Transportation and Logistics in Supply Chains

Gerard de Jong

Research Professor, Institute for Transport Studies, University of Leeds,

Director, Significance, The Netherlands

Director of Research, NEA, The Netherlands

Moshe Ben-Akiva

Edmund K. Turner Professor of Civil and Environmental Engineering,

Director, Intelligent Transportation Program,

Massachusetts Institute of Technology

Outline: 1 Introduction, 2 Outsourcing Transportation and Logistics, 3 Transport Chains, 4 Consolidation and De-consolidation of Shipments, 5 Choice of Time-of-Day and Scheduling, 6 Route Choice 7 Government Intervention, 8 Summary and Conclusions

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Abstract:

Transportation and logistics are critical elements of the supply chain. This chapter discusses the decisions made at the micro-level by firms interacting in a supply chain. These decisions include the choice of whether or not to outsource logistics, which transport chain to use from the point-of-production to the point-of-consumption including the mode for each leg of the chain, the consolidation and de-consolidation of shipments, the issues of timing and scheduling, and the route through the transportation networks. Freight transportation and logistics are also considered from the macro-perspective at a national and international scale.

1 INTRODUCTION

DEFINITION AND SCOPE OF LOGISTICS AND TRANSPORTATION

'Logistics' originates from a military term that refers to the supply of goods such as ammunition, food, fuel, and equipment for soldiers at war. Now it is used broadly in civilian settings. Two frequently cited definitions of logistics are from the U.S. Council of Logistics Management (1998) and from the handbook of business logistics management by Ballou (1992). The Council of Logistics Management (1998) defines logistics as follows:

> *"Logistics is the part of the supply chain process that plans, implements and controls the efficient, effective flow and storage of goods, services and related information from the point-of-origin to the point-of-consumption for the purpose of conforming to customers' requirements."*

Ballou (1992) states that:

> *"Logistics is all about guaranteeing that the right goods and services are delivered at the right time, at the right place, and in the right condition, and that, in making this happen, the company concerned should attain the highest possible yield."*

Many other definitions have been put forward, expressing different views on logistics and supply chains and the underlying model. For the purpose of this chapter, we base ourselves on the following notions about the scope of logistics and transportation, which are consistent with the two definitions of logistics given above (also see Figure 1):

- The supply chain process encompasses logistics. Supply chain management also integrates business processes other than logistics, such as production and marketing.
- However, logistics and supply chain management share the same point-of-origin to point-of-consumption perspective, as well as the same focus on customer requirements and quality.
- Freight is only a part of logistics. Beside the physical flow of the goods in space and time (freight transportation), logistics is also about service flow, information flow as well as inventory management.

On the other hand, transportation is more than logistics, because it also includes passenger transportation, infrastructure and public policy.

- see here Figure 1 -

Inventory management is discussed in other chapters (such as 61, 62 and 100) and will only be touched upon in this chapter where inventory and transport decisions are clearly linked. Information flow in the supply chain is also discussed in other chapters especially in the parts on supply chain management and electronic commerce. This chapter will focus on the planning of the movement of goods such as raw materials, semi-processed goods and finished products. This chapter will also include reverse flows through the supply chain. This can be seen from the perspective of an individual firm (in this chapter we focus on the shipping firm that requires transportation, but we shall also deal with issues that are relevant for a carrier firm that provides transportation), or an individual supply chain at a micro-level, or from the perspective of a country or a region at the macro-level. Both perspectives will be presented in this chapter.

ADDED VALUE OF TRANSPORTATION AND LOGISTICS

Coyle et al. (1996) states that in 1993, the total U.S. logistics cost was 10.5% of the gross domestic product (GDP). The share of logistics cost in GDP has been decreasing since the early eighties when it was almost 18%. This reflects a large improvement in logistics efficiency, and a great reduction in inventories. But the percent share of freight transportation costs in GDP has declined as well, reaching 6% in 1993/1994. There is evidence of a further relative decline in logistics costs. According to a survey of over 200 European firms, logistics costs represent 7.7% of sales value in Europe (A.T. Kearney, 2000). In 2003, studies in the UK indicated that 4.8% of the gross value added came from the service sectors' transport and storage and 7.8% when also including communications (National Statistics, 2007). In specific supply chains the transportation and distribution of goods can account for as much as 25% of the cost of products (Heizer and Render, 2007).

Logistics adds value by producing place and time utility as it moves goods to the locations where these goods are demanded, at the point in time that the goods are required. Unlike production activities, logistics usually does not yield utility by transforming the goods themselves. Indirectly, an efficient logistics system will lead to a greater scope for regional and international specialization as well as a greater product variety and lower prices for the consumers. Finally, logistics can make a major contribution to the competitiveness of a business (McKinnon, 2001). One example would be the timely delivery of fashion articles (efficient consumer response systems). This might even extend to the competitiveness of a supply chain, network and a nation.

TRANSPORT AND LOGISTICS COST FUNCTIONS

Cost functions are defined here at the level of an annual flow of a product from a production firm to the point-of-consumption. The point-of-consumption may be a producer that carries out further processing, or a retail outlet, where a consumer buys it ands takes it home on a shopping trip. An annual flow consists of one or more shipments. A shipment occurs when goods are ordered, transported and delivered. The total annual logistics costs (denoted by *G)* of a commodity (*K)* transported *with shipment size (q)* between a firm (*m)* in a production zone (*r)* and a receiving firm (*n)* in a consumption zone (*s)* via a transport chain (*l)* (that may include multiple legs, modes, vehicle types, loading units, and trans-shipment locations) are:

$$G_{rskmnql} = O_{kq} + T_{rskql} + D_{k} + Y_{rskl} + I_{kq} + K_{kq} + Z_{rskq} \qquad (1)$$

Where:

G: total annual logistics costs

O: order costs

T: transport costs

D: cost of deterioration and damage during transit

Y: capital costs of goods during transit

I: warehousing costs (storage costs)

K: capital costs of inventory

Z: stockout costs

This cost function needs to capture differences among firms to explain economies of scale in warehousing, ordering and transportation. Also varying among firms are the discount rate for the inventory capital costs and the other preferences such as attitude towards stockout risk. The total logistics costs could be minimized with respect to aspects of the transport chain and with respect to shipment size. Smaller shipments will lead to reduced storage cost, but greater order cost and potentially higher transport cost. This is because the fuller and larger the freight vehicles are, the less expensive is the cost per unit of product. Hence, firms make trade-offs with different outcomes depending on commodity type, location of shippers and receivers, etc.

