organization and they should be sensitive to quality and price differences in the available modes and infrastructure. Presently this consistency is mostly lacking, and this leads to model constructions that can potentially be inconsistent, and do not describe equilibrium processes between demand and supply adequately.

In this paper we have described a number of avenues that could be developed to streamline the modeling concepts in a consistent way. In Figure 12 these different avenues have been sketched. All modeling frameworks rely on a consistent and unifying Generalized Cost concept. Such a concept is necessary to make a consistent calculation of the way geographic distances are evaluated on the different levels of the modeling framework, but also it is necessary to use a consistent framework in finding market equilibria that in many cases reflect scale economies and thus need a consistent modelling frame work.

Our plea for a consistent approach will not be reached easily, it needs in depth data gathering, model development and testing and we hope to inspire many researchers to join us in this process.

References

Beuthe, M.B.J., J.-F. Geerts, C. Koul a Ndjang Ha, (2001), *Freight transportation demand elasticities: a geographic multimodal transportation network analysis.* Transportation Research Part E, **37**: p. 253-266.

Boerkamps, J., van Binsbergen, A.,(1999), *GoodTrip -- A New Approach for Modelling and Evaluation of Urban Goods Distribution*, Urban Transport Conference, 2nd KFB Research Conference, Lund, Sweden.

Bröcker, J.,(1998) *Operational spatial computable general equilibrium modeling.* The Annals of Regional Science, **32**: p. 367–387.

Burmeister, A., (2000) *Spatial dimensions of logistic strategies: a typology*, in *3rd KFB Research Conference*, Stockholm. p. 13.

Christopher, M. (1992), *Logistics and Supply Chain Management*, Financial Times Pitman Publishing, London

Dicken, P. (2003), 'Global Production Networks in Europe and East Asia: The Automobile Components Industries', *GPN Working Paper 7*, University of Manchester, http://www.sed.manchester.ac.uk/geography/research/gpn/gpnwp7.pdf

Fischer, M.L.O., Lihung Luke Cheng, Dike N. Ahanotu, Robert Calix, (2005), *Innovative Framework for Modeling Freight Transportation in Los Angeles County, California* Transportation Research Record: Journal of the Transportation Research Board, **1906/2005**: p. 105-112.

Groothedde,B. , C. Ruijgrok, L. Tavasszy, *Towards collaborative, intermodal hub networks: A case study in the fast moving consumer goods market.* Transportation Research Part E, 2005. **41**(6): p. 567–583.

Hausman, W.H, Lee, Hau, L, Subramanian, U.,(2004), 'Global logistics indicators, supply chain metrics, and bilateral trade patterns' , The World Bank, *Policy Research Working Paper Series , no 3773*
www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2005/11/17/000016406_20051117161830/Rendered/PDF/wps3773.pdf

Holguín-Veras, J. , E. Thorson, J.C. Zorilla (2008), *Commercial Vehicle Empty Trip Models With Variable Zero Order Empty Trip Probabilities*. Networks ans Spatial Economics, p. 19. http://www.springerlink.com/content/r2368mm8v2427733/fulltext.pdf

Hummels, D., (2001), 'Time as a trade barrier', *GTAP Working Papers 1152*, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University. <www.mgmt.purdue.edu/centers/ciber/publications/00-007Hummels2.pdf>.

Jin. Y., WSP Policy & Research (2005). The EUNET2.0 freight and logistics model - Final Report. Regional Pilot for Economic/Logistic Methods. DfT Contract PPAD 9/134/24. London: Department for Transport, Co-authored with Ian Williams. http://www.dft.gov.uk/pgr/economics/rdg/coll_theeunet20freightandlogisti/theeunet20freightandlogistic3127

Jong G. de, M.Ben-Akiva, (2007), A micro-simulation model of shipment size and transport chain choice. *Transportation Research Part B* 41, p. 950–965.

