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A Study of Economic Impacts of Freight Speed Increase and Travel Time Reliability Improvements by Rail

Research Report

Research report on the meta-analysis

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Research Report

Prepared for:	JASPERS Contact: Alan O'Brien a.obrien@eib.org
Submitted by:	**IMC Worldwide Ltd** 64-68 London Road Redhill RH1 1LG United Kingdom
Authors:	Prof. dr Gerard de Jong (Significance) Yuko Kawabata (Panteia) Kim Ruijs (Significance)
Framework Director:	**Patrick Gleeson** Frameworks Director, IMC Worldwide +44 (0)1737 231400 patrick.gleeson@imcworldwide.co.uk
QA Signed:	**Patrick Gleeson**

Content

1. Introduction

Aims and context of the project

The main objective of the study is to analyse the (1) value of time (2) value of reliability, (3) cost savings concepts and (4) to estimate the influence of benefits of modal shift from road to rail.

The focus of this study lies on the economic impacts of infrastructural developments in freight transport by rail and the determinants for modal choice (between road and rail). To this end, this study will cover the following four topics for rail freight transport:

- **Value of time** (VOT), also known as value of travel time (VTT) and value of travel time savings (VTTS);
- **Value of** (delivery time) **reliability** (VOR), also known as value of travel time variability (VTTV);
- **Cost savings** that accrue as a result of technological innovations in the train system (such as a higher loading gauge, longer trains, electric instead of diesel trains);
- **Approaches** and **outcomes** (e.g. elasticities) for estimating changes in modal split.

The project will review the available evidence on values of time, values of reliability, cost functions, modal split model approaches and elasticities.

Aims of phase 2 of the project and relation with other tasks

This report contains the outcomes of phase 2, the meta-analysis (this name does not imply that a meta-regression was estimated on outcomes of many studies). In this phase we review the results from existing literature. This analysis includes papers published in professional journals and conference papers, but also the grey literature (research reports from consultants and academics that have not been published in journals or presented at conferences) that we are aware of or that we could find through search engines.

In phase 4 of the project, conclusions will be drawn from the literature review to answer the research questions, i.e. what are the most likely values and range for the VOT, VOR, impacts on costs and elasticities, for use in cost-benefit analysis, and what are the most appropriate methods for modelling modal split in freight transport. In this way, together with 3 on the market analysis, phase 2 feeds into the appraisal phase (phase 4) and the final reporting phase (phase 5).

2. The rail freight transport market

The text of this chapter 2 is partly based on van de Riet et al. (2008), de Jong and Ben-Akiva (2010), de Jong and Kroes (2014) and VTI and Significance (2010).

2.1 The agents in freight transport

One of the key differences between freight transport and passenger transport is that in passenger transport there often is only a single decision-maker for a journey, whereas in freight transport multiple agents are usually involved in the decision-making about a single shipment. The shippers (these can be producers or traders of commodities or their representatives) are firms that have a demand for transport services. In most cases these transport services refer to the activity of sending products to their clients, which are the receivers or consignees. In some cases, the receiver organises the transport. The shippers themselves, in what is referred to as own account transport, meet part of this demand. The remainder, hire and reward transport, 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 organisations, including their own (e.g. multiple 3PLs for different parts of the logistics chain) to obtain a comprehensive supply chain solution.

2.2 The choices in freight transport

For freight transport, as for passenger transport, one can identify a set of choices which are made by relevant decision-makers that collectively determine the amount and composition of freight transport demand. These choices include (partly from de Jong and Ben-Akiva, 2010):

- Choices on production and consumption of goods and on trade and distribution. In most cases the underlying choice here is the sourcing decision; the decision of a producer, wholesaler or retailer from which supplier to buy the goods – this also determines the geographical location of the supplier and consequently the trade relation and transport needs.
- Shipment/inventory choices such as shipment size, frequency, etc. result in shipments of commodities with a certain weight, size, and value between the point-of-production and the point-of-consumption. 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-production and the point-of-consumption. This includes information on the transhipment(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 2-1. An example of a multi-modal, multi-leg transport chain would be: road transport from the point-of-production to a rail terminal, followed by rail transport to a second rail terminal, 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 transhipment 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-kilometres by mode.

- Finding return loads to avoid empty vehicle/vessel returns.
- 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.

Discussions about corridors sometimes exclusively focus on modal split, which is understandable given the potential that modal shift has for reducing external effects of freight transport. However, for understanding freight transport in such corridors, it is important to embed mode choice within the context of a transport chain all the way from producer to consumer and to consider sourcing, inventory an transport logistics (such as consolidation and distribution), timing and routing decisions as well.

At the macro-level, a distinction can be made between PC (production-consumption) flows and OD (origin-destination) flows. This distinction is the macro-level equivalent of the distinction at the micro-level between a transport chain and a leg of a transport chain (also see Figure 2-1). A transport chain can potentially be a multi-modal transport structure whereas a transport leg is a uni-modal structure, that is part of a transport chain.

By adding the volumes of the transport chains to and from the same zones, one obtains PC matrices. Similarly, by adding the volumes of the separate legs to and from the same zones, the OD matrices are 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, since a transport chain may be used with multiple modes and/or vehicle types as well as one or more transhipments along the route.

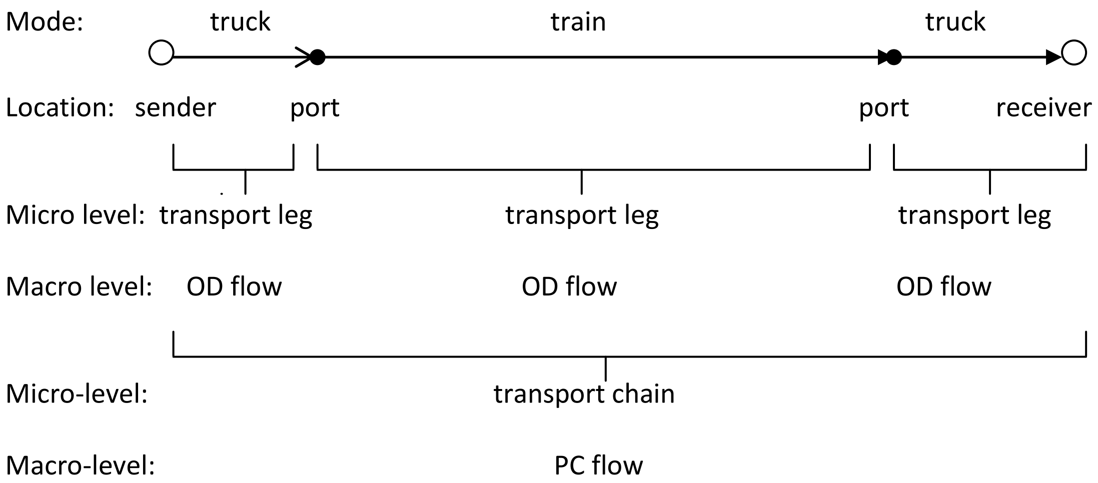

Figure 2-1. Transport chain, transport legs, PC flows and OD flows

PC flows represent economic relations and transactions within different sectors of the economy and between these sectors. Changes in final demand, international and interregional trade patterns, and in the production structure of the economy, have a direct impact on the PC flow patterns. The available data on economic linkages and transactions are in terms of PC flows, not in terms of flows between producers and transhipment points, or between transhipment points and consumers. Changes in logistics processes such as changes in the number and the location of depots, and in logistics costs, have a direct impact on the composition of the transport chains. This can result in different OD flows, that would only indirectly impact the economic and trade patterns (and hence the PC flows).

2.3 Who decides on what?

The relevant agents for production and consumption decisions are of course in first instance the sender and the receiver, but in the end the decisions are driven by consumer demand. Sourcing decisions are the domain of the receivers of the goods.

Managers of the shipper, the carrier and/or the intermediaries may make the transport choices such as the mode choice decision. In general, it is recognised that the shipper is the most common decision-maker for mode choice, also for transports that are actually contracted out to transport suppliers (carriers). Many carriers just offer a single mode, and in the case of a multimodal transport chain they may only be involved in a single leg of the transport chain (e.g. a road haulage firm that provides the first road transport in a road-sea-road transport chain). Logistics service providers on the other hand typically offer door-to-door transport services, and take over responsibility for the entire transport chain.

In most cases, the receivers are not responsible for organising the transport (deliveries to supermarkets can be an exception). But they usually are the key decision-maker concerning the moment in time that the delivery takes place, since they typically specify the delivery time window. This is also the case for the shipment size (and thus also the transport frequency) decisions, which are determined when they order the goods from the sender. The sender (and its transport suppliers) then has to take the delivery time and shipment size as given.

The firm that actually carries out the transport usually determines the route choice. In the case of road transport, truck drivers may have some freedom to choose the route or to change routes as a reaction to unexpected traffic delays.

A shipper or logistics firm can decide to make an integrated plan for a combination of the above choices; this is the topic of logistics network design, which is about finding well-balanced solutions 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 organisation (modes, vehicle types, routes, departure times). But is it also possible to distinguish between a group of long-term decisions (such as on the locations) and a group of short-term decisions (such as routing and departure time), that are conditional on the long-term choices. For several of the above choices, increasingly more powerful (commercial) software is available to support decision-making at the level of the firm (or supply chain), 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).

2.4 Evolution of freight transport and drivers of freight transport

Since World War II, in most years freight transport (measured in tonne-kilometres) has grown at least as fast as gross domestic product (GDP). This is related to the fact that (international) trade has tended to grow faster than income and production and that the distances over which goods are traded have increased. Inland freight transport in tonne-kilometres in the EU27 has followed closely the evolution of GDP in the period 1995-2007.

Freight traffic (measured in vehicle kilometres) has grown even more than freight transport, partly due to changes in logistics systems as described below. To reach the societal objective of greater environmental sustainability, several governments and international organisations have placed decoupling the link between economic growth and freight traffic growth on the political agenda.

Before the most recent economic crisis, decoupling for road freight vehicle-kilometres was observed in some countries, such as Denmark, Sweden and the UK, but the opposite was still the case in other countries including Germany and The Netherlands.

After many years of growth, freight transport volumes (in tonne-kilometres) fell in 2009 (ITF, 2013). This goes for worldwide maritime transport (-6%), worldwide air freight (-9%), rail freight (especially in the EU27: -18%), road freight (again especially in the EU27: -10%) and inland waterways transport (EU27: -12%). In 2010, there was a rebound for worldwide maritime and air transport, followed by a stabilisation in 2011. Similar patterns for 2010 and 2011 can be observed for road and inland waterway transport in the EU27, whereas rail freight has grown both in 2010 and 2011 by 7%. However, the US, Russia and China account for nearly 80% of total estimated global rail freight transport (ITF, 2013). In emerging economies, such as China and India, freight transport by road has been growing in all years in the period 2008-2011

In van de Riet et al. (2008) and de Jong and Ben-Akiva (2010) the key drivers of freight transport are identified (also see Figure 2-2). The most important drivers of total freight transport (measured in tonnes or tkm) are the volume and structure of consumer demand and production and the trade patterns. Logistic developments and attributes of the modes (especially costs, time, reliability, flexibility), on the other hand, are more important drivers of modal split and shipment size.

The following developments with respect to these drivers have taken place in recent years and can be expected to shape freight transport in the years to come:

- Consumer demand is likely to rise in many if not most parts of the world, which in turn would lead to an increase in the number of freight shipments. Furthermore, consumer demand is also likely to become more spatially dispersed (e.g. China, India, South America), which would lead to increases in transport distances.
- The above development will lead to an increase in trade among countries. But international trade will also grow due to globalisation of production. This is likely to lead to further increases in transport distances.
- A further shift away from bulk products such as coal, iron ore and oil, as energy will be coming more and more from other sources than coal and oil (including renewable sources) and many products are getting lighter and more technology-intensive. This will favour road transport and within rail transport the effect will be an increase of the share of container transport versus block trains as used for bulk goods.
- Further dematerialisation in areas like mail, newspapers, and tickets, leading to a reduction in freight transport trips.
- Increase in e-shopping and home deliveries. This will lead to a transition from shopping trips to freight distribution tours (usually with small shipment sizes).

- 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 (mainly in ICT). Developments in the logistics systems being used, that have been going on for some time now, and can be expected to continue are:

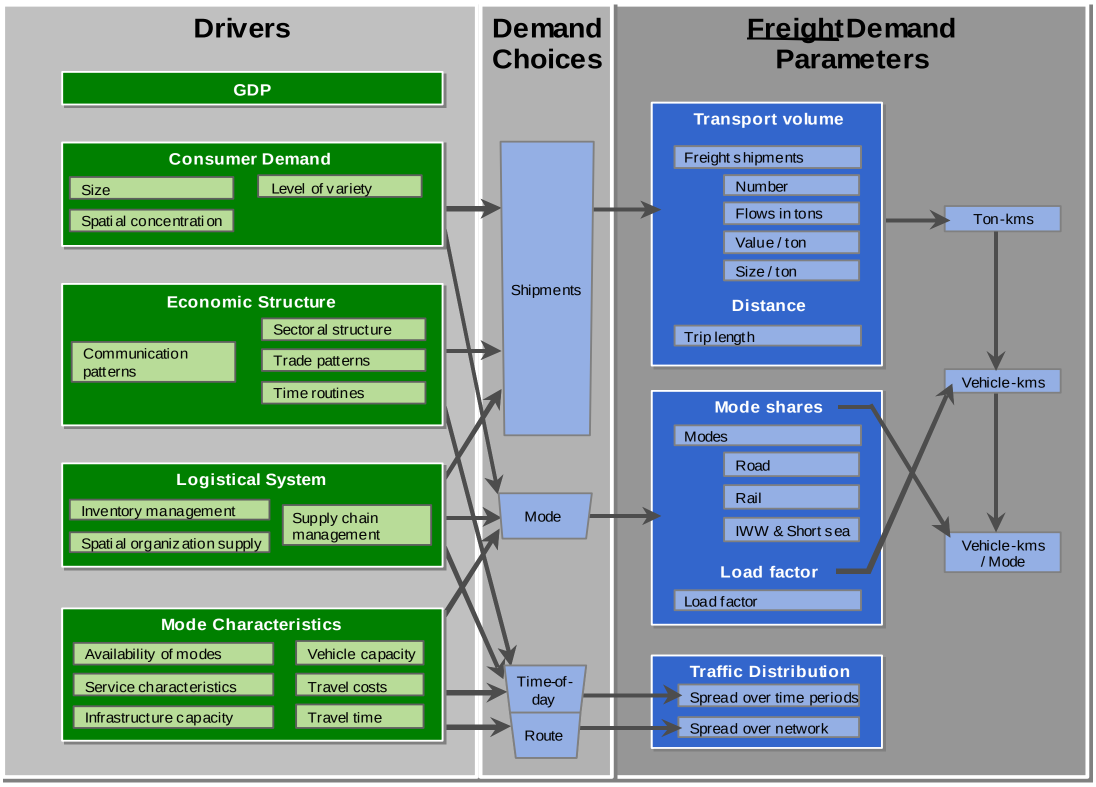

Figure 2-2. Drivers of freight transport demand (source: Van de Riet et al., 2008)

  - Unit transport costs have decreased over the last decades while unit inventory costs have increased (only in recent years these trends have halted). The change in the relationship between storage and transport costs has been a major cause of the use of the just-in-time (JIT) concept, which has led to a decrease in inventory levels and shipment sizes and an increase in delivery frequency. This has resulted in an increase in vehicle kilometres and an increased demand for transport by van or small truck instead of heavy truck transport. The growth of JIT transport increases the service requirements of the transport modes, especially with regard to reliability of the transport time (delivery at the agreed time or within the agreed time window) and flexibility (short reaction time between order and delivery). The dominant perception among firms that require transport services is that road transport modes perform considerably better than other modes on these factors. To some degree the actual performance of rail, inland waterways and short-sea shipping might be better than perceived, but it is also a matter of natural disadvantages and possibly inefficiencies in the organisation of non-road transport. So, the growth of JIT transport has improved the competitive position of road transport. Within rail transport, this trend will lead to an increase in the use of smaller units such as individual wagons and containers versus the use of system/block trains.

- Technological developments in production facilities and supply chains are facilitating demand-driven production. Two components can be distinguished here. The first component is lean production –this is the flexible production of (semi-)manufactured goods, whereby the production facility can be reconfigured within hours (instead of days) to switch between products. This enables manufacturers to produce a wide range of products and a wide diversity of a given product at a single facility. The second component is postponement manufacturing. Semi-manufactured goods are produced according to a demand forecast (BTS: built to store) at a central production facility and are shipped to assembly facilities near the market. At the moment a final product is ordered, it can be assembled at the assembly facility, resulting in very short lead times and quick fulfillment. Due to the production of a variety of components, orders can be customised to match the demands of the customer. This influences what needs to be shipped and where it is shipped, and these developments put specific demands on the supply chain. The supply chain must be flexible enough to enable short lead times (time between order and delivery) and also to enable a reliable delivery of products. ICT tracing and planning systems facilitate the control of material flows, providing real-time information on the status of the products. This has resulted in a restructuring in the management of the supply chain. The various transport modes differ in the way they can meet the demands for shorter lead times and JIT delivery. Shippers usually view road transport as the mode that can provide the highest flexibility and reliability.
- Another important development in supply chain management is the increased use of distribution centres and of hub-and-spoke systems. This helps firms to reduce the costs of distribution facilities, transport, warehousing, and inventory. Economies of scale can also be achieved by concentrating production facilities in fewer locations and by centralising inventory through a reduction of the number of stockholding points. Inventory centralisation nowadays occurs on a larger geographical scale than before, which results in longer routes in general, but also in a consolidation of traffic flows. Consolidating freight flows leads to higher load factors, use of larger vehicles, and opportunities for alternative modes (rail, inland waterways, short-sea shipping) on the long haul. Larger vehicles are more economical in terms of cost per tonne than smaller ones, provided they are fully loaded. By consolidating freight flows, it is possible to collect sufficiently large volumes for transport over longer distances by vehicles of a larger size. Furthermore, consolidating freight flows, especially in combination with a trend towards more containerisation and an increase in global trade volumes, makes non-road transport a more attractive option for the long-haul. Especially intermodal rail transport could benefit from this trend. Comparing this development to the two mentioned directly above, implies that we expect 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 transport, unless road congestion problems increase.
- 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 much more likely that the former developments will dominate and that freight transport and traffic will continue to increase during the coming decades.