The transport cost T includes fuel cost, tolls, labor cost, vehicle depreciation and insurance cost, initial loading cost, final unloading and transfer cost at trans-shipment locations such as road terminals, ports, airports, and inter-modal terminals. For a firm that hires transportation services, T in eq. (1) can be substituted by the price paid. Note that freight transport cost or price is only one of the components of the logistics cost. The order cost O is the fixed cost for ordering a shipment of some goods (e.g. administrative costs). Deterioration and damage costs D are much more relevant for some goods (fruits, fresh fish, flowers) than for others, and just as capital costs Y for the inventory on transit, depend on the value of the goods and total delivery time (but the latter also depends on the interest rate). The warehousing cost I consists of the cost of physical storage of the goods (e.g. depending on warehouse space and inventory size). The capital cost of the inventory K on the other hand depends on the inventory level and the value of the goods, and on the opportunity costs of capital (so the interest rate becomes relevant). Stockout costs Z have to do with the consequences of not being able to supply (costs of emergency shipment and of lost demand). These can be based on the costs of keeping a safety stock (related to variation in demand and in transportation time).

Specific functional forms for the logistics cost function can be found in de Jong and Ben-Akiva (2007). Ben-Akiva et al. (2008) extended the logistics cost function to include service quality and derived empirical estimates in a model for mode choice by shippers.

LINKS WITH OTHER ACTIVITIES IN THE SUPPLY CHAIN

The supply chain extends outside the individual firm, backward to suppliers and forward, encompassing the customers.

McKinnon (2001) distinguishes four phases of logistical integration since the early sixties. The first two deal with integration within the logistics function of a firm: the integration of the outbound distribution activities, and the integration of inbound and outbound flows of goods. The third is the integration of production, purchasing, marketing and sales, where logistics is the vehicle for cross-functional integration. Stage four is the advent of supply chain management where logistics activities are optimized over the supply chain. Nevertheless, there are still many firms that have not integrated their logistics activities, much less integrated their supply chains (whether this is a matter of insufficient real benefits from integration for their processes or a matter of inertia and lack of knowledge is a matter of debate and needs further examination).

AGENTS INVOLVED IN TRANSPORTATION AND LOGISTICS DECISION-MAKING

In freight transport, unlike passenger transport, multiple agents are usually involved in the decision-making about a single shipment. The shipping firms, such as producers or traders of commodities or their representatives, have a demand for transport services. In most cases these transport services are to send products to their clients, the receivers or consignees. In some cases, the receiver organizes the transport. Shippers themselves in what is referred to as own account transportation meet part of this demand. The remainder, hire and reward transportation, is contracted out to carrier firms or intermediaries known as third and fourth party logistics service providers. Third party logistics (3PL) service providers perform logistics activities for a shipper, whereas fourth party logistics (4PL) service providers integrate capabilities of several organizations, including their own (e.g. multiple 3PLs for different parts of the logistics chain) to obtain a comprehensive supply chain solution. Managers of the shipping firm, the carrier and/or the intermediaries, may make the transport choices such as the mode. In general, it is recognized that the shipping firm is the most common decision-maker of mode choice. The firm actually carrying out the transport usually determine route choice. In the case of road transportation, truck drivers may have some freedom to choose the route or to change routes as a reaction to unexpected traffic delays.

DIFFERENCES BETWEEN COMMODITIES

There is considerable heterogeneity in freight transportation, significantly more than in passenger transportation. The size of the shipment may vary from a parcel delivered by a courier to the contents of an oil tanker. The value of a truckload of sand is vastly different from a load of gold blocks with the same weight. As a result, decision-making and decision-outcomes will be different for different commodities. In this respect, the most important attributes of the goods are the density, monetary value per ton, and the handling characteristics such as containerized, palletized, refrigerated, etc.

AVAILABLE DATA ON FREIGHT TRANSPORTATION

An impediment to detailed freight transport analysis from the macro-perspective is that some of the information, especially on transport cost and logistics cost, is proprietary. Firms in freight transport are usually reluctant to disclose this information to clients, competitors and the public.

At the macro-level, data on transportation and logistics are available from:

- Trade statistics and customs data that provide information on import and export of goods usually in monetary units.
- National accounts, including input-output tables. These give the flow of goods and services between sectors of the economy in monetary units. Multiregional input-output tables provide information on trade between sectors in different regions of a country (see for instance Marzano and Papola, 2004). Tables that show commodity production by economic sector are then derived from tables that show commodity consumption by economic sector.

- Transport statistics such as roadside surveys providing information on vehicle origins and destinations, port statistics of incoming and outgoing tons by commodity type and truck surveys. In EU countries, information on origin, destination, commodity type, and load is collected from a sample of firms with trucks over 3.5 tons.
- Shipper surveys that collect detailed information about the firm's freight transport and selected individual shipments, (e.g. in France; see Rizet and Guilbault, 2004), and commodity flow surveys, where shippers provide a limited amount of information about a large sample of shipments, (e.g. in the U.S and Sweden; see Vanek and Morlok, 1998, and SIKA, 2002). Consignment bills and RFIDs, which are electronic tags for tracking and tracing, contain detailed information. But this information is not publicly available.
- Traffic counts containing both manual and automated counts that usually distinguish between trucks and cars. Network data from road, rail, waterways, etc., and timetables for transport services that operate at fixed times, such as liner services, are also available.
- Data on terminals such as location, types of goods, throughput, and costs.
- Cost functions that are usually based on a sample of firms, or engineering assumptions.

2 OUTSOURCING TRANSPORTATION AND LOGISTICS

OWN ACCOUNT AND HIRED TRANSPORTATION SERVICES

The party that is responsible for moving the goods from the point-of-origin to the point-of-consumption can either be the shipper at the point-of-origin, the receiver, or a combination of both. In the latter case a combination of shipper and receiver occurs when the responsibility changes from sender to receiver at a port. In the –dominant- former case, the receiver pays a 'delivered' price for the goods. In the second case, the price is 'ex works'. These parties choose whether to use own account transportation and organize the transportation by themselves or to use hire and reward transportation, which is to outsource transportation services to a specialized carrier. This is a manifestation of the 'make or buy' decision.

The percentage share of own account transportation in freight transport declined during the period of 1990-2001 in most European countries. This drop also varied considerably across countries. In 2001, more than 51% of all domestic road freight ton-kilometers were carried out as own account transport in Portugal. But own account transport only made up 15% of Spain's domestic freight transport (Eurostat, 2003). Professional carriers do practically all-international transport in/to/from Europe.

A shipper that selects hire and reward transportation has to choose the carrier. In many cases, the shipper selects a carrier that offers a single mode. This means that effectively, mode choice precedes carrier selection (Coyle et al., 1996). This subject is discussed in more detail in the section on transport chains. However, an increasing number of carriers have expanded their range of services and now also offer several modes for the same origin to destination pair, as well as multimodal services with a sequence of modes. Since most shippers require the same transport service repeatedly over time, the carrier selection decision is usually made for a fixed time period as dictated by formal contracts. Therefore, shippers may not have to review eligible carriers for every shipment. Some carriers only serve a single shipper or a limited number of shippers, as specified in contracts. Other carriers offer services to anyone. One example would be scheduled services. By concentrating on a limited number of carriers, a shipping firm may attain a greater bargaining power to lower price.