Jordans, M. , B. Lammers, L.A. Tavasszy, C.J. Ruijgrok, (2006) Het basispotentieel voor binnenvaart, spoor en kustvaart - een verkenning bezien door een logistieke bril – (*the base potential for inland navigation, rail and short sea shipping – an investigation through logistical spectacles* (in Dutch), report TNO 2006-D-R0839

Liedtke, G. (2005), An Actor-based Approach to Commodity Transport Modelling, PhD Dissertation, Karlsruhe: Universität Fridericiana Karlsruhe

Liedtke, G..; L. A. Tavasszy, W. Wisetjindawata, (2009), Comparative Analysis of Behavior-Oriented Commodity Transport Models, in *Proceedings 88th Annual Meeting of the Transportation Research Board.* January 11-15, Washington D.C. p. 21.

Nagurney, A., K. Ke, J. Cruz, K. Hancock, F. Southworth, (2002) *Dynamics of supply chains: a multilevel (logistical — informational — financial) network perspective.* Environment and Planning B: Planning and Design,. **29**: p. 795 - 818.

Östlund et al (2003), *A Logistics module for SAMGODS*, SIKA - Swedish Institute for Transport and Communications Analysis, Stockholm, Sweden

Pattanamekar, P. and D. Park, Estimating Multimodal OD Matrix from Mode Specific OD Matrices, in: Proceedings of the 88th Annual Meeting of the Transportation Research Board, Washington: TRB

Rodrigue, J.P **,** (1997) "Parallel Distributed Processing of Transportation / Land Use Systems: Theory and Modelling with Neural Networks", *Transportation Research C*, Vol. 5, No. 5, pp. 259-271

Rodrigue, J.P (1999) **,** Globalization and the Synchronization of Transport Terminals, *Journal of Transport Geography, 1999, Vol. 7, pp. 255-261.*

Rodrigue, J.P., (2006a), Transportation and the Geographical and Functional Integration of Global Production Networks, *Growth and Change*. Vol. 37, No. 4, pp. 510-525.

Rodrigue, J-P (2006b) "Challenging the Derived Transport Demand Thesis: Issues in Freight Distribution", *Environment & Planning A*, Vol. 38, No. 8, pp. 1449-1462.

Sheffi, Y, (2005) The Resilient Enterprise, MIT Press, Cambridge, MA

Simchi-Levi, D., P. Kaminsky, E. Simchi-Levi, Designing and Manageing the Supply Chain, (2000), McGrawHill Higher Education,

Swahn, H., (2001), *The Swedish National Model system for Goods Transport. A brief introductory overview*, SIKA report, Stockholm.

Tavasszy, L.A., C.J. Ruijgrok, (1998), *A DSS for modelling logistic chains for freight transport policy analysis.* International Transactions in Operational Research, **Vol. 5**(No.6): p. 447-459.

Tavasszy, L. A., van de Vlist, M., Ruijgrok, C. and van de Rest, J. (1998) *Scenario-wise analysis of transport and logistic systems with a SMILE*. Paper presented at the 8th WCTR Conference, Antwerp.

Tavasszy L.A., (2006) *Freight Modelling: an overview of international experiences*, in *TRB Conference on Freight Demand Modelling: Tools for Public Sector Decision Making*. 2006: September 25-27, 2006, Washington DC.

Tavasszy, L.A., J van Meijeren, J-F Perrin, A Burgess, A Koike (2007), Worldwide container model, in: Proceedings of the European Transport Conference 2008, London: PTRC

Van Nunen, J and D. 't Hooft, UNECE, (xxxx) Transport without Borders, www.transumo.nl/Downloads/UNECE%20%20Transport%20without%20borders%20(5).pdf

Wilson, J.S., C. L. Mann, T.Otsuki, (xxxx), Trade Facilitation and Economic Development, Measuring the Impact, World Bank, *Policy Research Paper 2988*, www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2003/04/11/000094946_03040104075221/Rendered/PDF/multi0page.pdf