2.5 Different response mechanisms to changes in transport cost

Freight transport demand can be measured (also see Figure 2-2) in terms of tonnes, tonne-kilometres (tkm), vehicle-kilometres (vkm) and vehicle-kilometres (and tonnes, tonne-kilometres) by mode (e.g. rail vkm). The amounts of tonnes and tkm are determined largely by international and intraregional trade patterns (that depend mostly on consumer demand and economic structure). The amount of vkm is also dependent on logistics decisions, such as on shipment size and the use of consolidation centres. For tonnes, vkm or tkm by mode, mode choice enters the picture as well. There can be changes in route and time-of-day that do not affect the total number of tonnes, tkm or vkm (by mode). The following response mechanisms can be distinguished for the effect of a change in the price of rail transport on rail transport demand

Changes in fuel efficiency

A. Energy/Fuel efficient vehicles: buy more energy-efficient trains and "fuels"; in the long run, changes in fuel prices can also influence the fuel efficiency of the vehicles used (at the same transport volume), by accelerating/decelerating technological change in vehicle efficiency or in energy transmission from power plants (for electric trains?)
B. Fuel efficient driving: change in the style of driving (more energy efficient driving, e.g. slower).

Changes in transport efficiency

C. Load factor (the amount of goods measured in tonnes, divided by vehicle capacity). The load factor can be improved by consolidating more and by getting more return loads
D. Change in route and time of day. This is mainly relevant for changes in prices that are differentiated by location and time of day (as suggested for the Swedish rail infrastructure fees 2011). But there may also be move to a more efficient route planning (e.g. fewer detours) because of the cost increase.
E. Increasing the shipment size (also implying a reduction in the delivery frequency; so this will increase inventory costs). Changes in transport prices might change trade-offs between transport costs and other logistics costs such as order costs and inventory costs.

Changes in transport volumes/transport demand

F. Change of mode (for whole distance/chain or part of chain): substitution to and from road, inland waterways, sea and air transport).
G. Changes in production technology (affecting the weight of the goods, e.g. trends towards lighter products).
H. Reduce kilometres per tonne:
    a. Choice of supplier and receiver: changes in the choice of supplier (procurement from more local suppliers, determining the origin given the destination) or in the geographical market size of the supplier. (changing the destination given the origin), including changes in the degree of globalisation. This leads to changes in the zone of production to zone of consumption (PC) pattern of goods flows, and thus to changes in transport distance.

  b. Production volumes per location: changes in production volumes per location, including use of raw materials and intermediate products for further processing. A producer can decide to shift its production to plants closer to its customers, to save transport costs.

I. Reduction in demand for the product.

Reactions A-D are decisions that are usually taken by the train operator and/or forwarder. The scope for doing these things depends on the current level of efficiency in logistics (which might be quite high already).

Only when the operator passes on some of the cost increase (and similarly for a decrease) to the shipper, the shipper will respond. The possibilities for passing on cost increases depend on the (type of) contract and market power, which may be different for different commodity markets. The response mechanisms E-H concern decisions that are usually at the discretion of the shipper (some decisions such as on shipment size can be taken by the sender, but are more commonly determined by the receiver). The manufacturers may pass on some of the cost increase to their clients (retailers, other producers, final consumers). This may then lead to the reduction in demand for the product (response I).

The mechanisms F, G and I will influence the number of tonnes transported by rail transport. These mechanisms plus mechanism C and E will influence the number of rail vehicles (=wagons) or trains used. Vehicle-kilometres by rail are influenced by all of these mechanisms plus the trip lengths (mechanisms D and H). Tonne-kilometres by rail are influenced by mechanisms D and F-I.

Many of these reactions (especially G and H and changes in vehicle technology) will only occur in the long run. Mechanisms B and D can be relevant in the short run and A, C, E and I in the short to medium run, whereas F (change in mode choice) is most relevant in the medium long run (this also means that in applying transport forecasting models one should not assume that a mode change happens instantaneously; the full effect will usually take several years). In the review of the literature on elasticities in chapter 8, we shall use these distinctions (which of these mechanisms are included?) to characterise the elasticities.

2.6 Freight transport models

Freight transport models are used to assess the impacts of different types of autonomous developments and policy measures, such as changes in national regulations and taxes or infrastructure investments in specific links, nodes and corridors. A wide range of models and model systems are applied by public agencies. Furthermore, a lot of freight transport modelling takes place at universities and at the individual firm level (see Tavasszy and de Jong, 2014, for a reference book). Models to optimise transport and logistics within a specific firm or supply chain are not discussed in this report.

The four-step modelling structure from passenger transport has been adopted in freight transport modelling with some success (see Figure 2-3 below):

- Generation models for production and attraction per sector (e.g. mining) or commodity group (e.g. petroleum);
- Distribution models, sometimes with a dependence of the distribution on the transport resistance between zones from the modal split model;
- Modal split models;
- Network assignment.

However, additional steps are often needed to transform trade flows in money units to physical flows of goods in tonnes and further into vehicle flows with specific vehicle utilisation factors. These additional processes can be modelled as fixed rates, but also by explicit representation of logistics choices. Also other logistics aspects that are related to the trade-off between transport and inventory costs are usually not included in freight transport models, even though the logistics solutions of firms influence the mode split.

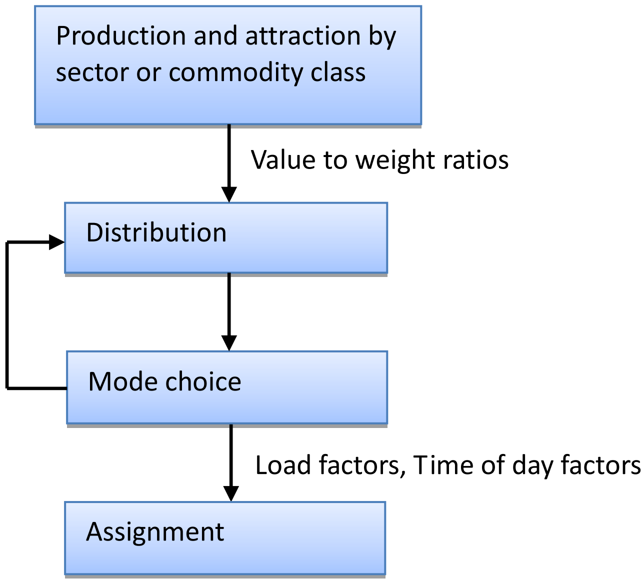

Figure 2-3. The conventional four-step model in freight transport

A better representation of the freight transport model system might be the following (Ben-Akiva, 2011).

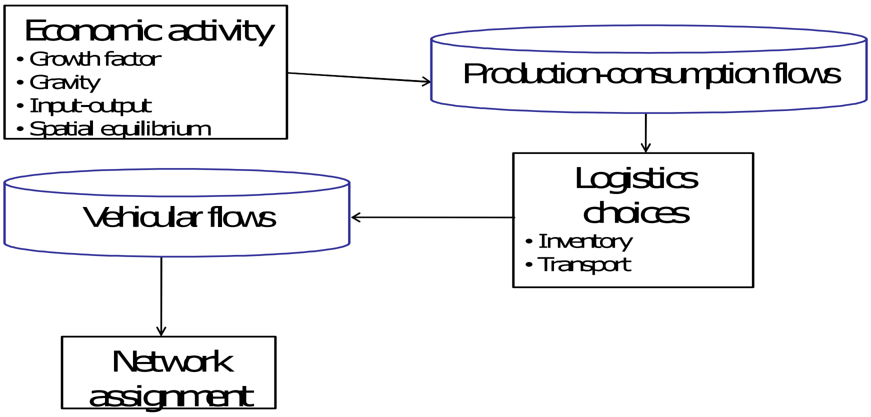

Figure 2-4. A revised representation of the structure of the freight model system

This structure has fewer steps: only three models: economic activity choices, logistics choices (including the choice of transport chain with a mode for each chain) and route choice, but each of the first two steps includes several related choices. This model representation is consistent with the distinction between PC flows and OD flows discussed above.

2.7 A comparison of perceived freight transport performance by road and rail

In terms of freight transport modes, the available options generally are road, rail, inland waterways, sea, air and pipeline. Within these modes, several types of vehicles or vessels, such as articulated trucks or solo 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 characteristics of the different modes are discussed below. First we present the modal split in the EU28.

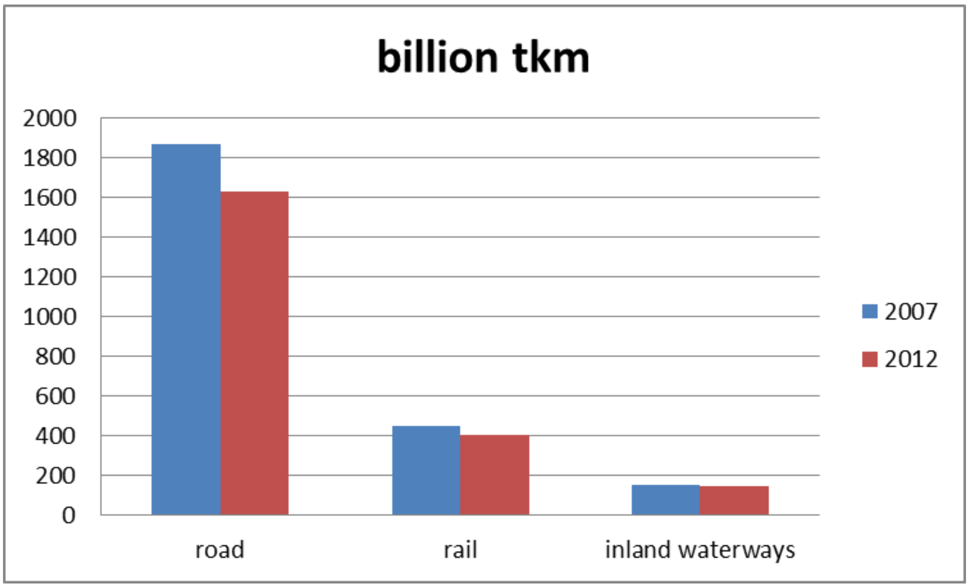

Figure 2-5. Freight transport (in billion tonne-kilometres) by mode in the EU28 (source: Eurostat)

The mode share of road within inland freight transport (this includes both national and international transport by road, rail and inland waterway transport) in the EU28 is 75%. This share varies considerably between the EU28 countries. It is above 90% for Ireland, Greece, Spain, Cyprus and Malta, but below 50% in the three Baltic states (where rail dominates for freight), The Netherlands (where inland waterways has about 45%) and Romania (where both rail and inland waterways have a substantial share).

Rail networks have a much lower density than 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. In this regard, three different rail products can be distinguished:

- Full train loads between two private sidings requiring no remarshalling or transhipment. Such services require very large consignment sizes, but then will have low costs at any length of haul.
- Wagonload services which require remarshalling to consolidate traffic; these are only viable for large flows over long distances.
- Container or other intermodal services which generally use consolidation and access by road; these require long distances (although traffic to or from ports can serve a terminal at the port, and do not require transfer by road, except perhaps within the port. Thus these are more favourable for rail than other intermodal traffic).

Rail transport requires very substantial investments in tracks, signalling, terminal facilities and equipment, some of which can be shared with passenger transport (but then the capacity also has to be shared with passenger trains, which often get priority, especially in Europe). 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, providing rail transport was historically regarded as a natural monopoly and even today a single entity usually manages the rail tracks of a country, although operations are separated from the management of the tracks. However, in many countries rail deregulation and privatisation have taken place. This has resulted in competition between freight transport rail operators.

In road transport, labour expenses are the main component of transport cost. The fixed costs are a considerably less significant portion of the total cost than that of rail transport, partly because it uses all-purpose roads supplied by the state. In most countries, the road haulage sector is also highly competitive, consisting of many firms varying in size from large corporations to one-person owner-operators.

In Table 2-1 the pros and cons of the rail and road systems are compared. This table is based on current practices in Europe 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 transport) 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 transport also produces lower emissions of conventional pollutants and greenhouse gases. Rail freight transport has the potential to be very reliable. But in reality, especially in Europe, shippers usually consider the timeliness of road transport to be superior; it is difficult for rail to hit tight delivery windows. If road congestion would further increase, this might change in the future.

Table 2-1. Strengths and weakness of road versus rail in EU freight transport

Mode	Strengths	Weaknesses
Railway	Adequate service level for bulk Direct transport between large-volume centres Safety Low emissions Price (long distance, large volume)	Less innovative (information systems) Compatibility in international transport Time and cost for loading and unloading and marshalling (if needed); 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 (also due to competition for road space with cars) Increases road maintenance costs

Train operations are also potentially 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 transport is commonly used to transport low value bulk cargo where the most important factor is low rates. In order to obtain substantial rail 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 would be required.

Intermodal and multimodal transport both use several modes in the same transport chain between point-of-production and point-of-consumption. The main difference is that intermodal or 'combined' transport is carried out for a single flat rate and uses the same loading unit and volume on all the modes in the chain as opposed to multimodal transport. 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 eight feet wide and twenty feet or forty feet long. Container movements are often measured in TEUs: twenty-foot equivalent units. The use of containers began in the maritime sector initiated by the Sea-Land Company, and it has grown tremendously over the past decades. Containers can be used on sea vessels, trucks, single and double stack trains, as well as inland vessels. Road-sea-road and road-rail-road are transport chains that are used regularly using containers all the way. Intermodal transport can also use swap bodies that have non-rigid sides, instead of containers. 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 (this is sometimes referred to as 'Rollende Landstrasse', 'Iron Highway').

3. VOT in rail freight transport

Chapter 2 and 3 of this report are mainly based on de Jong (2008) and Tavasszy and de Jong (2014), chapter 9, but also contain some new extensions.

3.1 Introduction

According to the Independent Newspaper (7 May 2013), the UK's first toll motorway, a 27 mile section of the M6 around Birmingham, is proving to be a flop, raising the prospect that tolls have to be cut or that the (private sector run) link has to be renationalised. Only one in nine lorries actually pays the £11 toll to avoid the shorter but often congested, free alternative. Originally it was forecast that twice as many vehicles would pay the toll.

On the 6th August 2015, in response to the closure of cross-Channel operations between the UK and France, due to security problems at Calais, the Kent police put in place emergency measures to accommodate the large queues of lorries waiting to board cross-Channel services. This was the so called "Operation Stack". Subsequently a filtering procedure was introduced in order to fast-track "Quick to market goods", such as fresh fruit, livestock, shellfish and emergency medicines. The Freight Transport Association stated that "Valuable cargo of lobsters and fish were being held up in queues – this can't be allowed to happen."

So, freight value of time matters and, at least for some exceptional cargoes, it can even be very important.

The value of freight travel time is mainly used for two different purposes. On the one hand, it is an input into the cost-benefit analysis of infrastructure projects, facilitating the comparison of the time savings for freight, as caused by the project, against other attributes, such as the investment cost. On the other hand, the value of travel time (VTT) in freight transport is also used in traffic forecasting models, in which one of the explanatory variables is a linear combination of travel time and cost, called 'generalised cost'. In this study both purposes are relevant, since for cost-benefit analysis one needs outcomes of traffic forecasting procedures as well as monetary conversion factors. In many cost-benefit analyses, the main benefits from the infrastructure project are the time savings, both for passengers and freight transport.

Unlike the passenger VTT, which is often expressed in terms of money units per minute, the freight VTT is practically always expressed in terms of money units per hour. This difference is due to the larger average transport times in freight transport, which results from larger distances, but also from lower average speeds compared to passenger transport. Other differences between passenger and freight transport, which are very relevant for VTT research, are described below.

The decision-maker in passenger travel is, in most cases, the traveller himself or herself or a group of travellers. In freight transport the goods cannot decide; different persons may be involved in decision-making at various stages. The shipping firms (producers or traders of commodities) have a demand for transport services, in most cases for sending the products to their clients (in some cases the transport is organized by the receiver). Part of this demand is met by shippers themselves (own account transport). The remainder is contracted out to carrier firms or intermediaries (hire and reward transport). Important choices in transport, such as the choice of mode, can be made by managers of the shipping firm, the carrier and/or the intermediaries. Interviews in the transport market have indicated that for mode choice the shipping firm is the most important decision-maker. Route choice is mainly determined by the managers of the firm actually carrying out the transport. In the case of road transport, lorry drivers may have some freedom to choose the route or to change route as a reaction to unexpected events (e.g., congestion).

There is considerable heterogeneity in passenger transport, but even more in freight transport. 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. This does not imply that the value of freight travel time savings is so heterogeneous that it cannot be established. Heterogeneity can be taken into account by applying a proper segmentation (e.g., by mode, type of good) and proper scaling (e.g., using a value for a typical shipment size or a value per tonne).

A specific problem in finding the VTT for freight, as opposed to the passenger VTT, is that some of the information in goods transport, especially on transport cost and logistic cost, may be confidential. Firms in freight transport may be reluctant, for obvious reasons, in sharing this information with client, competitors and the public. Also, there are only limited data on actual choices (e.g. mode and route choice) in freight transport; there are much more travel surveys than shippers surveys.

3.2 Classification of the methods used in freight VTT research

Freight VTT research tries to find the proper values to be used in evaluation or forecasting. The methods used can first of all be classified into factor-cost methods and modelling studies (Figure 3-1). These methods are explained in this section and section 3.3 below.