THE CHOICE CRITERIA

In the choice between own account transportation, hire and reward transportation, and carrier selection, the choice criteria for decision-making are not limited to the price of the transportation service. Transport time, the reliability of transport time in the sense of timely delivery, the degree of safe delivery, and the flexibility in handling unforeseen requests, are all relevant. Own account transportation is chosen in cases where tight control is an important criterion. It is also used in situations where specialized equipment or expertise, not offered by a competitive carrier, is required. Own transport is also attractive when there is a large flow of goods that allows a firm to achieve low transportation costs on its own.

Fridstrøm and Madslien (1994) carried out a stated preferences survey of a stratified sample of 300 wholesale firms in Norway. A specific shipment was drawn at random from each of the firms' outgoing shipments. For the specific shipment, the wholesale firm was asked to make nine choices between two options: using own account and hiring transport services. Both options were described in terms of the freight cost, transportation time, risk of late delivery and risk of damage. Discrete choice models were estimated using the stated preferences data. These models showed that the marginal rate of substitution between time and cost exceed the prevailing interest rate by a two-or three-digit factor. The cost of capital appears to play only a minor role in comparison to time factors. Risk of late delivery and risk of damage also turned out to be significant influences on the choice between own account and hire and reward transportation. Finally, the authors found that past decisions acted as considerable inertia for this choice. Companies tend to hang on to the actual chosen option, be it own account or hire and reward transportation.

OUTSOURCING LOGISTICS ACTIVITIES

In the movement to concentrate on the "core business" in recent decades, many firms that originally carried out their own logistics have decided to outsource logistics activities. Outsourcing logistics now often go beyond hiring transportation services. Third party logistics firms are now also offering a wide range of logistics services and have achieved a high level of efficiency. Apart from the more traditional transportation, outsourcing of warehousing, delivery and customs documentation, further logistics activities such as final assembly, packaging, labeling, order planning and processing, product tracking and tracing, assembly of pallets and containers, fleet and container management, invoicing, and logistics information technology may also be purchased (Browne and Allen, 2001).

3. TRANSPORT CHAINS

Information on orders, transactions, invoices and payments are now often exchanged electronically in a few seconds. However, the physical movement of goods needs considerably more time. This observation is especially significant in intercontinental maritime transport. In this section we focus on the physical flow of goods from a point-of-origin such as a manufacturer or a wholesaler to the point-of-consumption for further processing, or retail.

CHOICES IN FREIGHT TRANSPORT

For freight transport, as for passenger transport, it is possible to establish a set of choices made by relevant decision-makers that collectively determine the amount and composition of freight transport demand. These choices may include:

- Shipment choices such as shipment size, frequency, etc. result in shipments of commodities with a certain weight, size, and value between the point-of-origin and the point-of-consumption. The flow in tons times the trip length is the transport volume. The transport volume is measured in ton-kilometers or ton-miles. The shipment’s size and value are important characteristics because they affect the mode choice and the load factor. The load factor is the weight of the cargo divided by the capacity of the vehicle or vessel.
- Transport chain choices result in a series of modes and vehicle types used consecutively for a transport between the point-of-origin and the point-of-consumption. This includes information on the trans-shipment(s) between the modes or vehicle types for the same mode. A chain contains a single leg using a single mode in the case of direct transport. It can also consist of several legs, each with its own mode or vehicle type, as depicted in Figure 1. An example of a multi-modal, multi-leg transport chain would be: road transport from the point-of-origin to a port, followed by sea transport to a second port, and finally road transport to the point-of-consumption. Transport chain choices include the choice on the number of legs in the chain, the mode choice for each leg and the trans-shipment location(s). These choices result in a modal split and affect the vehicle load factor. Together, the transport volumes, the mode shares and the load factor determine the number of vehicle-kilometers (or vehicle-miles) by mode.
- Time-of-day choices and other timing issues such as the day of the week that produce a distribution of traffic over time periods.
- Route choices that yield the distribution of traffic over the network.

Shipment choices, like shipment size, are discussed elsewhere in this Handbook (especially in chapters 61, 62, 100). However, modelling mode choice is best done in conjunction with shipment size choice using an inventory-theoretic framework (e.g. Chiang, 1979; McFadden et al., 1986; Abdelwahab, 1998, Ben-Akiva et al, 2008). Holguín-Veras et al. (2008) discuss game theory on shipper-carrier interactions and provide econometric and experimental economic evidence on the subject. It is concluded that freight mode choice can be best understood as the outcome of interactions between shippers and carriers, and that mode choice depends largely on the shipment size that also results from the shipper-carrier interactions. Under typical market conditions, the shipper and carrier will cooperate. It does not really matter who "makes" the decision on the shipment size and the mode to be used at a given time period. Over time the shipper—that is the customer—ends up selecting the bids more consistent with its own interest. In other words, these results do not support the assumption that freight mode choice is made solely by the carriers. In recent years, different kinds of cooperation agreements have been reached between shippers; logistics service providers and government agencies such as port authorities. These agreements are called vertical integrations within the logistics chain (see Meersman and van de Voorde, 2001).

A shipping firm can decide to make an integrated plan for the above choices; this is the topic of logistics network design, which is about well-balanced solutions defined in terms of the number of consolidation and distribution centres, their locations, the places where inventories are stored and the inventory levels and the transport organization (modes, vehicle types, routes, departure times) (Chopra, 2003, Chopra and Meindl, 2006). For several of the above choices, increasingly more powerful (commercial) software is available to support decision-making, for specific operational problems (e.g. routing) all the way to more integrated and strategic decision-making (e.g. facility planning: number and location of warehouses).

Note that transport chain choice is the topic of this section, consolidation issues are presented in section 4, and time-of-day and route choice are discussed in section 5 and 6 of this chapter.

THE FOUR-STEP TRANSPORTATION MODEL

The phrase *'transportation model'* is used here to define mathematical models that produce estimates of the amounts of freight transportation in tonnes lifted, tonne-kilometres or vehicle kilometres. A '*traffic model'* is a mathematical model that produces estimates on the number of vehicles or vessels on different links of a transport network. Most traffic models are transportation models as well. But several transportation models determine the transportation volumes and do not include an assignment to networks. Without a network model the travel time and costs are approximated usually based on crow-fly distance or virtual networks. In other words, they are calculated without explicit models of the networks.

Many models for freight (and passenger) transport follow the so-called *four-step* approach. The four steps are:

- Production and attraction models predict the amounts of transport from the various origin zones and to the destination zones. These are the row and column totals of the origin-destination (OD) or of the production-consumption (PC) matrix. The OD and PC matrices are discussed below.
- Distribution models predict the flows of transport between the zones. These are the cell entries of the OD or PC matrix;
- Modal split models predict the allocation of the flows to transport modes, such as cars and trains.
- Assignment model with explicit network models extends a transport model to a traffic model as well. It loads the OD matrix entries of one or more transport modes onto the transport networks.

For freight transport in particular, additional transformation modules such as those from trade flows in monetary units to transport flows in tonnes are also important components for the total model system. Despite the fact that they are usually ignored, many other logistics choices such as shipment size, and use of consolidation and distribution centers could be thought of as further steps. This has been an important area for improvement and research.

Each step of the model can be based on either *aggregate* data, the data at the macro-level of the zones, or *disaggregate* data, the data at the level of the decision-maker such as shippers. Within disaggregate data there is a distinction between data on actual choices that are referred to as revealed preferences and data on choices in hypothetical situations, which are referred to as stated preferences. There are disaggregate national freight transport models in countries like Italy and Scandinavia. But most freight transport models are aggregate models that are sometimes highly segmented by commodity type.

PC FLOWS VERSUS OD FLOWS

At the macro-level a distinction can be made between PC (production-consumption) flows and OD (origin-destination) flows. This is the macro-level equivalent of the distinction at the micro-level between a transport chain and a leg of a transport chain. The transport chain can potentially be a multi-modal transport structure whereas the leg is a uni-modal structure that is part of a transport chain. By adding transport chains to and from the same zones, one obtains PC matrices. By adding legs to and from the same zones, the OD matrix is obtained. PC matrices contain commodity flows all the way from the production zone to the consumption zone. These flows may consist of several OD flows. This is because a transport chain may be used with multiple modes and/or vehicle types as well as one or more transhipments along the route,

- see here Figure 2 -

PC flows represent economic relations and transactions within and between different sectors of the economy. Changes in final demand, international and interregional trade patterns, as well as in the structure of the economy, have a direct impact on the PC flow patterns. Also, the data on economic linkages and transactions are in terms of PC flows. They are not in terms of flows between producers and transshipment points, or between transshipment points and consumers. Changes in logistics processes such as the number and location of depots, and in logistics costs, have a direct impact on the composition of the transport chains. This would lead to different OD flows that would only indirectly impact the economic and trade patterns (and hence the PC flows). Assigning PC flows to the transport networks require that they be first transformed into their corresponding OD flows. For instance, the transport chain road-sea-road would lead to road OD legs ending and starting at different ports. This would take the place of a long-haul road transport that would not involve any ports. A similar argument holds for a purely road-based chain that first uses vans to ship goods to a consolidation center, then consolidates the goods with other flows of goods into a large truck for the main haul, and finally, uses a van again to deliver goods from a distribution center to the C destination. In this scenario, the link assignment depends on the three OD legs. Therefore, converting the PC flows into OD flows, which can be done by a 'logistics model', (see de Jong and Ben-Akiva, 2007) is required for a meaningful network assignment. The data available for transport flows from traffic counts, roadside surveys and interviews with carriers are also at the OD level, not at the PC level.

THE TRANSPORT MODES

The options available for modes of freight transportation generally are road, rail, inland waterways, sea, air and pipeline. Within these modes, several types of vehicles or vessels, such as articulated trucks, can be distinguished. Road transport is generally the most widely available mode. The availability of inland waterways modes and short sea shipping is the most constrained. The mode shares for inland transport for both the U.S. and the European Union are in Table 1.

- See here Table 1 -

In Table 1 we can see that road transport is more important in the EU and rail transport relatively more important in the U.S.. This has to do with topographic factors (more domestic long distance transport in the US), but also with differences in the organisation of road and rail transport (e.g. rail freight getting priority in the U.S.). The characteristics of the different modes are discussed below.

Rail networks are not as dense as road networks and only a few firms have direct access. Railway operations often require reconfiguration of trains at marshalling yards, which is time-consuming and leads to relatively long door-to-door transport times. Rail transport requires heavy investments in tracks, signalling, terminal facilities and equipment. Because of these substantial fixed costs, the unit cost of transport is high at low transport volumes and decreases slowly with increasing transport volumes. Rail transport is often the least cost choice for large quantities of goods transported over long distances. For this reason, rail transport was historically regarded as a natural monopoly and even today; a single entity usually manages the rail tracks of a country. However, in many countries rail deregulation and privatization have taken place. This has resulted in competition between freight transport rail operators. In some countries, passenger transport rail operators are also competing against each other for regional franchises.

Labor expenses are the main component of transport cost in road transport. The fixed costs are a considerably less significant portion of the total cost than that of rail transport. In most countries, the road transport industry is also highly competitive, served by many firms varying in size from large corporations to one-person owner-operator.

Table 2 compares the pros and cons of the rail and truck systems.

- see here Table 2 -

The table is based on current practices instead of theoretical characteristics of the modes. In some countries, such as the U.S. where freight transport by rail usually gets priority over passenger transport by rail, the pros and cons of the two systems may be somewhat different. Road transport usually scores best on time, reliability, flexibility and accessibility. Conventional rail and combined road-rail transport (intermodal transportation) have relatively better safety and cost features especially for long distances and/or large volumes, In cases where there is a high load factor, inter-modal transportation also produces less emissions of conventional pollutants and greenhouse gases. Rail freight transport has the potential to be very reliable. But in reality, especially in Europe, shippers consider the timeliness of road transport to be superior. It is difficult for rail to hit tight delivery windows. If road congestion keeps increasing, this may change. Train operations are also less sensitive to weather conditions than road transport. International rail transport in Europe is still slow and costly due to the lack of interoperability and responsiveness to market forces dictated by national railroads. It can only remain competitive in long distance transport routes over 350-500 km (Beuthe and Kreutzberger, 2001). Therefore, rail transportation is usually used to transport low value bulk cargo where the most important factor is low rates.

For substantial market shares in other cargo, a truly inter-modal system with one logistics service provider that is responsible for the entire transport chain while offering reasonably fast and reliable door-to-door services is required.

Waterways and sea routes generally require no infrastructure investments from the carriers since public authorities usually undertake these costs. Carriers only invest in the equipment (Coyle et al., 1996). In the sea transport market, there are generally several large private carriers competing for international market share while smaller carriers compete for inland waterways transport. Water transport vessels tend to be considerably bigger than that of road and rail transport. They offer low unit rates but also low operational speeds. This makes this mode most suitable for the transport of low value goods over long-distances. Inland waterways transport competes with road, rail and short-sea shipping. Ocean shipping has a large market share when measured by shipping volume in tonnes. But in terms of value, a very high percentage of international transport goes by air.

While passenger transport planes are still used for freight transport in what is known as belly freight, airfreight transport via dedicated freight carriers is increasing. Air transport has high variable costs relative to the fixed costs (Coyle et al., 1996). Compared to other modes, the unit costs are quite high especially for large volumes. For long distances, air transport in considerably faster than all other modes. Given its high costs, it is predominantly used for goods that quickly deteriorate in value or that are needed urgently. Some examples are flowers, newspapers, spare parts, and express mail. But, more recently, the air transport market has been expanding to other goods.

Pipelines are only used for liquid petroleum and natural gas. The investment in the network is very substantial when transporting small volumes. This cost decreases as the quantity increases. The pipeline networks have low density and low speed.