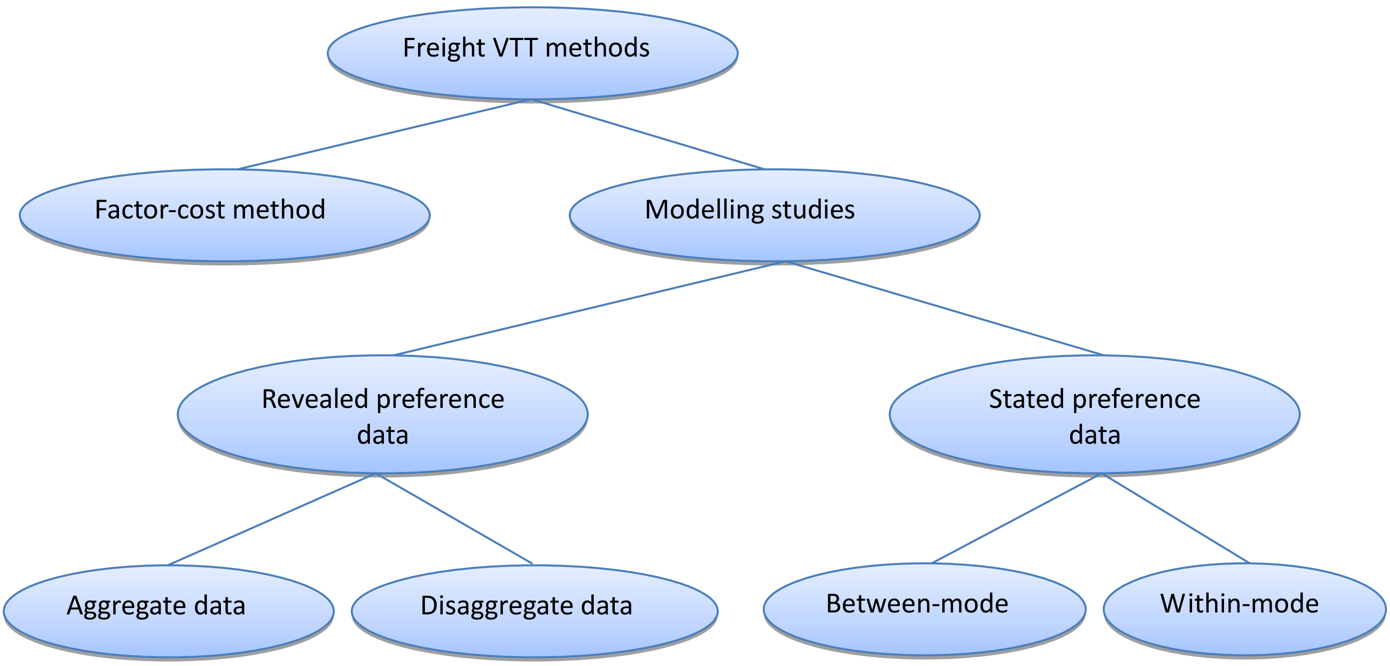

Figure 3-1: Classification of methods for establishing a freight transport VTT

Factor cost is defined as the cost of all input factors (not just time). The factor-cost **method** in value of time research tries to find the cost of the input factors that will be saved in case of travel time savings, or the cost of additional inputs if travel time is increased. A decrease in travel time could release production factors (e.g. labour, vehicles) to be used in other shipments. Studies that have been applying this method usually include labour cost and fuel cost among the time-dependent cost (however, we think it is better not to treat fuel cost as time-dependent costs, but as a special distance–dependent category, possible together with infrastructure access charges; we return to this in the conclusions and in task 4). These items can be calculated using data on wages and vehicles. There is no consensus on the issue whether fixed cost of transport equipment, overheads and non-transport inventory and logistic cost should be included. This could be analysed using the other type of methods, i.e., the modelling studies. Some researchers argue that not all labour and fuel cost should be used in the VTT, since some of the time gains cannot be used productively. This too can be analysed by modelling decisions in freight transport and focusing on the implied time-cost trade-offs. The issue of which cost items to include also depends on the time horizon: in the long run, more items will be time-dependent and the VTT will be higher. A more detailed discussion of cost components and which of these will be time-related in the short and long run can be found in chapter 6.

Another difficulty, which is most prominent when applying the factor cost method, is the distinction between the impact of transport time itself and the impact of transport time reliability. In a model it is possible to separate out the cost related to the average transport time and the extra cost of longer than average transport time, especially of delivering too late (possibly also of delivering too early). It must be said however that many models do not make a clear distinction on this. In a factor cost calculation that uses a simple transport cost function, it is very difficult to separate out the impact of transport time variability. However, if one would use a full logistics cost function, including components for the value of the goods, deterioration of the goods and the cost of keeping a safety stock (dependent on transport time variability), both the VTT and the VTTV can be calculated as the derivatives to transport time and variability (expressed standard deviation or variance). For a further discussion of this issue we refer to Bruzelius (2001) and Vierth (2012). So far this approach has remained a rather theoretical exercise and therefore we will not come back to it when making practical recommendations for appraisal.

Transport models typically apply mathematical choice functions to simulate, from the perspective of economic agents, rational behaviour within the transport market. Such mathematical functions are designed to allow the modelled system, consisting of traffic flows, networks and users, to react e.g. by route or mode switching, to supply-side factors such as cost and time.

Within a passenger transport model, it is normally clear that the relevant decision-maker in the simulated system, is the passenger. He or she decides whether to travel, and how to travel subject to a budget constraint, taking into consideration, preferences for travel time, reliability, safety, convenience and so on. Since the person booking the travel is also typically the traveller, it is clear whose preferences are being expressed in the selection of transport options.

In freight models, the “thing being transported” is inanimate so the circumstances, and therefore the model requirements change. A simple scenario for a freight shipment would involve a contract between three separate parties; (1) the shipper/sender/consignor, (2) the carrier and (3) the receiver/consignee. In practice, a further category of freight forwarders, acting as intermediaries might be added. Through a market mechanism these parties collectively decide what is to be transported and how. Within this collective decision it is not necessarily the case that all parties will have equal knowledge or control over every facet of the transport solution. To send a parcel overseas it is only necessary to know the delivery address, and the price, but once the parcel has been dispatched, all decisions are in the hands of the carrier.

Although it is now harder to characterise the decision maker in this scenario as a single, identifiable agent, it is still fairly clear that the agents in the freight system are collectively attempting to optimise the performance of the transport operation, albeit from slightly different viewpoints. Therefore, it can still be assumed that there is a collective willingness to pay for improvements, and to find a solution with a desirable balance of attributes such as cost, time, reliability, security, and avoidance of damage.

As implied, the valuation of improvements in the transport system, such as shorter journey times may differ according to the perspective of the different agents in the chain. For the carrier, shorter journey times mean potentially higher productivity, resulting in lower transport costs. These benefits might be absorbed by the carrier or the might be passed on to the consignor/consignee as lower freight rates. However, in addition, the consignor and consignee may receive a benefit from faster transit times because the transaction will be completed faster, therefore lowering inventory cost. This element, inventory cost, becomes more pronounced for products which have high depreciation levels, or which degrade quickly.

Conceptually there are important differences between (1) a passenger's value of time (I could be doing something else), (2) a freight-carrier's value of time (I could fit in an extra payload), and (3) a consignor/consignee's value of time (I need to turn my stock into cash-flow), and in a freight model there is a need to balance and reflect the latter two categories.

The freight-carrier's value of time typically relates to the driver and the transport equipment; drivers are paid for their time, and equipment has to be leased (or, equivalently, bought and depreciated). A freight carrier incurs these costs irrespective of what is being carried or even whether the vehicle is loaded. It is not commodity specific. Higher productivity in the transport operation ought to lower costs, so if the time taken to complete the delivery falls, then so should the cost of transport.

The freight-buyer's value of time relates much more to the contents of the shipment, its value, its depreciation, its tendency to degrade, its risk of being stolen, and also to the wider logistic system that the transport operation is part of. Examples can be seen in the field of air-cargo which offers a high-speed, high-cost option. Typical air cargo commodities include printed paper (documents), high-tech electronics, fresh flowers, seafood, fashion products, and " inputs to meet just-in-time production and emergency shipments of spare parts." (World Bank, 2009) Thus, the value of the product itself and its perishability play a part, but so does the context in which the product is needed within a wider production chain, and the extent to which a supplier needs to accelerate the transport process to meet a customer's delivery terms. Therefore, there can be cases where freight buyers will pay a premium for a faster service; less time taken, the higher the value-added for the consignor or consignee.

By contrast, slower transport operations can be managed cost effectively, if they are "on time". In the shipping industry there has been a tendency for container lines to use larger ships and "slow steaming" in order to save fuel costs. Because intercontinental sea freight is competing mainly on the strengths of low cost, high volume and high reliability rather than speed per-se, freight buyers have the scope to adjust their ordering patterns, so even if the ships are carrying high value cargo, the market will accept a certain degree of trade-off between lower speed and lower cost offered by slow-steaming.

These examples: the efficient haulier, the air cargo operator, and the slow-steaming container line all indicate the presence of trade-offs between time and cost in the freight sector. There are clear examples here, both of the willingness to pay for faster transport, as in the air freight case, and willingness to accept slower transport in return for other benefits, as in the slow-steaming case.

3.3 Different data and discrete choice models for freight service valuation

The modelling studies can be classified (see Figure 3-1), depending on the type of data used as a basis for modelling, into:

- revealed preference (RP) studies;
- stated preference (SP) studies.

Joint RP/SP models are also possible in freight, but have been very few so far.

RP studies in freight use data on the choices that shippers, carriers, intermediaries or drivers actually made in practice. So, the first step for an RP model is to find choice situations where these decision-makers have to trade off time (or another freight service variable) against cost. Examples of such situations are:

- mode choice between a fast and expensive mode and a slower and cheaper mode (see chapter 7);
- choice of carrier, or between own account transport and contracting out (Fridstrøm and Madslien, 1994)
- choice between a fast toll route and a congested toll-free route;
- choice of supplier.

After having modelled such choices, the estimated model coefficients can be used to find the freight service valuations implied by the actual choice-making outcomes.

Most existing RP freight studies that provided one or more VTT have been based on mode choice data (e.g. road versus rail, rail versus inland waterways). A problem that is often encountered when using RP data is the high degree of correlation between transport time and cost, which makes it difficult to estimate significant coefficients for both attributes. In SP studies, the researcher has control over the correlation, so this problem can be avoided. Nevertheless, there have been various RP studies where it proved possible to estimate both time and cost coefficients (e.g. the Dutch BasGoed model; de Jong et al., 2011).

In an SP freight VTT study, decision-makers (in practice almost exclusively shippers or carriers) are asked to elicit their preferences for hypothetical alternatives constructed by the researcher. These hypothetical alternatives refer to shipments/transports and will have different attribute levels for transport time and cost, and possibly also for other attributes of the shipment.

The setting (choice context) of the SP experiment can be that of mode choice (e.g. repeated pair-wise choices between a road and a rail alternative for the same shipment: between-mode experiment) or route choice, as in the RP. Figure 3-2 presents an example for mode choice.

Which alternative would you prefer?		
	Road transport	**Rail transport**
Transport cost	710 euro	640 euro
Transport time	2 hours and 40 minutes	3 hours and 40 minutes
Delivered 20 minutes early	10%	0%
Delivered on time	70%	90%
Delivered 40 minutes late	20%	10%
	O prefer this road transport	O prefer this rail transport

Figure 3-2: Example of a choice situation in a mode choice SP experiment

Good experience in freight VTT research however has been obtained in abstract time versus cost experiments in which all alternatives that are presented refer to the same mode and the same route. In an abstract time versus cost experiment the alternatives have different scores on travel time, travel cost and possibly other attributes, but the alternatives are not given a mode or route label, such as “rail transport” of “motorway with toll”. An example of such an abstract choice situation is given in Figure 3-3.

Which alternative would you prefer?		
	Transport A	**Transport B**
Transport cost	710 euro	640 euro
Transport time	2 hours and 40 minutes	3 hours and 40 minutes
% delivered on time	90%	95%
	O prefer transport A	O prefer transport B

Figure 3-3: Example of an abstract choice situation in SP

The representation of transport time variability of a transport alternative in an SP experiment requires special attention, because it relates to a concept that many respondents find difficult to understand.

The easiest way to include variability into a transport model is to add some measure of dispersion, such as the standard deviation or variance of transport time, to the utility function that already has transport cost and time (Significance et al., 2012a). This formulation does not require making departure time choice endogenous (which in turn requires hard-to-get information about preferred arrival times). Under certain assumptions this representation of variability is equivalent to the expected scheduling cost from scheduling theory (Fosgerau and Karlström, 2010). However, many respondents in an SP experiment on freight transport cannot be expected to understand standard deviations.

The presentation method for variability that has been used most in freight transport is the one given in Figure 3-3, which presents the percentage of the goods that is delivered at the destination on time (or possibly: within a pre-specified time window). However, this does not include anything on the severity of the delays and is very hard to convert to a measure for the standard deviation (de Jong et al, 2009).

In the most recent national Dutch study on the VTT and VTTV (Significance et al., 2013), variability was presented as a series of five equi-probable transport times (with five corresponding arrival times) within a single abstract transport alternative, described only verbally, not graphically (see Figure 3-4**Error! Reference source not found.**). This representation was selected after having tested several formats with verbal and graphical descriptions of five transport times in a pilot, where this format was clearly best understood and preferred by respondents (Tseng et al., 2009). It allows estimation of a model with variability as the standard deviation, a scheduling model and a combination of both.

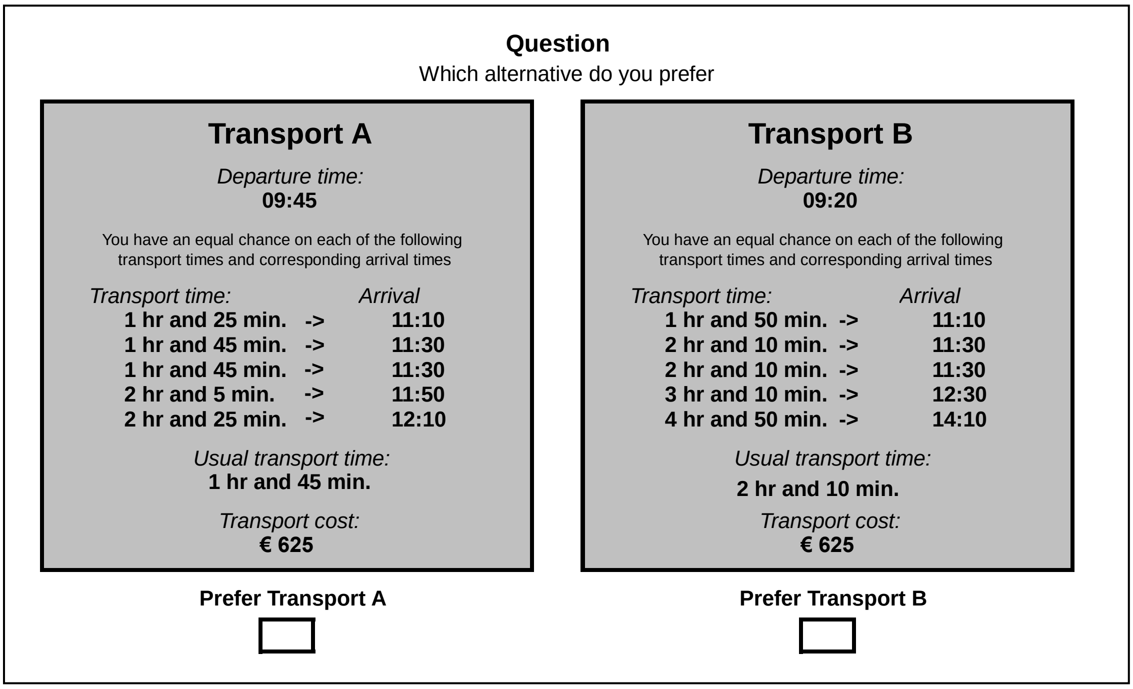

Figure 3-4: Example of an abstract choice situation in SP with variability represented in the form of five equi-probable transport times (based on Tseng et al., 2009 and Significance et al., 2013)

SP data has some advantages in the case of freight transport modelling, in particular as it may be possible to obtain data (e.g., on costs and rates) which would be difficult to acquire by other methods (Fowkes et al., 1991). The drawback of SP data is its hypothetical nature: these are stated responses to hypothetical choices, not actual decisions. This problem can be minimised using carefully designed SP surveys in which the respondents are asked to choose between alternatives relevant to their own circumstances (Contextual Stated Preference). In computer-based SP experiments decision-makers, such as logistics managers, can be presented with the choice between alternatives for a specific real-world consignment. The alternatives are defined using previous answers from these respondents; the attribute levels are based on the observed levels for the selected consignment. Practically all SP surveys in freight transport have been carried out as computerised interviews, which can provide the highest degree of customisation.

A difficult issue in SP surveys on freight service valuation is who to interview on what. Massiani (2005) argues that shippers will only give the time value of the cargo itself (related to interest on the inventory in transit and stock-out costs), whereas the willingness-to-pay of carriers will reflect all the components of the value of time. Booz, Allen, Hamilton and Institute for Transport Studies (2003) note that especially for carriers it might be difficult to separate between a change in time and a change in cost.

In the most recent freight VTT and VTTV study in The Netherlands (Significance et al., 2013), specific assumptions (a priori hypotheses) were made on the extent to which particular actors take into account different components of the freight VTT – and should do so, when responding to the SP questions (see Table 3-1).

Table 3-1: Hypotheses on the aspects that freight respondents include in their VTT (and VTTV)

	Values related to the cargo	Values related to the vehicles and staff
Carrier	Not included	Included
Own account shipper	Included	Included
Shipper that contract out	Included	Not included

Carriers are in the best position to give the component of the VTT (and VTTV) that is related to the costs of providing transport services. If the transport time would decrease, vehicles and staff would be released for other transports, so there would be vehicle and labour cost savings.

Shippers that contract out are most interested in other aspects, as expressed by the VTT (and VTTV) that is related to the goods themselves. This includes the interest costs on the capital invested in the goods during the time that the transport takes (only important for high-value goods), the reduction in the value of perishable goods during transit, but also the possibility that the production process is disrupted by missing inputs or that customers cannot be supplied due to lack of stock. The latter two arguments are also (possibly even more so) important for the VTTV.

Shippers with own account transport can give information on both the values that are related to the costs of providing transport services and the values that are related to the goods themselves. If both these components of the VTT (VTTV) are properly distinguished, the carrier VTT (VTTV) and shipper (contract out) VTT (VTTV) can be added to obtain the overall VTT (VTTV) for use in societal cost-benefit analysis.

In the new Dutch study (Significance et al., 2013) VTT and VTTVs were sought that include both components (not just the goods-related but also the services-related component), since in CBAs for transport projects in The Netherlands the user benefits of savings in vehicle and staff cost are included in the time savings of the project (unlike for instance Sweden, where the VTT only relates to the goods component, and transport cost changes are dealt with separately). Previous studies have not tried to disentangle the two VTT (VTTV) components, but this study obtained estimates for both components separately.

Of course there may be exceptions to the general pattern depicted in Table 3-1, but in the questionnaires the researchers steered the shippers that contract out only to answer on the components they generally know most about (bottom-left), and likewise for carriers (top-right). This was done by giving very explicit instructions and explanations to get clearly defined component values from each type of agent. In other words, the researchers:

- Explained to all respondents that the changes in time, costs and reliability are generic: these apply to all carriers using the same infrastructure, and are not competitive advantages for their specific firm.

- Explained to carriers (and logistics service providers) that a shorter transport time might be used for other transports: the staff and vehicles/vessels can be released for other productive activities. A higher reliability means that the carriers can be more certain about such re-planning/re-scheduling. They also explained that the carriers do not have to take into account what would happen (deterioration, disruption of production process, running out of stock, etc.) to the goods if they were late.