Both intermodal and multimodal transportation use several modes in the same transport chain between point-of-origin and point-of-consumption. The main difference is that intermodal or 'combined' transportation is carried out for a single flat rate and uses the same loading unit and volumes on all the modes in the chain. This unity reduces the transhipment costs and time as long as specialised equipment for transporting the containers at intermodal stops are available. The most common containers are the eight feet wide and twenty feet or forty feet long containers. Container movements are often measured in TEUs: twenty-foot equivalent units. The use of containers began in the maritime sector by the Sea-Land Company, and has grown tremendously over the past decades. Containers can be used on sea vessels, trucks, trains both single and double stack, as well as inland vessels. Road-sea-road and road-rail-road are regularly used transport chains that often use containers all the way. Instead of containers, intermodal transportation can use swap bodies that have non-rigid sides. Besides container ships, there are also roll on - roll off ships called RoRos, where the road trailers are driven on board. Trailers can also be loaded onto trains (sometime known as 'Rollende Landstrasse', 'Iron Highway').

A recent development, which influences all the modes, is the attention paid to making the logistics chains more secure (with respect to terrorism). The Customs-Trade Partnership Against Terrorism (C-TPAT) is a voluntary supply chain security program led by the U.S. Customs and Border protection. Participants include manufacturers, importers, road, rail, sea and air carriers, transportation intermediaries and terminal operators in the US, Canada and Mexico. The participants must carry out a standardized assessment of security of their supply chain.

MODE CHOICE ELASTICITIES

`The 'direct' price elasticity of transport demand by each mode gives the percentage change in demand for each mode as a result of a percentage change in the price of that mode. Cross-elasticity gives the impacts on the other modes. Elasticity in freight transport can be vastly different for different commodity types and local circumstances such as availability of water-based transport. In the following, we present some average outcomes from a study of freight transport in the European Union.

Price elasticity of demand for various transport modes is rather elastic in Europe.

- see here Table 3 -

Increases in road transport costs for general cargo and especially for bulk goods on transport distances over 500 kilometers have a substantial effect on modal choice. In Table 2 we see that a one percent increase in truck costs would decrease truck demand in ton-kilometers by –0.5% (case: bulk between 500 and 1000 kilometers) and increase demand on alternative modes by 1% (inland waterways), 1.5% (train), 0% (intermodal transportation), 0.3% (short sea). Raising truck transport costs will shift bulk transport from trucks to rail and inland waterway transport. It will also shift higher-value general cargo from truck to rail and intermodal transportation. For trips up to 500 kilometers, the elasticity is considerably smaller: between 0 and –0.3 for the truck price elasticity of truck transport of bulk products, and between 0 and –0.5 for general cargo.

High-value goods are usually more time-sensitive than lower value goods. Consequently, the transport costs of more high-value goods are of less importance than timely, reliable delivery. In transport model simulations (EXPEDITE Consortium, 2002), general cargo deliveries show substantial time elasticity values from road to other modes at distances over 1,000 kilometers.

- see here Table 4 -

A critical distance at around 1,000 kilometers may explain this sharp increase in the elasticity and in the absolute values. At an assumed average truck speed of 70 to 80 km/h, a distance of about 1,000 kilometers is an upper limit that can no longer assure timely overnight delivery. At distances below 500 kilometers, the time elasticity of truck ton-kilometers is lower: between 0 and –0.25 for bulk goods and between 0 and –0.5 for general cargo.

4. CONSOLIDATION AND DE-CONSOLIDATION OF SHIPMENTS

Combining several shipments in the same vehicle or vessel is called consolidation. This can occur for shipments with one or more legs of the transport chain in common.

- see here Figure 3 -

The main reason for consolidation is to share transport costs with other shipments. It allows the use of fuller and larger vehicles and vessels with lower unit cost. Consolidation can take place:

- At the place-of-origin. A shipper can organize batches of products to be transported so that a good match with available transport capacity is obtained.
- In consolidation centers that receive goods from several senders.
- Via vehicles that do collection rounds by visiting multiple senders.

Here we focus on the second and third categories. A consolidation centre (CC) is a transhipment terminal where small loads of goods that arrive are stored and organized into larger collections of goods for further shipping. A distribution center (DC) is a transhipment terminal where large collections of goods that arrive are stored and separated into smaller separate loads of goods for further distribution. We use the words 'terminal' and 'transhipment location' or 'transfer points' for both CC and DC. A CC can be a road terminal, a port, or airport for a railway terminal in cases of intermodal transport. The same applies to a DC. CC and DC also include the use of 'cross-docking', which has been increasing substantially in recent years. Cross-docking means that the vehicle from which the goods are unloaded and the vehicle on which the goods are loaded are present at the terminal at the same time, and that the goods are moved from one vehicle to the other, without any storage. Consolidation requires multi-legged transport chains. This would include at least a leg from the sender to the CC as well as a consolidated leg from the CC to the consumption zone. Usually, the second leg will be to a DC. There is usually also a third leg from a DC where the consolidated shipment is broken down into multiple shipments for the different receivers.

Four types of consolidation networks can be distinguished in addition to direct connections between senders and receivers (Beuthe and Kreutzberger, 2001):

- *Line networks*. These networks have links connecting a starting nod, an ending node, and a number of terminals in between where transhipments take place. There are no line network consolidation centers where shipments from several directions come together. The consolidation takes place along the route. An example is a shuttle train or a sea liner service that connects more than two stations/ports.
- *Trunk collection and distribution networks*. Several shipments from different senders come together at a CC and are then transported together on the main trunk line to the DC where they are de-consolidated and distributed to various receivers (as in Figure 2).
- *Hub-and-spoke networks*. All links converge at a main hub where transfer operations and bundling of flows take place. The best-know example is that of the airline industry.
- *Trunk feeder networks*. These are like a line network, but several of the terminals between the starting and ending nodes are feeder terminals, which act like a CC, for the trunk line. These networks can be unimodal or multimodal. An example in passenger transport is a public transport network with buses feeding a rail line.

The ‘milk round’ concerns a single vehicle visiting multiple suppliers and consolidating the shipments from each along the route. This is done by Toyota that has a limited number of part suppliers and a collection round that picks up shipments from these suppliers every four hours. De-consolidation can also be done using round tours. Delivering shipments at multiple receivers is called multi-drop tours.

5. CHOICE OF TIME-OF-DAY AND SCHEDULING

Freight transportation can shift to other routes and other time periods if satisfactory alternatives offering better transport <u>time, and cost advantages</u> are available. If several routes or departure times are available but provide different travel times, road freight vehicles will use the fastest route as long as there are no extra costs. Most freight transports put a higher importance on time in comparison to cost, and therefore require a substantial cost difference to outweigh the time difference. The evaluation study on the effects of the opening of the Amsterdam Orbital Motorway (Bovy et al., 1992) showed that after the opening of a major new motorway route that offered substantial time gains for many origin-destination combinations, truck traffic changed routes as much, if not more than passenger traffic. Shifts to time periods that avoid congestion and result in shorter travel times also occurred in freight transport. For example, some carriers shifted toward nighttime transport. This has only occurred on a small scale so far. Most long-distance freight transport is already avoiding rush hours. But city distribution often cannot do this because of the delivery time window.

Holguín-Veras (2007) argues that the effectiveness of tolls in shifting freight traffic to off-hours outside normal working hours might be limited. The competitive nature of the urban delivery industry results in a tendency for rates to be set at marginal costs. This prevents the carriers from transferring toll surcharges to their customers because the tolls are generally a fixed cost that vanishes from the calculation of marginal cost. In the long run, this is not sustainable since the carrier will be incurring losses. As a result, the receivers in competitive markets are not likely to receive any price signals. Price signals are only possible in industry segments where the carriers enjoy oligopoly power. Even when the carrier could pass toll surcharges to their customers, which is 9% of the case according to a survey in New York City, the price signal is of no consequence when compared to the receivers' incremental costs due to off-hour deliveries. To overcome this, Holguin-Veras proposed the provision of tax incentives to receivers willing to do off-hour deliveries. They also proposed the use of freight road pricing as a revenue generating mechanism to finance the tax incentives. Other objections for off-hour deliveries are overtime wages and community objections.

At present, many cities around the world have delivery time windows that are specified time intervals for delivery in the city (center). There are some advantages in terms of noise reduction during the night and better working hours for the staff at the destination locations. Theoretically, time windows could decrease the number of vehicle kilometers because they are additional forces that encourage multi-stop deliveries. But at the same time, they constitute a restriction that forces truck operators to use their equipment and personnel in a sub-optimal way. The number of stops that can be combined during a certain time interval is limited. Therefore, time windows will increase the number of separate vehicle trips and reduce the load factors if there are numerous destinations to be served in a city. A similar argument goes for night bans and weekend bans for freight traffic in specific areas and links. Delivering to pickup points instead of to the final customers can mitigate the restrictive influence of time windows.

6. ROUTE CHOICE

A transport *network* is modelled as a combination of *links* and *nodes*. Examples of links are sections of road and railway lines. The basic idea of a link is that traffic can only enter from the beginning of the link and has to remain till the end of the link. Traffic cannot enter or leave it midway. The ability to do so would imply a node and at least one other link. Usually, two parallel links are used to represent traffic on the same road, railway line or waterway going in two directions. These links are called uni-directional links. But links can also be bi-directional. Nodes such as injunctions or roundabouts are the points where links come together. Going from one link to another might lead to additional travel time. In addition to costs and time, links and nodes may also be associated with a certain maximum *capacity* which is the maximum amount of vehicles or vessels that can pass during a given time period.

A network can be a unimodal road network, or a multimodal network including different modes. In the case of a multimodal network, going from a link of one mode to a different link of another mode will constitute an interchange or a transhipment with specific consequences for travel time and transport cost. This means that mode choice and network assignments are carried out simultaneously in one step in what is called a “multimodal assignment”.

Within the transport models, the networks serve two purposes:

- The travel time and cost for origin-destination pairs for one or more modes can be calculated from the networks by calculating the cost and time for the shortest path through the network. This is called’ skimming’ the networks. These costs and times can than be used as explanatory factors of transport demand choices such as the mode choice.

- After the initial transport demand has been calculated in terms of traffic flows between the origin and destinations for a day or time-of-day period such as the morning, it can be assigned to the networks. Again shortest path algorithms will be used here. This stage in the transport model is called ‘assignment’ and several methods are available for this, including:
    - Simple ‘all-or-nothing’ assignment where a specific OD flow is entirely assigned to a single route through the network.
    - Capacity-constraint assignment that takes the capacity of the network component into account.
    - Equilibrium assignment (see below).
    - Stochastic assignment where several routes are used for the same OD combination.
    - Dynamic assignment that incorporates continuous clock time.
    - Schedule based assignment that can only be used for scheduled transport.

See Ortuzar and Willumsen (1994) or Hensher and Button (2008) for a treatment of assignment methods. In some transport models, passenger cars and trucks are assigned simultaneously to the same networks since they compete for the same network capacity. In several models, a ‘congestion feedback’ effect is included. This means that after the initial transport demand has been loaded on to the networks, new transport times, which include time losses to congestion, are calculated. These new times are then re-inserted into the demand models. This can create a change in demand such as a shift to less congested destinations and modes. The new demand is assigned again to the networks, and so on in a demand-supply iteration cycle until equilibrium is reached. An equilibrium assignment follows Wardrop’s first principle. This principle assumes that each user wants to minimize his own costs (this optimum is a ‘user optimum’). It says that the journey times on all routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route. No user can decrease his transportation costs by unilateral action. Wardrop’s second principle refers to the overall system optimum, and individual choices will only lead to this if the transportation costs are equal to the marginal social costs (thus including the external congestion costs). It says that at equilibrium the average journey time is minimum: the best route for the user also is best for the network (system) as a whole.

An important aspect of logistics optimization is to strive toward greater vehicle utilization. Empty and partly loaded vehicles are a major source of inefficiency. They also contribute to air pollution and noise pollution. Considerable efforts have been made to increase the load factor of the vehicles. The load factor is calculated as the weight of the cargo divided by the capacity of the vehicle. An example would be optimizing fleet management and organizing vehicle tours to multiple senders and/or receivers in order to consolidate (see section 4) deliveries and return loads. Sometimes considerable discounts are given for pre-designated return load appointments in order to avoid single return runs. Given the existing imbalance between delivery flows and return flows, it is apparent that consolidation and fleet optimization management could be more efficient. Improvements in load factors may be possible if carriers and shippers had a better knowledge of freight flows in their business region. Furthermore legal requirements of a shipper to only use privately owned vehicles bearing the shippers logo may hamper the more efficient use of vehicles.

Besides raw material and semi-finished products, providers of logistics services can also transport waste material in the reverse direction. This is called ‘reverse logistics’. This has developed as a whole new sub-discipline in logistics. A closely related concept, is that of ‘closed-loop supply chains’. This encompasses flows in both directions (commodities and waste material), so that no materials are left somewhere along the chain. Sometimes the word ‘green logistics’ is used to mean ‘reverse logistics’ (Rodrique et al., 2001). The former expression potentially covers a much wider area that also concerns the choice of more environmentally friendly modes and going against the trend of increasing shipment frequency of smaller shipments.

7. GOVERNMENT INTERVENTION

The public authorities’ main objectives for transportation and land use policies with respect to freight transport demand are to promote accessibility and decrease the negative external and environmental effects of transportation. Apart from this, security in transportation is also an important reason for government intervention. Among the key drivers of freight transport demand, the most important driver is growth in the gross domestic product (GDP), growth in trade and the growing distance between suppliers and receivers. International trade has been growing considerably faster than global GDP. In Europe, the creation of the single market has contributed to the growth of freight transport. Logistic developments such as the centralization of inventories, emergence of hub ports and airports, reduction of lead time (as part of just-in-time (JiT) supply chains, see chapter 64 of this book), increase of business-to business electronic information exchange (see Ruijgrok, 2001; and also chapters 104-105 on RFID, 66 on ERP and 179-199 on e-commerce) and more efficient mode attributes such as costs, time, reliability and flexibility are more important drivers for modal split and shipment size.