- Explained to the shippers that contract out that they only have to take into account what would happen (deterioration, disruption of production process, running out of stock, etc.) to the goods if the transport time or its reliability would change (whether these things would occur and how important they are was left to the respondent (shipper).

- Explained to shippers with own account transport that they have to take all of this (=cargo and vehicle) into account.

The types of models (such as multinomial logit, nested logit and mixed logit) that are estimated on the types of data discussed in this subsection and from which VTT, VTTV and other values for service quality are derived, are the same as the discrete choice models discussed in chapter 7 (and Annex 1). But for models that are built for the sole purpose of deriving monetary valuations, the mixed logit specification is nowadays the prevalent type of model (especially in passenger transport). Among models that are estimated for use as forecasting models, multinomial and nested logit models are dominant. This is caused by the fact that forecasting models are run many times after they have been estimated (and this would take very long with mixed logit because of the repeated simulation that is involved) whereas for a monetary valuation model estimation is sufficient.

Furthermore, many valuation studies only use SP data. Forecasting models on the other hand are usually based on RP or joint RP/SP data (an explanation for this difference can be found in section 7.2.1).

Many models follow a linear utility specification in time and cost:

$$U = \beta_C \cdot C + \beta_T \cdot T + \beta_R \cdot \sigma \qquad (3\text{-}1)$$

where:

U	= Utility
β_C	= Transport cost coefficient (to be estimated)
C	= Transport cost
β_T	= Transport time coefficient (to be estimated)
T	= Transport time
β_R	= Variability (reliability) coefficient (to be estimated)
σ	= Standard deviation of the transport time distribution

The value of transport time VTT can be calculated by dividing the time coefficient by the cost coefficient:[1]

$$VTT = \frac{\beta_T}{\beta_C}.$$

The value of variability is calculated in a similar way:

$$VTTV = \frac{\beta_R}{\beta_C}$$

A measure that is sometimes used to express the VTTV (based on the standard deviation) relative to the VTT is the reliability ratio RR:

$$RR = \frac{\beta_R}{\beta_T}$$

Some models are not in utility space but in willingness-to-pay (WTP) space:

$$U = \beta_C \cdot (C + VTT \cdot T + VTTV \cdot \sigma) \tag{3-2}$$

Here the VTT and VTTV are estimated directly. The same goes for the logWTP space model (Fosgerau, 2006), where the natural logarithm is taken of the term between brackets in eq. (3-2)

3.4 The issue of small time savings

HEATCO (Bickel et al., 2006) already commented that the value of small time savings often is a contentious issue. At that time, with the exception of Germany all the EU-25 countries plus Switzerland used a constant VTT value irrespective of the size of the time saving. The German approach was to discount the value of small time savings on non-work trips by 30%. Previously, such practices had also been adopted in the Netherlands, France and the USA, though they have now been abandoned in favour of the use of a constant unit value. But also in Germany, this reduction did not apply to freight transport or to business travellers, the reasoning apparently being that in a commercial environment time savings will be converted to their full money value, even if the time savings are small.

In the course of the work for the Federal Infrastructure Plan 2015 (BVWP 2015), Germany also abandoned the use of a reduction in the VTT for small time savings. The only remaining exception to the unit value rule that we know of is Transport Canada, that does not include time savings of less than five minutes per one-way trip in the calculation of the net present value (again, this refers to passenger transport only).

[1] Exact methods also exist for calculating standard deviations or t-ratios of the VTT or VTTV on the basis of the statistics for the individual coefficients (see Daly et al., 2012).

Constant unit values of time are also recommended in the EU's Guide to Cost-Benefit Analysis (European Commission DG Regional Policy, 2008; European Commission, DG Regional and Urban Policy, 2014).

The principal objection to the use of a constant unit value for VTT is that small amounts of time:

- cannot be usefully transferred to any other activity (e.g. employ the staff and the vehicle time saved for other transports; save on interest on the capital tied up in the transported goods),
- they cannot be perceived, and
- measurement error may be large in comparison to the size of a small time saving.

Moreover, SP studies often find (at least in passenger transport) that the value per minute of small time savings is lower than for large time savings. This could be an artefact of the experimental approach, but it's not unlikely that we would also find such responses in RP data, at least for reactions in the short run.

In passenger transport the discussion is about whether travel time savings of below five or ten minute are worthwhile. In freight transport, the issue is about time savings say less than an hour, or an even higher threshold specifically in rail freight transport.

However, with the exception of the measurement error problem there are strong counter-arguments to these points which led HEATCO to favour the use of a constant unit value in appraisal for all modes.

One pragmatic point is that within the context of incremental upgrades to a route or multiple design options, the aggregation issues associated with non-constant unit values are problematic: it does not make sense to value parts of a project at a lower unit value than would be used for the project as a whole. It would also lead to incentives for proponents of projects to combine projects to benefit from a higher unit value of time. In the literature this is called the 'adding up' argument.

Another key argument for a constant unit value is the 'averaging' argument that says that even if some agents will not be in the position to use a small time saving productively, other agents will be better positioned to reap the time savings, and on average there will be benefits for society.

A recent extensive treatment of the issue (though focussing on passenger transport) can be found in Daly et al. (2014), but the conclusion for appraisal remains that for the long run a constant unit value of time is preferred. An additional argument they provide for the use of a constant unit value, which also applies in freight transport, is that for transport projects we are not simply modelling changes from a situation without the project to a situation with the project where agents will experience small time changes. On the contrary we are modelling the transitions from a base situation to alternative futures, often ten or more years away. In these transitions, firms experience small and large changes, firms are created, dissolved, split, merged, expanded, reduce or relocated. What we are comparing are difference between alternative futures, which cannot be equated to time savings (or losses) to the same set of firms.

Fowkes (1999) also discussed the issue of small time savings (in passenger and freight transport) in detail, with some focus on the notion of a threshold for small savings. He admits that small time savings are less useful than large time savings, since large blocks of time can always be split up, but small amount can be difficult to aggregate. Nevertheless, he argues that for this very reason, the starting position will be suboptimal: some beneficiaries will find that a small time saving pushes them over a threshold and so put the essential finishing touch to a large block of time. He worked this argument out mathematically and proved that the total effect is equivalent to assuming that all time savings are valued equally. In this way the main argument for lower or zero values of time for small time savings is countered quite effectually.

We find the arguments for a unit value in evaluation that is the same for small and large time savings put forward in for instance Fowkes (1999) and Daly et al. (2014) convincing and recommend this approach also for JASPERS.

4. Results for the value of transport time in rail freight transport

4.1 Outcomes from the literature

De Jong (2008) is a review paper on freight VTT that contains outcomes for the freight VTT for different modes from different studies reported up to 2007. In the tables below, we summarise the main findings of the 2008 paper and add some new studies. Another recent overview of VTT is given by Feo-Valero et al. (2011).

Not all the studies included in de Jong (2008) or in the tables below were specific VTT studies; some focused on the valuation of several freight service attributes, others were designed for predicting future freight volumes. Several assumptions with regard to average shipment size, shipment value, transport cost and times had to be made and exchange rates and price index numbers were used to convert to 2010 Euros. The values should therefore be only regarded as indications of the outcomes of the studies quoted. Furthermore, unlike the tables in de Jong (2008), we now tried to group the empirical outcomes (which for some studies was a somewhat subjective task) into:

- outcomes for the goods component of the VTT
- outcomes for the transport service component (vehicles and staff) of the VTT
- outcomes for both components together.

For other modes than road transport (see chapter 9 of Tavasszy and de Jong, 2014), fewer values are available from the literature. Most other VTTs refer to rail transport. Table 4-1, contains the values from the literature that refer to rail or combined road-rail transport, or to all modes without distinction. These values were taken from de Jong (2008), updating the units to euro of 2010 and adding some new evidence. It only includes studies that yield values expressed per tonne (for the Dutch studies 950 tonnes for a complete train was used for the average load).[1]

Some general findings from this overview of VTT studies in Table 4-1 are:

- All specific VTT studies collect SP data (some in combination with RP or factor cost data);
- The type of model estimated on the data is mostly the multinomial logit (MNL) model (see chapter 7 and Annex 1);
- There are two different definitions for the VTT in freight transport, each of which has about the same number of studies: one group tries to find only the cargo component and the other group tries to determine the sum of the cargo and the transport cost component; this difference is caused by the differences in how countries do the CBA: the former group used a limited VTT but also calculates a transport cost benefit that includes time-dependent cost. The second group calculates a broad VTT and only defines the transport costs benefit in terms of shorter distances in freight transport (leading to savings in the distance-dependent cost only).

[1] VTT for transport by road, inland waterways, sea and air transport can be found in de Jong (2008) and Significance et al. (2013).

In terms of numerical values for the VTT, the picture that emerges from Table 4-1 is that in all studies, except the recent German study (BVU and TNS Infratest, 2014), the value of the goods component in the VTT is rather low (between 0.04 and 0.45 euro/tonne/hour for all goods together, with a central value of about 0.2), relative to the values found for the sum of both components (say around 1-2 euro/tonne/hour). Large values for the goods component of the VTT are only found for specific high-value commodities (e.g. in the recommend values for France: CSGP, 2013; or for automotive, container, finished goods and especially express goods in the UK). As for road transport, the goods component appears to be the minor component in the rail VTT. The BVU and TNS Infratest study with its rather high values for the cargo component, is an outlier relative to the other studies. Maybe these high values are due to the fact that the German study did not differentiate between VTT for road and rail transport, so that the common values for both modes might be pushed upwards by including road as well, where the cargo component, also within commodity types, is usually higher.

Table 4-1. Value of transport time (VTT) in goods transport by rail (in 2010 Euro per tonne per hour)

Publication	Country	Data	Method	VTT
The goods component in the VTT:				
Widlert and Bradley (1992)	Sweden	SP	MNL	0.04
Kurri et al. (2000)	Finland	SP	MNL	0.11
Beuthe and Bouffioux (2008)	Belgium	SP	MNL (on ranking data)	0.20
Johnson and de Jong (2011)	Sweden	RP (mode and shipment size choice)	MNL and mixed logit	0.1
Significance et al. (2013)	Netherlands	SP	MNL	0.3 for all
				0.4 for container
				0.2 for bulk train
				0.5 for wagonload
CGSP (2013)	France	SP	MNL	0.01 for freight with low added value (< 6000 euro/t): e.g. bulk/aggregates
				0.20 for ordinary freight (6000-35000 euro/t): e.g. other rail, sea and river transport
				0.60 for freight with high added value (> 35000 euro/t): e.g. combined, parcels, refrigerated, roro

Publication	Country	Data	Method	VTT
BVU and TNS Infratest (2014)	Germany	SP	Nested logit	median: 0.73 for all modes, depending on the commodity type
				0.31 for sea container
				1.18 for land container
				0.02 for shipments 100+ t
				1.01 for agri/food products
				0.37 for stone and earth
				0.75 for petroleum (products)
				0.73 for chemicals and fertilisers
				0.83 for metal (products)
				1.51 for vehicles and machines
				0.20 for other intermediate and final products
Fowkes (2006, 2015)	UK	SP (LASP interview)	Manual method and weighted regression	0.45 for all goods
				0.18 for coal
				0.05 for metals
				0.05 for aggregates
				0.54 for oil and chemicals
				1.76 for automotive
				0.14 for other bulks
				0.90 for container
				1.35 for finished goods
				9.00 for express goods
The transport service component in the VTT:				
Significance et al. (2013)	Netherlands	transport cost functions	MNL	2.4 for all goods
				1.8 for container
				1.4 for bulk train
				4.8 for wagonload
Both components in the VTT:				
Fowkes et al. (1991)	UK	SP	MNL	0.10– 1.44
Vieira (1992)	USA	SP+RP	Ordered logit	0.77
de Jong (1992)	Netherlands	SP	MNL	0.96
de Jong et al. (2001)	France	SP+RP	MNL	0.30 – 1.31
De Jong et al. (2004)	Netherlands	SP	MNL	1.14
Halse et al. (2010); Halse and Killi (2013): GUNVOR study	Norway	SP	MNL	3.5

Publication	Country	Data	Method	VTT
Halse and Killi (2012): PUSAM study	Norway	SP	MNL	1.7 for all goods
				6.1 for general cargo
				0.9 for palletised goods
Significance et al. (2013)	Netherlands	SP for short-run and transport cost functions for long run	MNL	Short-run:
				1.2 for all goods
				1.1 for containers
				0.7 for bulk train
				2.2 for wagonload
				Long-run:
				2.7 for all goods
				2.2 for container
				1.6 for bulk train
				5.3 for wagonload

The range that we obtain in Table 4-1 for the cargo component and for the combined value of time is rather large. Apart from methodological differences between studies and in income levels between countries, this can be explained by variation between commodity types. The total VTT for rail per tonne is clearly lower than for road (which amounts to about 5 euro per tonne).

The Norwegian values are at the high end. The value of 0.9 for Norway refers to truckload shipments, which will only go by rail if time is relatively unimportant. The 6.1 for general cargo on the other hand refers to less-than-truckload shipments. In many countries, rail transport would not be attractive for such shipments, but in Norway, the rail operator Cargonet acts as a consolidator of such goods. Transport of less-than-truckload shipments will be relatively expensive, also when carried out by rail (this partly explains the high VTT), but will keep the inventory costs down. A major difference between Norway and most other countries in Europe is that in Norway rail transport mostly concerns general cargo transported in containers and not so much bulk goods.

For The Netherlands (Significance et al., 2013), the variation between goods/types of train is mainly caused by differences in the transport cost per tonne (which are strongly related to differences in the average loads of the train types). In CBA in The Netherlands for rail transport projects, for the first year the value directly from the SP is used (denoted 'short-run' in the table), whereas after ten years, the long-run value is used (and for years in between linear interpolation). The distance-dependent costs for rail freight in The Netherlands are 16-18% of the total transport cost. Therefore, they are more or less equal to the cargo component of the VTT (which in this study was 10% of the full transport cost for non-containers and 20% for containers). in other words, for the long-run, in The Netherlands the distance-based cost and the cargo component cancel out and the VTT can be taken to be equal to the full transport cost (time and distance dependent).

For passenger transport, so many VTT are available that various meta-regressions have been carried out, that try to explain the VTT obtained from attributes of the respective countries and study methods used. For freight transport, the number of VTT available is somewhere near the margin of what is minimally needed for a meta-regression.

RAND Europe and CE Delft (2004) contains meta-regressions for passengers and freight transport, carried out in a project for the EIB (for passenger transport there now is a more recent meta-regression report for EIB that also used more extensive literature: Wardman et al., 2012). The meta-regression for freight only concerned road freight transport. The recommended default values for other modes, including rail transport were based on a Dutch SP study (de Jong et al., 2004c) with modifications for GDP per capita differences relative to The Netherlands to obtain outcomes for other countries. This means that effectually the elasticity for GDP per capita differences between countries is 1 (if one considers that the VTT in freight transport mainly consists of transport costs, a differentiation over space and time in terms of transport costs makes more sense, and this could very well increase considerable slower over time than GDP). These recommendations are presented in Table 4-2 below.

The default values for the freight VTT suggested by the HEATCO project (Bickel et al., 2006) for the European Commission were based on a meta-regression of the literature carried out by Jeremy Shires and Gerard de Jong of ITS Leeds. This is a so-called 'double logarithmic' model, indicating that both the VTT and GDP/capita of a country are in natural logarithms. As a result, the estimated coefficient for GDP/capita is a constant elasticity. A distinction is made in the estimated freight model between road and rail values (and also between types of data used and studies before and after 1990). The recommended default values are reproduced below in Table 4-3.

The HEATCO project for the EU found that the GDP per capita elasticity of the freight VTT (road and rail) was between 0.3 and 0.4 (Bickel et al., 2006). To be more exact, this elasticity is 0.33. The finding of a value clearly below unity was attributed to the openness and competitiveness of transport markets.

The differences between the recommendations for rail transport from RAND Europe and CE Delft (2004) and HEATCO are substantial, though they are in euros of only one year apart. This is best seen in Figure 4-1. All HEATCO values are higher, and the differences increase when a country has a lower GDP/capita. The country with the lowest value that is in both tables is Lithuania, with 0.09 euro/tonne according to RAND Europe and CE Delft (2004) and 0.72 euro/tonne in HEATCO. The highest value is for Luxembourg (1.70 euro per tonne in both). The main reason for the differences is the difference in the GDP per capita elasticity. In the HEATCO regression this was estimated on the data to be equal to 0.33. This leads to freight VTTs that vary considerably less between countries than GDP per capita. In RAND Europe and CE delft (2004) as assumption was made that effectually implies the elasticity is 1. This makes the freight VTT much more variable between countries with different GDP per capita[1]. Moreover, the base for the HEATCO values is somewhat higher (the value for The Netherlands, which is the pivot point in the RAND Europe and CE Delft (2004) work in HEATCO is 1.38 euro/tonne, versus 0.98 in the work for EIB). In HEATCO this base is an outcome of the estimation of the meta-regression equation; in the RAND Europe and CE Delft (2004) work the base for rail is an assumption (since their meta-regression itself did only include road transport).

[1] In both studies GDP in market exchange rates was used, not in purchasing power parity (PPP).

Table 4-2. RAND Europe and CE Delft's recommended default values of transport time for freight transport (in 2003 Euro/hour, using 2002 input data)

Mode: Country:	Road transport: VoT per truck	Rail transport: VoT per tonne	Air: transport: VoT per tonne	Sea transport: VoT per tonne	Inland water transport: VoT per tonne
Albania	4.25	0.0331	9.13	0.0011	0.0017
Austria	36.53	0.9688	266.90	0.0323	0.0505
Belgium	35.04	0.9074	250.00	0.0302	0.0473
Bosnia and Herzegovina	5.46	0.0491	13.52	0.0016	0.0026
Bulgaria	5.62	0.0514	14.16	0.0017	0.0027
Croatia	11.89	0.1664	45.85	0.0055	0.0087
Cyprus	22.27	0.4457	122.79	0.0149	0.0232
Czech Republic	13.74	0.2087	57.51	0.0070	0.0109
Denmark	41.55	1.1856	326.64	0.0395	0.0618
Estonia	14.15	0.2187	60.25	0.0073	0.0114
Finland	36.54	0.9692	267.03	0.0323	0.0505
France	34.42	0.8821	243.02	0.0294	0.0459
Germany	35.48	0.9253	254.92	0.0308	0.0482
Greece	23.99	0.5008	137.96	0.0167	0.0261
Hungary	19.35	0.3574	98.46	0.0119	0.0186
Ireland	37.45	1.0070	277.43	0.0336	0.0524
Italy	28.74	0.6648	183.16	0.0222	0.0346
Latvia	8.10	0.0911	25.09	0.0030	0.0047
Lithuania	8.20	0.0929	25.59	0.0031	0.0048
Luxembourg	52.30	1.7008	468.57	0.0567	0.0886
Macedonia, FYR	7.22	0.0761	20.97	0.0025	0.0040
Malta	17.58	0.3075	84.71	0.0102	0.0160
Netherlands	36.83	0.9811	270.30	0.0327	0.0511
Poland	14.20	0.2200	60.62	0.0073	0.0115
Portugal	22.41	0.4499	123.95	0.0150	0.0234
Romania	5.05	0.0435	11.98	0.0014	0.0023
Slovak Republic	13.95	0.2138	58.91	0.0071	0.0111
Slovenia	25.62	0.5550	152.91	0.0185	0.0289
Spain	26.76	0.5942	163.71	0.0198	0.0309
Sweden	36.13	0.9520	262.27	0.0317	0.0496
Turkey	8.21	0.0931	25.64	0.0031	0.0048
United Kingdom	28.29	0.6486	178.68	0.0216	0.0338
Yugoslavia, Fed. Rep.	4.58	0.0373	10.27	0.0012	0.0019

Table 4-3 HEATCO's recommended default values of transport time – freight trips (2002 Euros per freight tonne per hour, factor prices)

Country	Freight	
	Road	Rail
Austria	3.37	1.38
Belgium	3.29	1.35
Cyprus	2.73	1.12
Czech Republic	2.06	0.84
Denmark	3.63	1.49
Estonia	1.90	0.78
Finland	3.34	1.37
France	3.32	1.36
Germany	3.34	1.37
Greece	2.55	1.05
Hungary	1.99	0.82
Ireland	3.48	1.43
Italy	3.14	1.30
Latvia	1.78	0.73
Lithuania	1.76	0.72
Luxembourg	4.14	1.70
Malta	2.52	1.04
Netherlands	3.35	1.38
Poland	1.92	0.78
Portugal	2.58	1.06
Slovakia	1.86	0.77
Slovenia	2.51	1.03
Spain	2.84	1.17
Sweden	3.53	1.45
United Kingdom	3.42	1.40
EU (25 Countries)	**2.98**	**1.22**
Switzerland	3.75	1.54

In CBA, VTT is needed for a series of future years. The default values in RAND Europe and CE Delft (2004) and HEATCO were only given for a base year. For future years RAND Europe and CE Delft recommend to increase the VTT by the full growth of GDP per capita in real terms (elasticity of 1). HEATCO recommends using an intertemporal elasticity to real GDP per capita growth of 0.7 (with a sensitivity test at 1). In the absence of intertemporal data on the VTT in freight transport, HEATCO recommended the same income elasticity as for passenger transport (for which there was evidence at the time, and even more now, indicating that it is close to 1). However, the main driver of VTT change over time in freight transport will be changes in transport cost (per hour). So in our view it is better to base the growth of the freight VTT on estimates or scenarios for the increase in the real, time-dependent transport costs over time (as has been used in The Netherlands for freight VTT). These real cost increases could very well be considerably smaller than real GDP per capita growth. We will also come back to this issue (called: 'approach to escalation') in Report 4 (Appraisal Report).

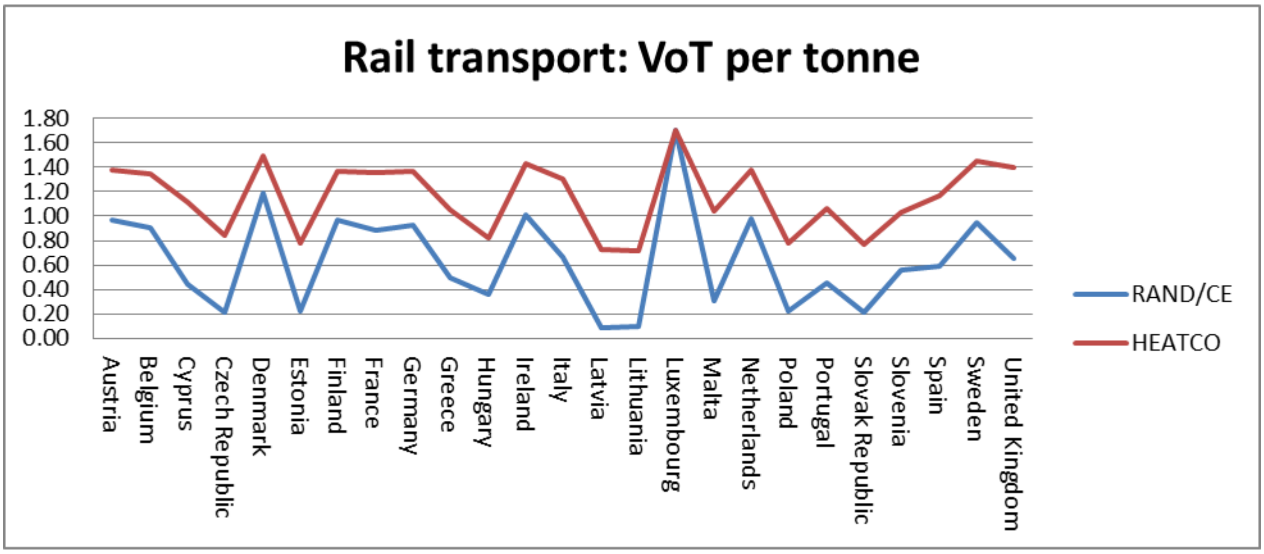

Figure 4-1: Comparison VoT per tonne RAND Europe/CE Delft with HEATCO

In these two meta-regression studies, the distinction between the VTT that is related to the cargo and the VTT that is related to the transport services was not yet made. But it is fair to say that the outcomes in both tables are dominated by values that include both components of the VTT and can best be interpreted as the VTT for both components (energy costs and infrastructure access charges were not included in these VTTs).

Zamparini and Reggiani (2007) assembled 46 observations on the VTT in freight transport for 22 countries in Europe and North America. Their regression function explained the natural logarithm of the VTT from GDP per capita, region and mode. Their GDP per capita elasticity of the VTT was 0.68.

4.2 Conclusions on the value of time

In conclusion with regards to the VTT in freight transport, we can say that there are two distinct 'schools' or approaches in terms of what is included in the VTT (see Figure 4-2). The first school defines VTT as the cargo component only and includes impacts of projects on staff and vehicle time saved in the CBA through the transport cost savings (together with the distance-based cost, including energy and access cost, that should not be in the VTT in either approach). The second group uses a VTT that contains both the cargo and the transport services component; in the CBA all time benefits are expressed through the VTT, and transport costs benefits only refer to reductions in the trip lengths (if any). Both methods can be carried out in such a way that no benefits are forgotten and no benefits are counted twice. If VTT is the cargo component only, one should, in evaluating time-saving projects, take care not to forget reducing the time dependent transport costs (as part of the cost savings). If both components are in the VTT one should take care not to double count the distance-dependent transport cost.

Approach A	Approach B
Time savings:	**Time savings:**
Cargo time saved	Cargo time saved Staff time saved Vehicle time saved
VTT	VTT
Transport cost savings:	**Transport cost savings:**
Distance cost saved Staff cost saved Vehicle cost saved	Distance cost saved

Figure 4-2: Approaches to time/cost benefits in CBA

A key result is that the transport service component of the VTT will be (especially in the long run) more or less equal to the cost of producing the transport services per hour (the sum of the staff and vehicle cost per hour including overheads, but not including distance-dependent cost). It is therefore not really needed to do new SP research to get these values, one can simply use the factor costs method to find this component. This component will hardly or not vary between commodity types, but it will vary between modes.

The cargo component of the VTT cannot so straightforwardly be derived from the factor cost. If possible, specific SP surveys are recommended. If these are not possible, one could use for the cargo component of the VTT in rail freight a fraction, e.g. 10-20%, of the full transport cost (including time- and distance dependent cost); this fraction is based on the results from Significance et al. (2013) for The Netherlands. Variation between commodity types (which one would expect for the cargo component) can be derived from the French, German or UK results in Table 4-1 (but the German values are higher than the values other studies, and as such rather an outlier).

5. The value of transport time reliability

This chapter is mainly based on earlier work for the German, Scottish and Swedish transport authorities.

5.1 Operational definition

Reliability for **road vehicles** is best expressed by means of the reliability ratio (RR), defined as:

Reliability Ratio = Value of SD of travel time / Value of travel time

We prefer to write that as:

$$RR = (\text{Value of } \Delta\sigma_T) / (\text{Value of } \Delta T) = VOR / VOT \qquad (5\text{-}1)$$

where:
VOR: value of reliability (also known as VTTV: value of travel time variability)
VOT: value of travel time (also known as VTT); the sum of the transport costs and the cargo component
$\Delta\sigma_T$: a change in the standard deviation of travel time
ΔT: an identical change in expected travel time.

For example, we might have an estimate of the value of a travel time saving as euro 6/hour for some group. That means that the value of a $\Delta T= -10$ minutes is estimated at 1 euro. We now need to know the value of reducing the standard deviation of travel times also by 10 minutes. From the literature, the consensus of opinion is that RR is often around 0.8, in which case the value of reducing the standard deviation of travel times would be about euro 4.80 per hour, and so the value of reducing the standard deviation by 10 minutes would be 0.80 euro.

For **scheduled services** however (including rail freight transport), the RR can be defined differently. The justification given for this is the existence of a timetable. Users of scheduled services are said to be concerned less about journey time variability per se, but more about lateness relative to the timetable.

The value of (mean) lateness is

$$VOL = \text{value of } L = \textstyle\sum_d \text{prob}(L_d) \,.\, L_d = f \,.\, VOT \qquad (5\text{-}2)$$

VOL: value of lateness (also known as value of delay)
L_d: lateness or delay of a certain size d (for instance a delay of two hours)
Lateness L is calculated as $A_i - A^S$, where A_i is the actual arrival time of trip i and A^S is the timetabled arrival time referring to that trip; with $A_i – A^S \geq 0$, i.e. early arrivals are treated as being on time
Prob(L_d) is the probability of a delay of size d
f is a factor to be estimated (then 1 hour expected delay has the same disutility as f hours transport time).

5.2 Results

In Table 5-1 is an overview of quantitative results for the VTTV in freight (largely based on Batley et al., 2008 and Significance et al., 2012a, b). As discussed in the previous section, the reliability ratio RR (that uses VTTV expressed as the standard deviation) is probably the most practical measure for including the VTTV in freight transport models. However, only few studies using this measure have been carried out. Recently, some results (Fowkes, 2006; Halse et al., 2010; Significance et al., 2013) have become available that indicate that in freight transport the RR may not be as high as previously thought (MVA, 1996; de Jong et al., 2009).

UK
In a study on the VOT of road transport for the Department for Transport, Accent/HCG (1995) also studied the value of time, but also the value of the probability that the shipment will be delivered later than the agreed time or time interval. These results could only be used under the assumption that the size of the delay would not change. The outcomes on reliability were not included in the recommendations for CBA.

Fowkes et al. (2001) studied several formulations of reliability on SP data. They concluded that there are many complex and varied reasons why freight transport and logistics operators value a high level of journey time predictability.

Fowkes (2006) describes SP experiments carried out in 2003 and 2004 with basically the same setup as in Fowkes (2001), but now with a mode choice (road versus rail). Originally, Fowkes obtained a reliability ratio (value of reliability divided by value of time) of 0.31 (Fowkes, 2006). Both of these investigations are not used in official CBA guidelines, but the values of delay time are used in the freight road-rail modal split model LEFT, as part of the generalised costs function. Recently, Fowkes re-worked the calculations of the reliability ratio and obtained different (generally higher) values (Fowkes, 2015).

The Netherlands
The first national freight value of time study in The Netherlands was Hague Consulting Group (HCG) (1992). This SP-based study also included as one of the attributes the probability of delay. In the recommended values for the CBA however, only the VOTs were adopted, not the reliability value (mainly because information from the Q-side was missing).

Bogers and van Zuylen (2005) studied transport time variability from the viewpoint of the truck drivers. This was part of a PhD research at the Delft University of Technology; the outcomes were not implemented in official project assessments or transport models.

Table 5-1: Value of transport time variability (VTTV) in goods transport (in 2010 Euro), by VTTV measure

Publication	country	data	method	Quantitative outcomes (+definition) : transport time or cost equivalent
				Percentage not on time
HCG, (1992)	Netherlands	SP survey among shippers and carriers	MNL	An increase in the percentage not on time by 10% (e.g. from 10% to 11%) is just as bad as 5-8% higher transport costs.
Accent and HCG, (1995)	UK	SP among shippers and carriers (road)	MNL	A 1% increase in the probability of delay of 30 or more minutes. Is equivalent to 0.5 – 2.1 Euro per transport.
Bruzelius, (2001), based on Transek, (1990, 1992)	Sweden	SP survey among shippers	MNL	For rail transport, a 1% increase in the frequency of delays is equivalent to 5-8 Euro per wagon; For road transport: 4-37 Euro per transport.
Bruzelius, (2001), based on INREGIA, (2001)	Sweden	SP survey among shippers	MNL	The value of the risk of delay is 7 Euro per pro mille per transport for road, 128 for rail and 30 for air transport.
De Jong et al. (2004) Also used in de Jong et al. (2009)	Netherlands	SP survey among shippers and carriers	MNL	A change of 10% in the percentage not on time (e.g. from 10% to 11%) is equivalent to 2 Euro per transport for road transport. When converted to reliability ratio: 1.24. Also values for rail, waterways, sea and air.
IRE and RAPP Trans (2005), Maggi and Rudel (2008)	Switzerland	SP among shippers	MNL	A 1% point increase (e.g. from 10 to 11%) in the percentage not on-time has a cost of 42 euro per shipment
Fries et al. (2010)	Switzerland	SP among shippers	Mixed logit	A 1% point increase (e.g. from 10 to 11%) in the percentage not on-time has a cost of 16 euro per shipment
BVU and TNS Infratest (2014)	Germany	SP survey among shippers and carriers	Nested logit	A 1% increase in the percentage on time reduces the cost by 0.1 – 1.4 euro per tonne per hour (depending on commodity type; median 0.5); 1 hour delay costs between 0.1 and 53.6 euro per tonne per hour Results per commodity type: see Table 5-2

Publication	country	data	method	Quantitative outcomes (+definition) : transport time or cost equivalent
				Reliability ratio (with standard deviation)
MVA (1996)	UK	Literature review		Reliability ratio for transport: 1.2
Halse et al. (2010)	Norway	SP (mainly shippers in road transport)	MNL	Reliability ratio for shippers using road transport: 1.2 Reliability ratio for carriers (road): 0 Overall reliability ratio for road: 0.1
Significance et al. (2013)	Netherlands	SP survey among shippers and carriers	MNL	Reliability ratio for shippers using road transport: 0.3-0.9 Reliability ratio for carriers (road): 0 Overall reliability ratio for road: 0.4 Reliability ratio for rail: 0.2 Also values for inland waterways, sea and air transport.
Fowkes (2006, 2015)	UK	SP (LASP interview) among shippers using or potentially using rail	Manual method and weighted regression	Overall reliability ratio 0.66 -1.40 for coal
				0.41 – 1.33 for metals
				1.22 – 2.12 for aggregates
				1.51 – 2.00 for oil and chemicals
				1.35 – 1.81 for automotive
				1.53 – 2.35 for other bulks
				0.94 – 1.56 for container
				0.79 – 1.32 for finished goods
				2.79 – 2.93 for express goods
				Schedule delay
Small et al. (1999)	USA	SP survey among hauliers	MNL scheduling model	A reduction in the deviation from the agreed delivery time (schedule delay) by 1 hour is worth 450 Euro per transport
Fowkes et al. (2001)	UK	SP survey among shippers and carriers (road)	MNL	The value of the difference between the earliest arrival time and the departure time is on average 1.4 Euro per minute per transport (more or less the free-flow time); For the time within which 98% of the deliveries takes place minus the earliest arrival time, the value is 1.7 Euro (‘spread’); For deviations from the departure time (schedule delay) the value is 1.3 Euro.

Publication	country	data	method	Quantitative outcomes (+definition) : transport time or cost equivalent
				Other
Bogers and van Zuylen, (2005)	Netherlands	SP among truck drivers and managers of shippers and carriers	MNL	Truck drivers value the unfavourable travel time twice as high as its objective (risk-neutral) worth. Managers of shippers and carriers did not have this relatively higher value for unfavourable travel times.
Hensher et al. (2005)	Australia	SP for tolled and toll-free roads	Mixed logit	VTTV of 2.5 Euro per percentage point for transporters, 7.50 Euro for shippers. This is obtained when looking solely at the freight rate; when further incorporating all costs in the calculation, the VTTV rises to 9.1 Euro. Giving an actual meaning to these values, the results would imply that, if a toll free route had a 91% probability of on-time delivery, with 97% for the tolled route, the VTTV for transporters would be 15 Euro per trip.

In 2003-2004, a study (RAND Europe et al., 2004) was carried out to update the first Dutch freight value of time study. Again, probability of delay was among the attributes. In a special follow-up study (reported in de Jong et al., 2009) the outcome was converted to a value for the standard deviation of transport time by mode, which became a provisionally recommended value for CBA.

The third national study on value of time and reliability for passenger and freight transport was completed in 2013 (see Significance et al., 2013; de Jong et al., 2014). The client was the Ministry of Infrastructure and the Environment. Again, SP methods were used, but this time unreliability was presented to the respondents in the form of five equi-probable travel times with the corresponding arrival times (all within a single choice alternative). The SP-experiments were carried out among more than 800 shippers and carriers, making the data set arguably the largest ever in freight in terms of the number of interviews. In the models estimated on the SP data, unreliability was expressed as the standard deviation of transport time. This definition was chosen especially because it is relative easy to incorporate in transport forecasting models. The study was the first to make a very explicit distinction between the cargo and the transport costs component in both the VTT and the VTTV and the interviews were arranged so that the shippers would provide the former and the carriers the latter. The outcomes are now used in CBA in The Netherlands.

Sweden

Bruzelius (2001) is an overview of studies on the value of time and reliablity in freight transport. It decribed two studies carried out in Sweden (and originally reported in Swedish): the 1990/1992 studies for rail and road by Transek and the 1999 study by Inregia and COWI. Both studies presented reliability as the probability of delay. The VTTs from these studies were used in the official recommendations for CBA in Sweden, but not the reliability values.