Transportation policies do not focus on these important drivers of total freight transportation. Hence they can only have a limited impact on the volume of freight transport. Transportation and land use policies only have a significant impact on the following factors (also see van de Riet et al., 2004):

- These policies can affect residential and business location choices. For example, regulations or financial incentives to businesses can stimulate mixed land use or spatial clustering.
- Governments can promote certain logistic developments. For example, they can encourage the emergence of information brokers and other means of providing data on consignments.
- Transport policy can influence some of the characteristics of the modes such as time by investing in network links and public or public/private terminals as part of city logistics. They can also affect cost by implementing taxes, tolls and subsidies. Note however that several logistics costs components have already been increasing considerably in recent years, due to fuel price increases, driver shortages and environmental concerns. In some segments of the freight transport market such as low value goods and long distance shipments, the modal split is responsive to time and cost changes by mode. The scheduling of freight transport and of distribution in particular may be influenced by delivery time windows, time-of-day specific vehicle bans and by time-of-day specific road pricing. These restrictions are more effective when in combination with incentives for the receivers to change delivery times to periods outside the normal business hours. The choice of vehicle type can be influenced by vehicle weight and height restrictions, emission standards or load factor requirements in specific areas such as city centers.

- Introducing more competition into the rail sector through government policies might lead to improved service characteristics such as innovativeness, reliability, interoperability, and flexibility of the rail freight sector vis à vis the road sector.

8. SUMMARY AND CONCLUSIONS

Efficiently organized freight transportation and logistics are vital to businesses and national economies and provide competitive advantages. Firms sending or receiving goods make freight transport decisions in interaction with elements of their supply chains. These decisions include whether or not to outsource logistics, who to outsource to, the transport chain that will be used from the point-of-production to the point-of-consumption including the choice of mode for each leg of the chain, the consolidation and de-consolidation of shipments, the issue of time-of day choice and scheduling, and the route choice through the transportation networks. Freight transportation at the national or international scale is shaped by these micro-level decisions. But it is usually studied at a more aggregate level because of a lack of available micro-level data.

Over the past few decades, logistics has changed dramatically due to greater competition in the logistics and transport markets that has been advanced by various technological innovations. Developments that have been going on for some time now, and can be expected to continue are:

- Globalization of production and consumption. This will lead to more long-distance transports, especially more intercontinental transport flows. It will also increase product demand with increasing wealth.
- Further dematerialization in areas like mail, newspapers, and tickets, leading to a reduction in freight transport trips.
- Further use of trunk and hub-and-spoke collection and distribution systems that allow the use of bigger vehicles and vessels on trunk lines.
- Reduction in lead times that will result in more trips, smaller vehicles and a stronger focus on reliable transport times (comparing this development to the one mentioned directly above,

implies that we expect change changes working in opposite directions; however the spatial scale is different: bigger vehicles are used more and more in hub connections for long distance (national, international) transport, whereas smaller vehicles are used more and more in urban and regional distribution. This favours road transportation, unless road congestion problems increase.

- Increase in e-shopping and home deliveries. This will lead to a transition from shopping trips to freight distribution tours.
- Shared use of transport and warehouse facilities that will lead to higher vehicle load factors.
- A further use of logistics planning systems, tracking and tracing and real-time information. This will lead to higher load factors and use of less congested routes and time periods.

Some of these developments are increasing the future freight volumes and some are decreasing them. Nevertheless, based on recent trends, it is inevitable that the former developments will dominate and that freight transport and traffic will continue to increase during the coming decades.

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Glossary

Aggregate data: data at the macro-level (usually: the level of geographic zones).

Carrier: firm that provides transportation services to shippers.

Closed-loop supply chains: encompasses flows in both directions (commodities and waste material), so that no materials are left somewhere along the chain.

Consolidation: combining several shipments in the same vehicle or vessel.

Consolidation center (CC): a transhipment terminal where small loads of goods that arrive are stored and organized into larger collections of goods for further shipping

Cross-docking: the vehicle from which the goods are unloaded and the vehicle on which the goods are loaded are present at the terminal at the same time, and the goods are moved from one vehicle to the other, without any storage.

Cross price elasticity of transport demand: the percentage change in demand for a mode as a result of a percentage change in the price of another mode.

Customs-Trade Partnership Against Terrorism (C-TPAT): a voluntary supply chain security program led by the U.S. Customs and Border protection.

Direct price elasticity of transport demand by each mode: the percentage change in demand for a mode as a result of a percentage change in the price of that mode.

Disaggregate data: data at the level of the decision-makers, such as shippers.

Distribution center (DC): a transhipment terminal where large collections of goods that arrive are stored and separated into smaller separate loads of goods for further distribution (we use the words 'terminal' and 'transhipment location' or 'transfer points' for both CC and DC).

Fourth party logistics (4PL) service providers: firm that integrates capabilities of several organizations, including their own (e.g. multiple 3PLs for different parts of the logistics chain) to obtain a comprehensive supply chain solution.

Freight transportation: the physical flow of the goods in space and time.

Hire and reward transportation: transport is contracted out by shipper to carrier firms or intermediaries known as third and fourth party logistics service providers.

Link: traffic can only enter from the beginning of the link and has to remain till the end of the link. Traffic cannot enter or leave it midway. The ability to do so would imply a node and at least one other link.

Logistics: the part of the supply chain process that plans, implements and controls the efficient, effective flow and storage of goods, services and related information from the point-of-origin to the point-of-consumption for the purpose of conforming to customers' requirements.

Logistics network design: is about well-balanced solutions defined in terms of the number of consolidation and distribution centers, their locations, the places where inventories are stored and the inventory levels and the transport organization (modes, vehicle types, routes, departure times).

Node: the point where links come together (e.g. junctions or roundabouts).

OD (origin-destination) matrices: representation of commodity flows on one transport leg of the transport chain (e.g. from consumption location to consolidation center).

Own account transportation: transport organized by shipper

PC (production-consumption) matrices: representation of commodity flows all the way from the production zone to the consumption zone.

Reverse logistics: logistics services are provided not only for flows of raw material and semi-finished products, but also for transport waste material in the reverse direction.

Shipment: a number of product units that are ordered, transported and delivered together.

Shipping firm, shipper: producers or traders of commodities or their representatives that have a demand for transport services.

Supply chain management: integrates business processes, such as production, logistics, finance and marketing, along the product and information chain from supplier to manufacturer to wholesaler to retailer to consumer.

Third party logistics (3PL) service providers: firm that performs logistics activities for a shipper

Traffic model: a mathematical model that produces estimates on the number of vehicles or vessels on different links of a transport network.