Norway

Halse et al. (2010) report the methods used and the outcomes of the Norwegian freight value of time study ('GUNVOR'). The SP design was partly adopted from de Jong et al. (2007), using a representation with five transport times per alternative that are all equally likely. The study produced values of reliability for shippers, for carriers the reliability values were not significant. Halse et al. (2012) is a follow-up study (PUSAM) that focuses on rail transport time and its reliability between railway stations. For practical CBA in rail freight transport in Norway, the outcomes of PUSAM are used now. The measure of unreliability here is the expected delay (size of the delay multiplied by its probability), which was chosen to be consistent with the tradition in Norwegian rail transport to measure reliability as delays. In the SP experiments this was presented by asking the respondents to compare a 100 reliable transport alternative against an alternative where some fraction (say 80%) of the transports arrive on schedule and the remaining fraction arrives with a specified delay (e.g. 20 minutes) relative to the agreed schedule. By multiplying the probability of delay times its size the researchers can calculate the expected delay for each alternative, and this is the variable that was used in model estimation and for recommended values in rail transport.

France

De Jong et al. (2001) carried out an SP study on attributes in modal choice in freight transport in the French region Nord-Pas-de-Calais. The project yielded values for the probability of delay, but these were not used further.

Australia

In Australia, Puckett (with Hensher, Rose and others) has developed SP methods and model specifications that allow for interaction between shippers and carriers. The SP attribute that they include on reliability is the probability of a delay (Pucket and Rose, 2009). These studies have been carried out by the University of Sydney and are not meant to derive values for official CBA or transport models.

Germany

The German Federal Ministry of Transport (BMVDI) commissioned BVU and TNS Infratest to develop a model that can be used to determine modal shift in freight transport as well as VTT and VTTV for the federal infrastructure planning 2015 (BVU und TNS Infratest, 2014). To this end, SP/RP interviews were carried out with almost 500 senders and receivers of goods as well as carriers. The researchers decided not to use the standard deviation of transport time because firms often cannot understand this concept. (this however should not be a problem, see Tseng et al. (2009), Significance et al. (2007, 2013) and de Jong et al., (2014)). Therefore they present transport time unreliability in the SP using two complementary attributes:

- Probability that there will be no delay (BVU and TNS Infratest call this 'punctuality');
- Size of the delay.

The same attributes are used in the model estimation. Models have been estimated for ten different commodity types (see Table 5-2).

Table 5-2: Value of transport time variability (VTTV) in goods transport (in 2010 Euro per tonne per hour) from BVU and TNS Infratest (2014), by commodity type (for all modes)

Commodity type	a 1% increase in the percentage on time reduces the cost by:	1 hour delay costs:
median:	0.46	2.26
sea container	0.36	1.92
land container	0.33	2.64
shipments 100+ t	0.10	0.08
agri/food products	0.42	2.42
stone and earth	0.16	0.91
petroleum (products)	0.74	3.95
chemicals and fertilisers	0.81	0.34
metal (products)	0.50	2.09
vehicles and machines	1.38	53.61
other intermediate and final products	0.90	3.58

In Figure 5-1 the various results for the reliability ratio (using the standard deviation of travel time to the total VTT) are compared. For road transport, the few available studies lend some support for an overall RR below 0.5. For rail, considerable variation in the overall RR between commodities has been found (Fowkes, 2006), but also considerable disagreement between the study of Significance et al. (2013) and Fowkes (2006). In the latter publication, all individual commodity types studied have an RR that is above that for all commodity types together of Significance et al. (2013). It is unclear what causes this discrepancy.

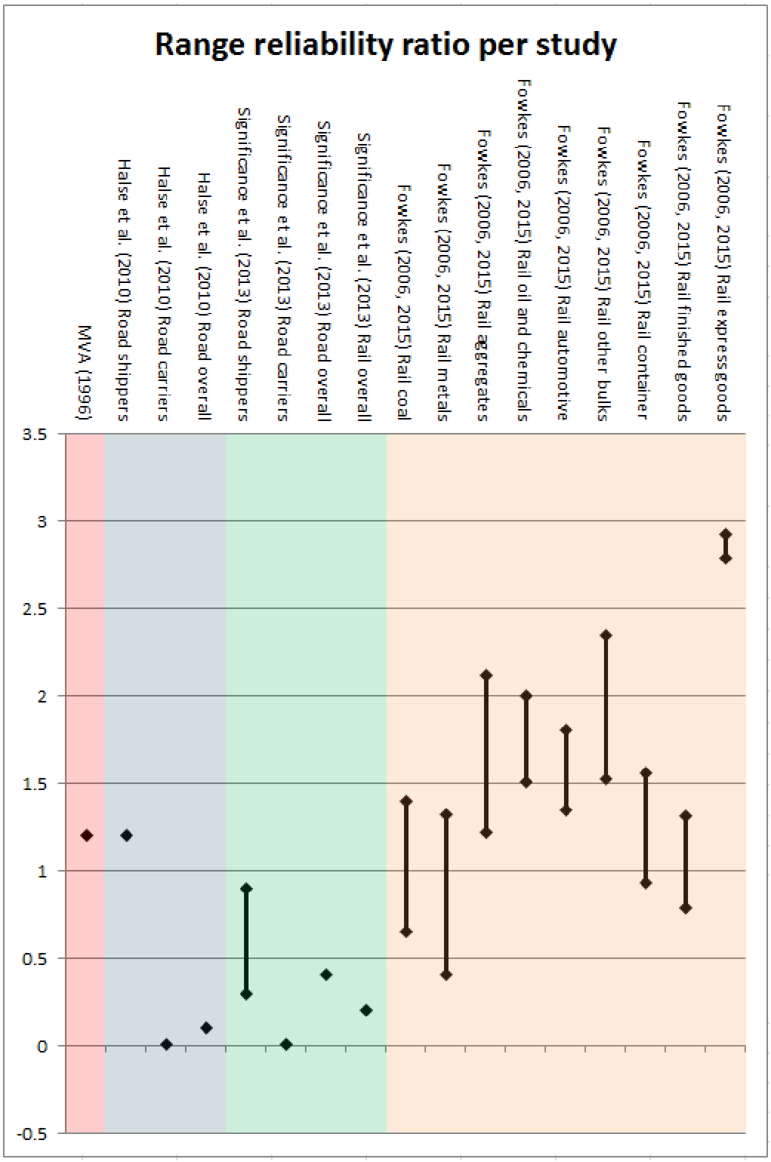

Figure 5-1: Range reliability ratio per study

5.3 VTTV measurements and values

Table 5-3 show the results from:

- GUNVOR: freight value of time and reliability study for Norway (Halse et al., 2010);
- PUSAM: specific rail freight value of time and reliability study in Norway (Halse and Killi, 2012),
- VOTVOR: freight value of time and reliability study in The Netherlands (Significance et al., 2013).

These values are taken directly from each respective study presented in local currencies at different points in time and with different measures of VTTV, hence the table does not provide comparable values.

Direct comparisons between the studies is possible with the information in Table 5-4, the values are translated into Euro using the appropriate exchange rates and changing the unit in the Dutch study to per tonne-hour instead of train-hour (based on the average weight of 265 net tonnes in the VOTVOR-survey).

Table 5-4 can be used to compare the values but it is important to keep in mind that different measurements are used in the three studies and that the results are not always reliable, which will be discussed later. Here is a short summary of some assumptions and definitions in the three studies:

- VOTVOR: 200 Euro/hour per train – Standard deviation for door-to-door transports. Both early and late arrivals included. VTTV is calculated based on replies from shippers in all modes.
- GUNVOR: 27 NOK /tonne-hour – Standard deviation for door-to-door transports. Both early and late arrival included. GUNVOR covers all modes, but a second survey - PUSAM – was carried out in order to get more precise and transparent results for rail transport.[1]
- PUSAM: 13 NOK /tonne-hour – Value of expected delay (VED: the additional time relative to the agreed time) between railway terminals. Only late arrivals included. Based on the largest operator CargoNet's customers, mainly forwarders transporting containers. No ore transports are included

Table 5-3: Rail VTTV as reported in each respective study

Rail	VTT	VTTV	VED
GUNVOR - NOK/tonne-hour	27	44	89
PUSAM general - NOK/tonne-hour	47	-	278
PUSAM Pallet - NOK/tonne-hour	7	-	35
PUSAM All - NOK/tonne-hour	13	-	72
VOTVOR Container - Euro/train-hour	880	100	-
VOTVOR Non-container - Euro/train-hour	1200	250	-
VOTVOR All - Euro/train-hour	1100	200	-

Table 5-4: VTTV in Euro/tonne-hour of 2013

Rail (SEK/tonne*hour)	VTTV	VED
GUNVOR (NOR)	4.09	8.27
PUSAM all weighted (NOR)	-	7.21
VOTVOR all (NL)	0.75	-
Simple calculation (SWE)	3.48	-
Current ASEK value (SWE)	0.30	-

[1] The results reported here are based on estimations carried out after the publication of the original GUNVOR report, and are documented by Halse and Killi (2013) in TOI report 1250/2013.

Table 5-4 also includes a back-of-the-envelope calculation based on Bo-Lennart Nelldal's report (2014) on extreme delays. Based on data from SSAB, a steel manufacturer, Nelldal has estimated that delays in rail freight cost a total of SEK 1.5 billion. Out of these 1.5 billion 12/19 (=63%), or 0.947 billion, is considered to be losses for the shippers, the remainder for forwarders/carriers. Given that SSAB produces goods which are slightly more valuable than the average in ASEK, 3.30 SEK/tonne-hour compared to the average of 2.62 SEK/tonne-hour, the average calculated value needs to be scaled down. According to the Swedish Transport Administration (2014) there were a total 62191.3 delay hours per year in freight transports and the average train is assumed to have 400 tonnes of cargo[1] . Given that SSAB's values are true and a lot of other underlying assumptions the VTTV can be calculated as follows:

(12/19*1.5*10^9) / (3.30/2.62*62191.3*400) = 30.2 SEK/tonne-hour = 3.48 Euro/tonne-hour

This value should be taken with a pinch of salt given that it is extrapolated from one firm and there are many simplifying assumptions.

The current Swedish average VTTV value is 2.62SEK/tonne-hour (0.30 euro/tonne-hour). It is generally perceived to be low, both by industry groups and by the Swedish Transport Administration who claim that it does not even use the value in its CBA due to the low impact. The current VTTV is the lowest value in Table 5-4, which is an indication that it might be too low but that really depends on the reliability and applicability of the other values. If the results of the GUNVOR, PUSAM and VOTVOR would have been more similar, it would have made the choice of an appropriate value easier, but the values differ by a factor of ten. This should be seen as a warning sign that there are major differences between the countries and studies. A major difference between Norway and most other countries in Europe is that in Norway rail transport mostly concerns general cargo transported in containers and not so much bulk goods. This can (partly) explain the higher VTTVs in Norway.

In Sweden VTT and VTTV have traditionally been split into the commodity categories. It has been the wish of the Swedish Transport Administration to keep using the NSTR commodity classification but with updated VTTV. Norway does not differentiate between products in GUNVOR or PUSAM. The only categorization which is used is between pallet and general goods. In the Dutch VOTVOR study the only categorization used is container and non-container, but other categorizations such as commodity types has been tested without significant results. The lack of significant results might be because there is no effect or it might be a type 1 error. If the VTTV values should be updated keeping the existing commodity categorization a different method than a value transfer is advisable.

For rail freight transport projects assessed by JASPERS, expected delay (= size of delay*probability of delay), as used in Norway (but both components have also been distinguished and estimated in Germany, see BVU and TNS Infratest, 2014), would be an alternative to using the standard deviation of transport time. In task 4 of this project, we'll come back to this issue. The choice depends to a considerable degree on the issues for which measure one could give estimates for the future reference situation and of the effects of a project on reliability.

[1] Sweden has heavier trains than the Netherlands, hence a higher value than 265 tonnes which was used in the VOTVOR calculations

5.4 Other freight service values

Other freight service quality attributes for which monetary values have been derived, mainly in SP studies, are (see Feo-Valero et al. (2011), Table 5 for an overview by study):

- Probability of damage during transport
- Frequency
- Presence of a trans-shipment
- Flexibility
- Provision of information about delays
- Greenhouse-gas emissions from transport.

For probability of damage, results from the literature are in Table 5-5.

Table 5-5: Value of damage and loss to the goods (in equivalent time or 2010 euro)

Publication	country	data	method	Quantitative outcomes (+definition) : transport time or cost equivalent
HCG, (1992)	Netherlands	SP survey among shippers and carriers	MNL	A 10% increase in the probability of damage (e.g. from 10 to 11%) is equivalent to an increase in transport **cost** by 3.5% (rail)
de Jong et al. (2004)	Netherlands	SP survey among shippers and carriers	MNL	a 10% increase in the probability of damage (e.g. from 10 to 11%) is equivalent to an increase in transport **cost** by 5%.
Danielis et al. (2005)	Italy	SP survey among shippers	Ordered probit	Taking away the risk of a loss and damage of 50 euro per 1000 euro shipment value is worth 4.6 **euro** (of 2010)
Beuthe and Bouffioux (2008)	Belgium	SP among shippers	MNL (on ranking data)	A 1 percentage point increase in the share of commercial value lost from damages, stealing and accidents (e.g. from 10 to 11%) is equivalent to an increase in transport **time** by 1.5% (rail)
Zamparini et al. (2011)	Tanzania	SP survey among shippers	Multicriteria utility model on ranking data	A 10% reduction in the share of the value of loss and damage of relative to the shipment value is worth 0.02 -0.04 **euro** (of 2010) per tonne-km

For risk of damage and loss it is important to state that these should only be used in project evaluation when a case can be made for improvements in this attribute, not as some fixed surcharge. The range for probability of damage for which these results are valid (e.g. is the 5% reduction in transport cost also valid for a reduction of the probability from 1 to 0.9%?) can be based on the amount of variation that was presented to the respondents in the original Dutch data (de Jong et al., 2004). This range starts at 0% damage and ends at a damage probability of 10% (average probability of damage in then data for rail: 0.6%). There might be higher probabilities of damage and loss in Eastern Europe than in Western Europe.

5.5 Conclusions on the VOR

As discussed in de Jong and Bliemer (2015) and several other papers and reports, there are two groups of operational definitions for reliability:

- Reliability as a measure of dispersion of the travel time distribution (usually the standard deviation, sometimes the variance, range or measures based on percentiles);
- Expressing the consequences of reliability as the expected number of minutes/hours early or late relative to the preferred arrival time.

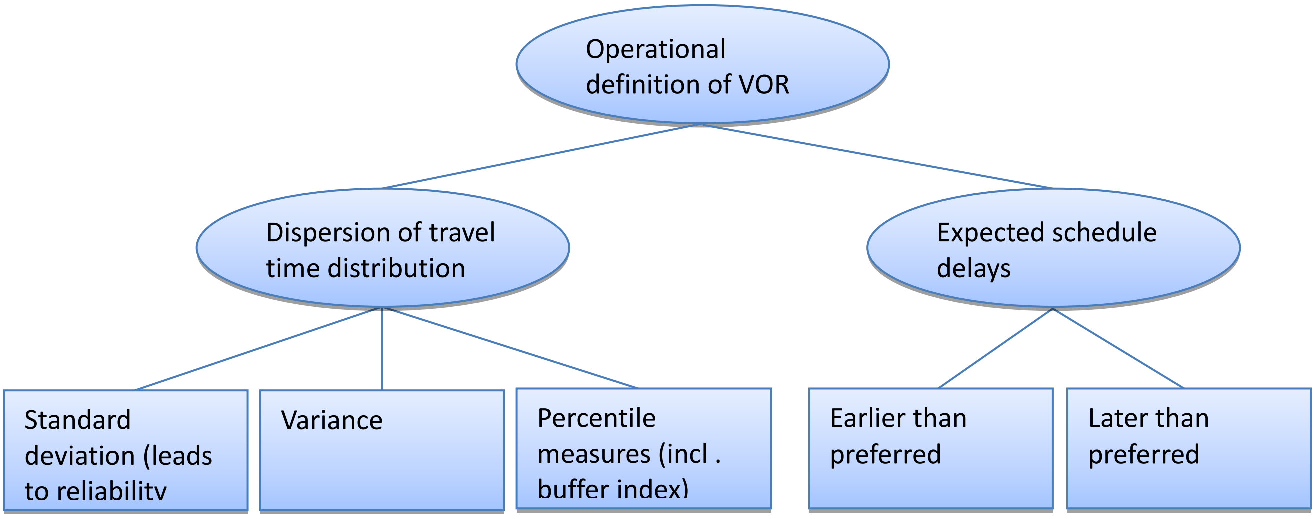

Figure 5-2: Operational definitions of VOR

There is a reasonable degree of consensus among the experts that for road transport the former definition is to be preferred for use in practical applications in the coming years. This leads to the definition of the reliability ratio, which is the value of reliability expressed as the standard deviation divided by the value of time. For rail transport (and other scheduled services) some argue for the standard deviation as well, others prefer to use deviations relative to the timetable. A measure which has elements of both approaches is the standard deviation of lateness (relative to the schedule). This can also be included in a reliability ratio.

For the VOR, the same two components as for the VOT, can be distinguished: the cargo (shippers) component and the transport cost (carriers) component. However, for the VOR, studies usually attempt to determine the sum of both components, since no transport time variability is included in the transport cost in CBAs that we know about.

Similarly to what was said for the cargo component of the VOT, for the VOR the preferred method is to carry out a specific SP study. Most studies so far employed the basic MNL method.

The overall impact of reliability on the carriers has been found by some recent studies to be very limited (not significantly different from 0). But a significant impact on the shippers (comparable to the cargo component of the VOT) has been found. The relative size of this shipper VOR to the shipper VOT reliability ratio) and of the total VOR to the total VOT varies a lot between studies and presumably between commodity types, but a conservative estimate would be a reliability ratio (for the total VOR and VOT) of 0.2 for rail transport (or 0.8 for the shipper component only).

This conservative estimate (that is in line with the latest Dutch results on the VOR) could be used here to give a reliability surcharge on the time benefits (e.g. as a last resort), but using the German results might be more attractive (should they not be considered too high or too low, which requires testing for specific projects as examples in task 4), since: they provide more distinction between commodities, use variables that the sector can provide and understand (% on time and hours delayed) and it would be good to distinguish between projects that focus on time savings and projects that focus on reliability (i.e. not assume these are proportional). The Norwegian results (for two commodity groups) for the value of expected delay could also be used here, but these values seem to be unusually high.

6. Review of freight transport and logistics cost functions used in various European countries

6.1 Different cost components and their time sensitivity in the short and long run

In value of time research in freight transport one needs to find the "time-marginal transport cost": the transport costs that will change when the amount of transport time changes. This is the derivative of the total logistics cost function with respect to transport time (the standard marginal cost approach is about the derivative with respect to a unit of transport services, say measured in tonne-kilometres).

The total logistics costs consists of:

- transport staff cost (e.g. train drivers)
- energy costs (e.g. diesel)
- vehicle costs
- overhead costs (e.g. office space and administrative staff).

These are all costs that carriers incur (=transport cost), but the total logistics costs also comprise:

- the deterioration of the goods
- the interest costs on the value of the goods during transport
- the costs of having a reserve stock for safety.

The last three items then relate to the cargo component of the VOT.

Furthermore, in the total logistics costs we have:

- the interest and storage costs of the standing inventory
- order costs per shipment.

The costs used in factor costs methods only refer to the costs of the carriers (the full transport costs). These are also the costs that are presented to respondents (both for shippers and carriers) in stated preference experiments when asked to trade off time and cost. Therefore, when also including the cargo component in the value of time, the trade-off ratio of the VOT taken relative to the transport cost may in principle exceed 1. For most commodities however, deterioration, interest and safety stocks will be very limited, and the maximum for the trade-off ratio will not be substantially higher than 1, with an actual trade-off ratio that might be equal to or smaller to 1. An important question is whether all elements of transport cost are time-marginal. This is discussed below.

In several countries, freight values of time are based on the factor cost and various assumptions are used regarding the costs that should be included in the value of time: e.g. only the transport staff cost, or all transport costs minus overheads. The basic idea here is that if transport time decreases, carriers will have their vehicles and staff back earlier and can (in the long run) either reduce costs or use the vehicles and staff for other assignments. So vehicle costs (such as depreciation and insurance) and wage cost can be regarded as time-marginal and be included in the full VOT (that is used for the long run).

An argument for not including energy (fuel) costs savings in the VOT is that most transport projects nowadays are carried out to reduce congestion, not to reduce transport distances: there are time gains, but the project does not change the fuel costs. But even if a project does lead to shorter routes, it may be better to evaluate these fuel cost benefits separately, as is done in the UK, and not include these through the time gains. Including these costs changes (brought about by some transport project) in the CBA as changes in transport costs and as time benefits is a form of double counting that should be avoided.

Similarly there are valid arguments for not including track access charges in the time-marginal cost. It is unlikely that a transport time saving will reduce the track access charges. There is no mechanism that translates time gains to a reduced need for rail access or lower unit charges (which does exist for time gains and staff and vehicle use). So it seems best to exclude rail access charges from time savings and treat energy costs savings as a special component in the CBA besides time gains.

But even taking these exceptions into account, It can happen in practice that the trade-off ratio for transport time versus transport costs will be smaller than 1, because it may be difficult for firms to convert the time gains fully into cost reductions or additional revenues. The time gain for instance could be too small to use for other transport activities, or additional work for a transport firm can only be realised against high costs (marketing, discounts), taking into account that the volume of transport services is not very price elastic (because the demand for transport largely depends on product markets). Furthermore there are regulations in the opening times of firms at the origin and destination, on driving and on sailing times and on labour contracts, that prevent full flexibility in using time gains productively for other transports or for reducing costs. In the longer run, which is the proper perspective for CBA of transport infrastructure, there will be more possibilities for reorganising logistics and therefore to reduce costs or increase output to benefit from time savings.

The imperfect flexibility (or kinked production function or cost function) argument will be more relevant for train, inland waterways and sea transport, since these modes have larger indivisibilities (large vehicle and vessels that are used for trips that take a long time, possibly also with slot allocation). Also for the products transported using these modes, which generally have a lower value per tonne than products transported by road and air transport, the cargo component in the VOT will be relatively small.

Therefore in the long run we expect that the trade-off ratio between the value of time and transport costs (excluding fuel cost) for road transport will be around 1. Those for other modes, including rail transport, may be somewhat smaller, but in the long run these too should not be very far from 1.

The monetary transport time gain in a certain year in the future consists of a P (price: the VOT) times a Q (quantity). If the transport volumes increase over time, Q will increase each year (based on interpolation, since the transport models are only run for a very limited set of years).

The P-part itself will consist of the trade-off ratio TR times the factor cost (per hour). If the transport costs increase with time, the factor cost will increase each year.

So, in a CBA, both Q and the factor cost need to be calculated for each year after the introduction of the new infrastructure that is evaluated. Using a different TR for each of those years then poses no extra complication.

It is sensible to assume that 10 years after the introduction of the project the maximal TR will be attained: all reactions of the freight sector have then been implemented.

In The Netherlands, in practical CBA, the official recommendation now is using the minimal TR for year 1 and the maximal TR for year 10 (and after), and a linear interpolation in between.

The question then is which values should be used for the minimal and maximal TR. For the minimal TR it was recommended to take the value from the SP (Significance et al., 2013), see Table 4-1 (e.g. 1.2 euro/tonne/hour for all goods). The maximum could in principle even exceed the factor costs per hour (because of the VOT component from the cargo itself), but this additional component usually is quite small, whereas it may also be difficult to reduce the transport costs all the way to zero to benefit from transport time gains, even in the long run. The official recommendation in The Netherlands now is using TR=1 as the maximum for the VOT, for year 10 and later. So after 10 years, the time gains are the full transport costs per hour (energy cost or trail access charges are not subtracted, but there is much to be said for excluding these from the factor cost; in The Netherlands these happened to be of a similar size as the cargo component).

In the following sections, several examples of the freight transport cost models are explained in more detail. The first example is the cost calculation used in the NEAC10 model, followed by Dutch, EU-wide and Belgian examples. These costs functions in the first place serve as inputs to transport forecasting models. Especially (but not exclusively) the modal split models within these transport models react to input on the transport costs by mode. However, in the CBA, such transport costs functions can (and are) also be used directly to compute time and energy cost benefits. Some costs models (e.g. those of NEA/Panteia for road and inland waterway transport) are even used by firms in the transport sector as an indication of the freight rates that would be appropriate (that might form the starting point for negotiations on the rate between shipper and carrier) In the final sub-section of this chapter we discuss how various types of transport projects (e.g. speed increases, longer trains, electrification) will affect the logistics cost function.

6.2 NEAC10 Cost Model

NEAC10 is the latest version of a freight transport model for Europe, developed and owned by NEA (now Panteia). It is in some ways similar to TRANSTOOLS, but should be regarded as an independent model. Cost functions and unit values by mode are used as input to this model. The cost formula is generic for different modes, consisting of five basic elements:

- Track or infrastructure
- Traction or haulage
- Equipment; wagons, containers etc.
- Terminals or transhipment/loading points
- Service

For road or rail, these elements would be:

	Road Network	Rail Network
Track	Road tolls	Infrastructure/track charges
Traction	Haulage	Locomotive
Equipment	Trailer	Wagon hire
Terminals	Loading/Unloading	Loading/Unloading
Service	Profit margin	Profit/Subsidy

Cost items are termed "Variable" if they depend on distance, and "fixed" if not. Costs such as wages and capital costs are considered fixed because they are time based rather than distance based.

6.3 Road Costs

An example is provided showing how road costs are calculated for a given journey:

Cost Item	Basis	Example	Example Rate
Track Variable	Per Km	Road Toll	0.05€/km
Traction Variable	Per Km	Haulage. Mainly (95%) fuel	0.35€/Km
Traction Fixed	Per Min	Haulage, including wages and capital costs.	0.50€/Min
Equip Variable	Per Km	Wear and tear on trailer.	0.03€/Km
Equip Fixed	Per Min	Capital costs of trailer.	0.04€/Min
Terminals Fixed	Per Load	Hours spent waiting, loading and repositioning.	150€ per HGV load.
Service Fixed	Per Min	Profit margin	0.25€/ Min

Thus a complete journey of 1000km, at an average speed of 50kph, implying a door to door time of 20 hours (1200 minutes) would cost:

Table 6-1: Example road costs for 1000km/1200min trip

Cost Element	Calculation
1) Track	1000km * 0.05 = 50€
2) Traction Variable	1000km * 0.35 = 350€
3) Traction Fixed	1200**min** * 0.50 = 600€
4) Equipment Variable	1000km * 0.03 = 30€
5) Equipment Fixed	1200**min** * 0.04 = 48€
6) Terminal Fixed Costs	150€
7) Service	1200**min** * 0.25 = 300€
TOTAL per HGV door to door	€1528
Rate per Km	1.528€/km
Rate per HGV per Hour	€76.40 per HGV/Hr
Time related elements: (3)+(5)+(6)+(7)	€47.40 per HGV/hr

The model estimates that a HGV journey of 1000km and 1200 minutes (average 50kph) would cost €1528. Under one interpretation this could be expressed as €76.40 per hour (similar to the rates estimated in the UNITE project). However, since some elements, such as fuel consumption, depend on distance rather than time, the time-related costs (items 3, 5, 6, and 7) might be separated out, giving an estimate of €47.40 per HGV/Hr.

6.4 Rail Costs

Estimating a single value for rail costs between two regions is less straightforward than the road example. While it is possible to assume that most long distance road transport takes place using standard 40 tonne or 44 tonne lorries and broadly comparable tractor-trailer combinations, there is greater variation for rail. In NEAC10, rail is treated as a homogenous mode, without any differentiation between bulk and unitised transport. Cost estimations are based on unitised rail freight (containers and swap-bodies), since these are most relevant for modal shift, and these rates are applied to all forms of rail freight. The costs are expressed as costs per forty foot equivalent (FEU), which has approximately the carrying capacity of a 40-44T road trailer.

The most important assumptions underlying the cost function are:

Cost Element	Assumption
Train Type	Combined transport: unaccompanied forty foot (12m) freight unit.
Train Length	600 metres trailing length. 30 Wagons (each one can hold one FEU and one TEU)
Average Load	24 FEU (approx. 400 tonnes)
Avg Loco Km per Year	150-200000
Track Cost	Typically 0.05 to 0.15 Euro per FEU km (1.20 EUR to 3.60 EUR per train km)
Traction Cost	Typically: 8 to 12 Euros per FEU per hour (around 240 Euro per train hour), PLUS 0.1 Euros per FEU per km (around 2.4 Euro per train km)
Wagon Hire Cost	Typically around 1 Euro per FEU per hour
Terminal Cost	Typically around 50 Euro per lift (load or unload)
Service/HQ Cost	Typically around 10 Euros per FEU

For a journey of 1000km, taking 36 hours terminal to terminal, with four additional hours required for train preparation (thus 40 hours/2400 min in total), the cost would therefore be:

Table 6-2: Example rail costs for 1000km/2400min trip

Cost Element	Rate	Cost per FEU	Cost per Train
1) Track	0.1 EUR per FEU km	100 EUR	2400 EUR
2) Traction fixed	10 EUR per FEU **per hour**	400 EUR	9600 EUR
3) Traction variable (per km)	0.1 EUR per FEU per km	100 EUR	2400 EUR
4) Wagon Hire	1 EUR per FEU **per hour**	40 EUR	960 EUR
5) Terminal Cost	50 EUR per lift	100 EUR	2400 EUR
6) Service Cost	10 EUR per FEU	10 EUR	240 EUR
TOTAL Costs (EUR)		750 EUR	18000 EUR
Cost Per Km		0.75 EUR per Km	18 EUR
Cost per TKm		0.05 EUR per Tkm	
Cost per FEU per Hour		18.75 EUR per Hour	
Time related elements: (2)+(4)+(5)+(6)		13.75 EUR per Hour	

Total costs per FEU per hour are estimated to be €18.75, with the time-based elements accounting for €13.75. This is approximately a quarter of the road cost per hour for a trip of this length (the road trip takes half the time; the cost per trip per FEU for road is half that for rail here).

6.5 Inland Waterway Costs

Waterway costs also are calculated with a degree of simplification. Apart from differentiation arising from different modes of appearance (liquids, dry bulks, containers), costs will vary significantly according to vessel size. So whereas it is possible to make reasonable assumptions about typical lorry weights and train lengths, it is important to be able to handle different vessel configurations for waterways. One of the relatively recent additions (2015) to NEAC-10 has been to include different cost structures for different CEMT class vessels. The example below is for a CEMT IV container barge for a 1000km trip taking 100 hours (avg. 10kph). Costs are estimated per FEU.

Table 6-3: Example waterway costs for a 1000km trip (CEMT 4)

Cost Element	Rate	Cost per FEU	Cost per Vessel
1) Track	0.013 EUR per FEU km	13 EUR	351 EUR
2) Traction fixed	2.94 EUR per FEU per **hour**	294 EUR	7929 EUR
3) Traction variable (per km)	0.143 EUR per FEU per km	143 EUR	3872 EUR
4) Wagon Hire (N/A)			
5) Terminal Cost	50 EUR per lift	100 EUR	2700 EUR
6) Service Cost	10 EUR per FEU	10 EUR	270 EUR
TOTAL Costs (EUR)		560 EUR	15122 EUR
Cost Per Km		0.56 EUR	15 EUR
Cost per TKm		0.037 EUR	
Cost per FEU per Hour		€5.60 per Hour per FEU	
Time related elements: (2)+(5)+(6)		€4.04 per Hour per FEU	

A summary comparing road, rail and waterway costs, expressed as a rate per HGV or FEU unit per hour is shown below. The cost per trip per FEU varies less between modes, as the transport time between modes varies quite a lot.

Table 6-4: Summary of Costs per Truck/FEU per Hour in NEAC10

Mode	Cost per FEU/Hr – all costs.	Cost per FEU/Hr – only time-related elements.
Road	€76.40	€47.40
Rail	€18.75	€13.75
Inland Waterway	€5.60	€4.04

Based on a hypothetical 1000km trip.

These can also be compared with the TEN-STAC figures (these are at the European level), which were in-turn based upon the UNITE project. Overall, if the simplest definition of cost per hour (total cost/ total hours) is used, the numbers appear to be broadly similar. TEN-STAC also quoted a cost per tonne-hour of €1.64 to €12.10 for air cargo, but this appears to be an underestimate.

Table 6-5: Summary of Costs per Truck/FEU per Hour in TEN-STAC/UNITE

Mode	Cost per FEU/Hr
Road	€76.99
Rail	€17.00
Inland Waterway	€4.00

Figures quoted originally as costs per tonne per hour have been multiplied by 12.5 tonnes per HGV/FEU. Based on the figures quoted for the Netherlands.

6.6 Dutch cost models

For national and international transport cost analysis for the Netherlands, Panteia regularly present reports per surface modality (road: Panteia, 2014, rail: NEA, 2008 and inland waterways: NEA, 2009; also see NEA et al., 2003) and its developments over years (http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2011/11/01/kostenbarometer.html). These cost analysis are used for several Dutch and international cost benefit analyses (CBA). For all three modes, the structure of the cost components are chosen similar to each other. In Table 6-6 below the cost components are listed:

Table 6-6: Transport and infrastructure cost components used in Dutch transport cost analysis

	Inland waterways	Rail	Road
Vessel/vehicle characteristics; Mode of appearance	- Vessel size (33 classes) - Mode of appearance (4 classes: Container, Dry bulk, Liquid bulk, General Cargo) - Type of route: National/international - Operational hours (4 types: dag, semi-continu, continu and alleenvaart)	- Type of locomotives (Electric, Diesel) - Type of wagons (3 types: Containers, Hoppers, General Cargo)	- Type of route: National/International - Vehicle type (4 types: - Container, Trailer, Dry bulk, Liquid bulk (tank))
Fixed costs (annual cost)	- Repairs and maintenance (50%) - Insurance - Staff - Depreciations - Interest costs - Other costs	- Repairs and maintenance (50%) - Insurance - Staff - Depreciations - Interest costs - Other costs	- Repairs and maintenance (50%) - Insurance - Staff - Depreciations - Interest costs - Other costs
Variable costs	- Repairs and maintenance (50%) - Fuel cost [per km] - Infrastructure cost - Port fees - Canal tolls	- Repairs and maintenance (50%) - Traction cost - Electricity - Diesel - Infrastructure cost - Access Charges (database Europa)	- Repairs and maintenance (50%) - Fuel cost - Infrastructure cost (toll)

Source: Panteia

Besides the transport and infrastructure costs mentioned above, the loading and unloading costs, storage costs and handling costs should be taken into account for the total cost calculation and comparison. In most cases, assumptions are made to cover the mode specific costs.

The rail freight transportation costs are usually calculated per route (corridor), when country specific costs are distinguished. For example, NEA (2008) distinguishes three different locomotive types: one standard is chosen for The Netherlands and Belgium, one standard for Germany, France, Austria and Switzerland, and one standard for Italy. The cost function consist of five main components similar to the elements used in NEAC-10 model, namely:

- Locomotive costs [in NEAC-10: included in traction/haulage cost]
- Wagon costs [equivalent to equipment cost]
- Infrastructure (access) costs [equivalent to track/infrastructure cost]
- Energy costs [included in traction cost]
- Labour costs [not in NEAC-10 as separate element]

Another example of a Dutch study (database) with mode specific cost components is VKM (**V**ergelijkings**k**ader **M**odaliteiten: NEA, 2004). This research was done for the Dutch Ministry of Transport and it is a tool aimed at policy makers to compare transport chains consisting of different modes of transport. This tool contains cost estimates per vehicle -hour, vehicle-km or hour for 6 transport modes (road, rail, inland waterways, short sea, pipeline and air transport). The cost estimates from the VKM were used to set up the base year data for several national and European transport models, for example: NEAC (Europe), TRANSTOOLS (Europe) and BASGOED (The Netherlands). The main elements used within the transport models are:

- Average fixed costs (€/vehiclehour) – includes all fixed cost components as mentioned in Table 5-6
- Average variable costs (€/vehiclekm) – includes e.g. repairs and maintenance cost
- Average energy costs (€/vehiclekm) – based on the annual fuel cost
- Average loading and unloading costs (€/hour)
- Average waiting costs (€/hour)

The tool contain different indicators from which the user is able to execute cost per mode comparison and cost calculation for a transport chain.

These cost estimations cover the freight-carrier's value of time related components and there is discrepancy in mode of appearance (dry bulk, liquid bulk, containers or general cargo). However, in terms of the freight-buyer's value of time, this database give not enough coverage since no cost estimates included which related to the goods themselves.