Transportation model: mathematical model that produces estimates of the amounts of freight transportation in tonnes lifted, tonne-kilometres and/or vehicle kilometres.

Transport chain: series of one or more transport legs between the sender and receiver, each with its own mode or vehicle type, e.g. road-sea-road.

Transport modes: road, sea, rail, inland waterways, air (pipeline).

Transport network: a combination of links and nodes.

Table 1. Mode shares (%) in the number of ton-kilometers in the U.S. and the European Union (EU27: 27 countries), 2005, inland modes

	Road	Rail	Inland waterways	Pipelines
U.S.	32.9[1]	44.2	8.3	14.6
EU27	72.4[2]	16.6	5.5	5.5

Source: European Commission, DGTREN (2007)

1: intercity truck traffic only

2: national and international road haulage by vehicles registered in the EU27.

Table 2. Strengths and weakness of road versus rail transport

Mode	Strengths	Weaknesses
Railway	Adequate for bulk Direct transport between large-volume centers Safety Low Emissions Price (long distance, large volume)	Less innovative (information systems) Compatibility in international transport Time for loading and unloading; limited opening hours of facilities Bottlenecks on some links due to competition with passenger trains
Truck	Speed Flexibility, timely available Spatial coverage, possibilities for consolidation-en-route Small consignments Point-to-point shipments Quality of handling Information systems Transport time reliability	Higher emissions Capacity bottlenecks, congestion risks

Table 3. Truck price direct and cross elasticity for various modes of bulk and general cargo at different transport distances for the EU-15

Mode	Distance range			
	500 to 1,000 km		More than 1,000 km	
	Bulk	General cargo	Bulk	General cargo
Truck	-0.5	-0.7	-1	-0.8
Inland waterway	1	0.5	0.6	0.2
Train	1.5	1.1	1.7	1.2
Intermodal transport	0	1.1	0	1.2
Short sea	0.3	0.2	0.3	0.1

Source: EXPEDITE consortium (2002)

Table 4. Time direct and cross elasticity for various modes of bulk and general cargo at different transport distances for the EU-15

Mode	Distance band			
	500 to 1,000 km		More than 1,000 km	
	Bulk	General cargo	Bulk	General cargo
Truck	-0.55	-0.7	-1.2	-1.4
Inland waterway	0.8	0.4	0.5	0.15
Train	1.8	1.0	2.0	1.0
Intermodal transport	0	1.3	0	1.4
Short sea	0.04	0.1	0.03	0.1

Source: EXPEDITE consortium (2002)

Figure 1. Scope of supply chain management, logistics and transportation

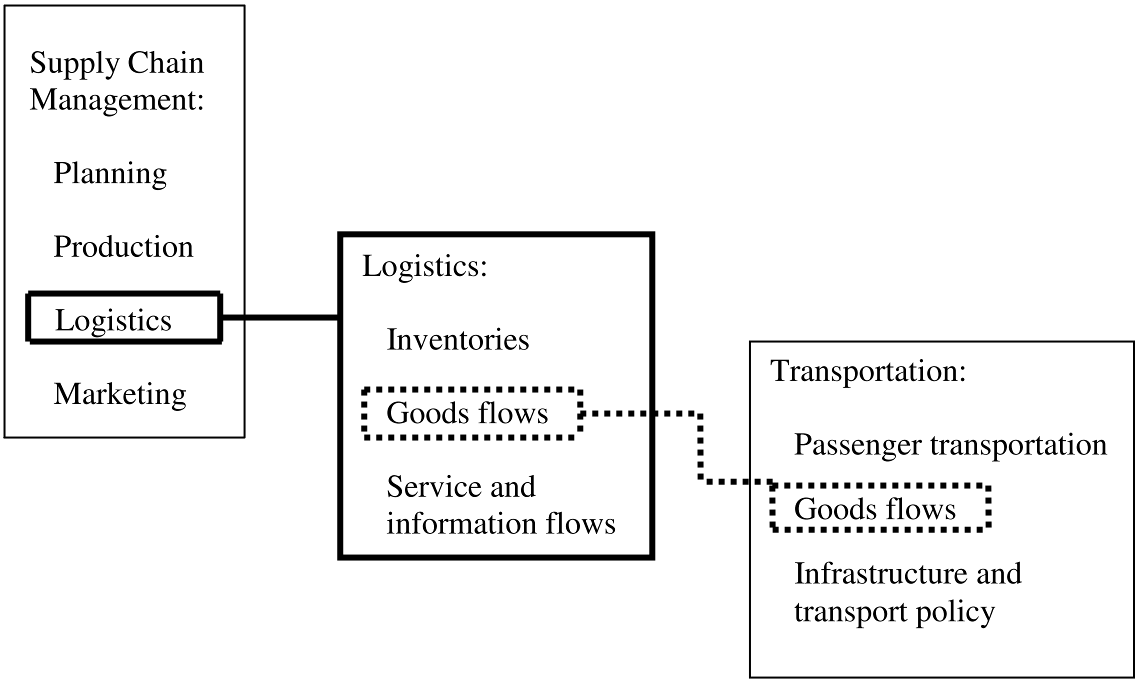

Figure 2. Transport chain, transport legs, PC flows and OD flows

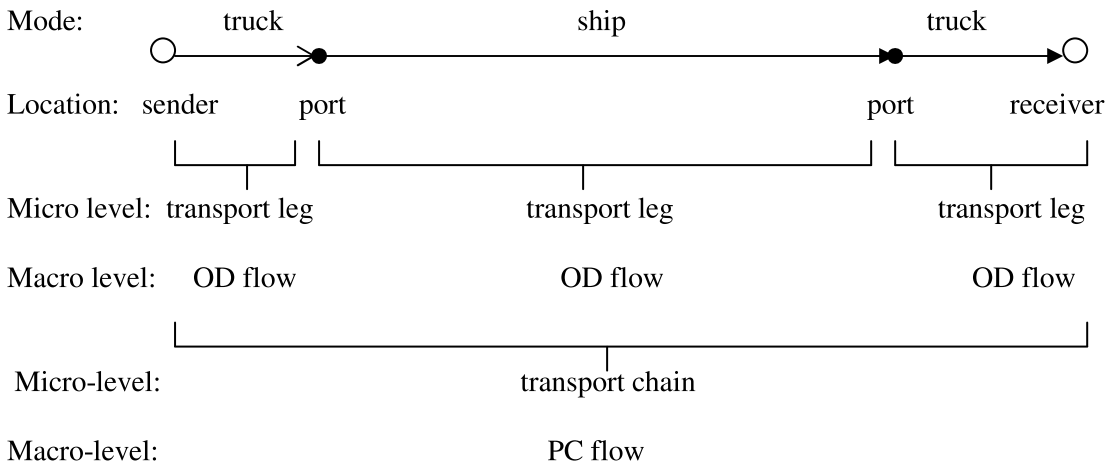

Figure 3. Consolidation and distribution: the shipment of goods from location A to B is consolidated at C and distributed at D