Table 6-7: Indicators and units used in VKM

Transport indicators		Economic indicators		Externalities		
Indicator	Unit	Indicator	Unit	Indicator	Unit	
					number	**value**
Transport characteristics		*Transport costs*		*Safety*		
Total tonnage	Ton	Fixed	Euro / hour	Fatalities	number / vehiclekm	Euro / vehiclekm
Transport performance	Tonkm	Variable	Euro / vehiclekm	Injured	number / vehiclekm	Euro / vehiclekm
	Vehiclekm	Energy	Euro / vehiclekm			
		Loading and unloading	Euro / vehicle	*Emissions*		
Vehicle characteristics		Waiting	Euro / vehicle	CO_2	gram / vehiclekm	Euro / vehiclekm
Engine	KW			NO_x	gram / vehiclekm	Euro / vehiclekm
Energy usage	MJ / vehiclekm	*Infrastructure*		NMVOS	gram / vehiclekm	Euro / vehiclekm
Annual mileage	Vehiclekm	Construction	Euro / vehiclekm	PM_{10}	gram / vehiclekm	Euro / vehiclekm
		Maintenance	Euro / vehiclekm	SO_2	gram / vehiclekm	Euro / vehiclekm
Transport time				CO	gram / vehiclekm	Euro / vehiclekm
Main transport	Hour					
Pre- and end haulage	Hour			*Other*		
Loading and unloading	Hour			Noise		Euro / vehiclekm
Waiting time	Hour			Landuse	m2 / vehiclekm	Euro / vehiclekm
Mandatory rest break	Hour					

Source: VKM 1.0

6.7 Transport costs functions in the TRANSTOOLS freight modal split model

Within TRANSTOOLS the factors cost and time, are used as the main determinants of mode choice within the freight modal-split model. These factors are quantified with data from a study performed by NEA (2004) that constructs a comparison framework for modalities (also see section 6.6). This report holds information on costs, times and load factors for freight transport in Europe. The data in this comparison study is specified for vehicle type and manifestation. The reported manifestations are dry bulk, liquid bulk, container and general cargo and the vehicle types are for every modality a range of vehicles of different sizes. This distinction is made because distinct manifestations and vehicles have different transport characteristics.

In TRANS TOOLS the data on transport flows is divided into commodity groups, not manifestations and vehicle types so data from CBS[1] (1999) and Comext[2] (2000) is used to convert the

[1] Centraal Bureau voor de Statistiek = Statistics Netherlands.

[2] Eurostat reference database containing external trade statistics.

manifestation and vehicle type specific data to commodity group specific data. These conversions are schematically displayed in Figure 6-1:

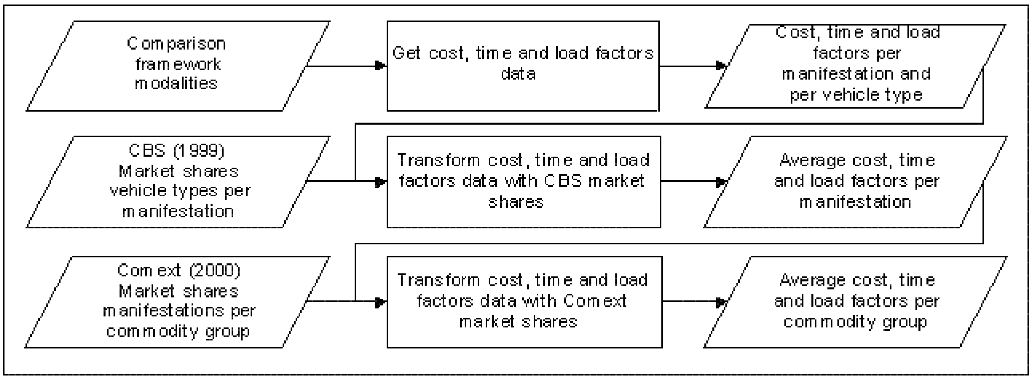

Figure 6-1: Schematic view of the conversion of the cost, time and load factors data.

The CBS data gives market shares of vehicle types per manifestation and is used to convert the data from manifestation and vehicle type specific data to only manifestation specific data. The Comext data offers market shares of manifestations per commodity group and converts the manifestation specific data to the required commodity group specific data. The conversion of the data is based on preceding research for the NEAC modal-split model. These data sources are on European level, they are not available on regional level everywhere. Also it would be a lot more laborious to use regionally specified data for the cost and time functions that are used to compute the factors transport cost and time for all origin-destination pairs for every mode and commodity group. Thus the average transport costs, time and load factors per commodity group are calculated as described above and no zone- of country-specific transport costs are used[1]. All the data is representative of the base year 2000.

To make the transport costs comparable across modes they are calculated per tonne. For this purpose the load factors are used. The available load factors are the average loading capacity, the average load as a fraction of the capacity, and the average number of loaded trips as a fraction of the total number of trips. The multiplication of these last two fractions is called the load rate. The average loading capacity multiplied by the load rate gives the average number of tonnes per vehicle. The total cost per vehicle divided by this average number of tonnes per vehicle is the total cost per tonne.

The transport costs, the costs of door-to-door and possibly inter-modal transport, consist of four components:

- Line haul costs
- Loading / Unloading costs
- Transhipment costs

[1] In TRANSTOOLS3, which is developed at the moment for DGMOVE, there is differentiation between countries for road costs, since the driver cost and the diesel costs vary substantially between countries. Also, road infrastructure fees and rail infrastructure charges are treated as country–specific. The remaining road transport costs (e.g. for the depreciation of the vehicle) and the transport costs for the other modes, including rail transport (except the rail access charges), are assumed to be the same in all European countries.

- Mode specific costs

The line haul costs are the costs that occur during the actual movement of the transported goods. These can be separated into fixed and variable costs.

The fixed costs consist for the various transport modes consist of administrative, depreciation, insurance, interest, labour, and vehicle costs. The fixed costs per tonne per hour show that the commodity groups with relatively high capacity and load percentages are relatively cheaper per tonne, because the average number of tonnes per vehicle is higher.

For all modes, the variable costs (km variable) consist of repair and maintenance costs and variable depreciation and insurance costs. The energy costs are also variable and are separately reported in the data.

To calculate the line haul cost per tonne, the distance and average speed are also needed. Because the fixed costs are per tonne per hour, these costs have to be multiplied by the number of hours. The number of hours is calculated by dividing the distance, which is available for every origin-destination relation, by the average speed.

The loading / unloading costs consist of all the, for transport relevant, costs that occur during the loading, unloading and the possible waiting before, during and after loading and unloading. This boils down to the fixed costs per vehicle per hour multiplied by the hours the vehicle is not on the way: the sum of the average loading, unloading and waiting times. This includes all the time it takes to do the actual loading and unloading, sorting, unitisation, packing, unpacking and waiting.

The transhipment costs are the extra loading / unloading costs caused by the change of a carrier (mode, vehicle) within the transport chain. Basically a transport chain with transhipment is just two consecutive direct transport chains: the first from origin to transhipment region on the first mode of transport, the second from transhipment to destination region on the second mode of transport. For the calculation of the total cost for a transport chain with transhipment, the total cost of the direct parts of the chain is calculated and added up.

There are some other costs that do not always occur. These mode specific costs are toll costs and the cost of mandatory rest breaks for road transport and connecting transport for the other three modes.

In several countries a toll fee has to be paid for the use of the main motorways. A traffic assignment software package is used to calculate the toll cost for every O-D relation. For transport from every origin to every destination the best route is assigned by the program and the toll costs for the used roads is given as an output. These toll costs are added to the total cost per vehicle.

Road traffic regulations in Europe impose that professional drivers (trucks and coaches) take rest breaks after driving for several hours. It is assumed that the costs of driving with two drivers who can alternately drive and rest are approximately equal to the costs of taking a rest break. The costs of rest breaks are calculated in the freight modal-split model and are not added to the cost and time in the Level of Service Matrices (LoS).

For the other three modes of transport not all origins and destinations of transport are connected to the network. Not every sender is located in a port and not every recipient has his own rail terminal. So in order to use rail, inland waterways or sea transport they need connecting transport. This is transport by road between senders, receivers and ports or terminals. When the origin or destination region is not connected to the network of the used mode of transportation, there is always interregional connecting transport. In this case the nearest region that is connected is considered an extra point of transhipment. The part of the transport chain between this new transhipment region and the non-connected region has road as transport mode. In this case there are no connecting transport costs added to the chain but the costs are calculated for the new chain with extra point of transhipment within the freight modal-split model.

In case the origin and destination are connected to the network of the used mode of transportation there is a possibility for intraregional front and end connecting transport, respectively. The probability of intraregional connecting transport depends on the transport mode, commodity group, volume of transport, and origin/destination region. The probability can also differ for front and end connecting transport. These connecting transport costs are calculated within the freight modal-split model.

The total cost is calculated per tonne for a given combination of O-D relation, commodity group and the mode of transport. If the transport chain has transhipments the total costs are calculated as the sum of maximally three parts of the chains. The three parts of the chain are transport before the first transhipment, transport between the transhipments, and transport after the last transhipment. Here a description of the cost functions used to calculate the cost for the parts is provided. The costs of the different parts are added together within the freight modal-split model. The input is the LoS for the parts of the chain and the same cost functions are valid for all parts of the transport chain.

The formula for transport cost is:

$$TC_{c,m,od} = \left(\frac{fc_{c,m}}{lr_{c,m} \cdot lc_{c,m} \cdot s_{c,m,od}} + \frac{vc_{c,m} + ec_{c,m}}{lr_{c,m} \cdot lc_{c,m}} \right) \cdot d_{m,od} + \frac{tf_{m,od}}{lr_{c,m} \cdot lc_{c,m}} \qquad (6\text{-}1)$$

Where:

$d_{m,od}$: distance (km) for mode *m* for origin and destination pair *od*
$ec_{c,m}$: average energy cost (€/vehicle km) for mode *m* carrying commodity group *c*
$fc_{c,m}$: average fixed cost (€/vehicle hour) for mode *m* carrying commodity group *c*
$lc_{c,m}$: average load capacity (tonne/vehicle) for mode *m* carrying commodity group *c*
$lr_{c,m}$: average load rate for mode *m* carrying commodity group *c*
$s_{c,m,od}$: average speed (km) of mode *m* carrying commodity group *c* for origin and destination pair *od*
$TC_{c,m,od}$: Transport Cost (€/tonne) for mode *m* carrying commodity group *c* for origin and destination pair *od*
$tf_{m,od}$: toll fee (€/vehicle) for mode *m* for origin and destination pair *od*
$vc_{c,m}$: average variable cost (€/vehicle km) for mode *m* carrying commodity group *c*

The formula for loading and unloading cost is:

$$LUC_{c,m} = \frac{\left(lt_{c,m} + ut_{c,m} + wt_{c,m}\right) \cdot fc_{c.m}}{lr_{c,m} \cdot lc_{c,m}} \qquad (6\text{-}2)$$

Where:

$fc_{c,m}$:	average fixed cost (€/vehicle hour) for mode *m* carrying commodity group *c*
$lc_{c,m}$:	average load capacity (tonne/vehicle) for mode *m* carrying commodity group *c*
$lr_{c,m}$:	average load rate for mode *m* carrying commodity group *c*
$lt_{c,m}$:	average loading time (hour) for mode *m* carrying commodity group *c*
$LUC_{c,m}$:	Loading / Unloading Cost (€/tonne) for mode *m* carrying commodity group *c*
$ut_{c,m}$:	average unloading time (hour) for mode *m* carrying commodity group *c*
$wt_{c,m}$:	average waiting time (hour) for mode *m* carrying commodity group *c*

6.8 Transport costs in the Strategic Freight model for Flanders

The cost functions used in the mode and vehicle type choice model of this model system (Grebe et al., 2015) include transport time dependent cost, transport distance dependent cost, toll fees, resting periods, as well as costs for loading, unloading and transshipment. The general formula is:

$$Costs = \tilde{\alpha} + \beta_1 \cdot t_1 + \gamma_1 \cdot d_1 + \tilde{\Delta} + \beta_2 \cdot t_2 + \gamma_2 \cdot d_2 + \varepsilon . \qquad (6\text{-}3)$$

- $\tilde{\alpha}$ is the sum of the loading costs α_1 in the origin zone and the unloading costs α_2 in the destination zone. We assume that loading and unloading costs are equal and only depend on the vehicle type. As time and distance costs scale linearly, threshold effects are also incorporated in the costs for loading and unloading.
- β_1 and γ_1 are the time and distance dependent costs for rail or IWW. They are multiplied with the transport time t_1 and transport distance d_1 with one of these modes. The times and distances are vehicle type dependent.
- $\tilde{\Delta}$ are the transshipment costs for intermodal transports. In the model the assumption is made that these costs have to be paid once if the origin or destination zone is a harbor and otherwise twice. This implies that non-harbor zones require pre- and post-carriage by road transport.
- β_2 and γ_2 are the time and distance dependent costs for road transport (either direct or serving as access to and egress from rail or IWW). They are multiplied with the transport time t_2 and transport distance d_2 with this mode. Road user charges ε can add to the transport cost of the road shipment. The distances and times are vehicle type dependent.

For direct trips the equation simplifies:

$$Costs = 2 \cdot \alpha_{1,2} + \beta_{1,2} \cdot t_{1,2} + \gamma_{1,2} \cdot d_{1,2} \left(+\varepsilon\right). \qquad (6\text{-}4)$$

The cost functions are determined based on data from studies in Scandinavia, the Netherlands and Belgium. In addition to the determination of the $\alpha, \beta, \gamma, \Delta$ and ε special attention has been given to also determine the shares of fuel, taxes, personal, insurances and other important contributions to the total costs per hour and per km. This is important in the forecast of future years and for the simulation of policy effects. An overview of the unit cost inputs per ton is given in Table 6-8.

Table 6-8. Overview of the cost indicators (in Euro per ton) for 2010 in the cost functions of all transport modes in the freight model. The two vehicle types with the addition (co) are trucks with containers.

	Category	Capacity	β	ϒ	α	Δ
Road	Van	1.5	20.087	0.086	14.400	14.400
Road	Small truck	12	3.128	0.019	2.700	2.700
Road	Small truck (co)	12	2.954	0.019	2.167	1.500
Road	Large truck	27	1.741	0.014	1.481	1.481
Road	Large truck (co)	27	1.656	0.014	1.541	0.970
IWW	dry bulk	600	0.163	0.004	0.800	
IWW	Wet bulk	600	0.171	0.004	1.000	
IWW	Container	600	0.120	0.004	0.600	
IWW	Dry bulk	1350	0.090	0.002	0.700	
IWW	Wet bulk	1350	0.111	0.002	0.800	
IWW	Container	1350	0.071	0.002	0.500	
IWW	Dry bulk	2000	0.075	0.002	0.654	
IWW	Wet bulk	2000	0.095	0.002	0.754	
IWW	Container	2000	0.060	0.002	0.454	
IWW	Dry bulk	4500	0.058	0.001	0.600	
IWW	Wet bulk	4500	0.077	0.001	0.700	
IWW	Container	4500	0.047	0.001	0.400	
IWW	Dry bulk	9000	0.038	0.001	0.600	
IWW	Wet bulk	9000	0.050	0.001	0.700	
IWW	Container	9000	0.031	0.001	0.400	
Rail	Carriage	501	0.898	0.021	1.500	
Rail	Intermodal	765	0.598	0.014	1.500	
Rail	Block train	765	0.598	0.014	1.435	

The capacities and the cost indicators take the average load factors into account. All costs have to be paid for integer numbers of vehicles, wagons or containers. For road transport the minimum shipment size is one truck. For (wet en dry) bulk ships it is the capacity of a ship. For container ships and intermodal rail transport costs are per containers of 12 tonnes. Carriage trains have a minimum shipment size of 20 tonne (one wagon) and for block train only whole trains can be booked. Note that for intermodal shipments (IWW and rail) the road transport part is exclusively with heavy trucks (with containers) in the model.

For IWW the model distinguishes direct and intermodal shipments. For intermodal shipments the cost indicators of container ships are applied. For direct transport, the assumption is made that all NST classes except 2, 7 and 8 are dry bulk goods. For the other three classes we assume a mixture of wet and dry bulk with percentages of 50% (NST 2), 75% (NST 7) and 100% (NST 8) wet bulk.

6.9 How do rail transport projects impact on transport costs?

JASPERS is involved in the appraisal of all kinds of different projects in the rail sector. Many of these projects have impacts on transport costs. Cost functions as presented above can provide guidance on which and how transport costs will be affected by the projects, and also by how much (though not all cost structures are equally useful for this). We will work out recommendations on this in task 4 of this project (e.g. based on work we did in Trans-Alpine projects). More in general terms, one can distinguish the following types of projects and their impacts on transport cost (and/or speed, reliability, damage):

- Increasing train length – affects cost via productivity calculation – i.e. how many tonnes per train (the link-based transport costs of a train are divided by more tonnes, so the cost per tonne is reduced). On the other hand larger shipments would also lead higher inventory costs.
- Electrification affects traction costs and also train speed, so can lead to transport costs and time benefits (there might also be an impact on transport time reliability, but even the sign of that is difficult to give) .
- Increase maximum axle loads – may not be so relevant for intermodal trains, but could be for bulk trains (then the effect is again more tonnes per train, see above) – these categories are separated in some cost models and modal split models.
- Increase train speed: reduces time-based transport costs (which could be handled separately in the CBA as transport costs, or be part of the time benefits) and cargo-based costs such as interest on the capital in transit (which will be in the time benefits).
- Improving the railway infrastructure and its maintenance to modern standards in specific corridors, will enable trains with more loading capacity and faster train (see the effects above) and improve transport time reliability.
- Improve the prioritisation for specific freight trains: this will reduce the time (see above), but also improve reliability of transport time.
- There might also be measures/projects that reduce the probability that the goods will be damage/lost (better equipment, particularly for loading/unloading and for packaging, closer monitoring).

6.10 Conclusions on transport costs

Transport cost functions are available for several countries, either for monitoring/guideline purposes or as input for transport modelling. There is no serious disagreement in the literature on form of the transport cost functions and its components. The numerical values however vary considerably, also for relatively comparable countries and even within countries. It is not clear whether this reflects differences that exist in practice or that these differences are due to the methods used in the various studies. In this report we have presented various approaches and outcomes for the EU and for The Netherlands and Belgium. In the CBA of transport projects one has to take care that all relevant components of costs are included but also that these benefits or costs do not overlap with time benefits (through the VOT). A possible mistake would be to include the savings in terms of staff time and vehicle use in both the transport cost savings and the time savings.

7. Mode choice models

This discussion below of model approaches for mode choice is based on the chapters 6, 10 and 11 of the new textbook 'Modelling Freight Transport' (Tavasszy and de Jong, 2014). More detail on mode choice can be found in these chapters. And other components of freight transport models (e.g. generation) are described in the other chapters of the textbook.

7.1 Introduction

7.1.1 Mode choice at different spatial levels

Mode choice or modal split models in freight transport explain the allocation of a given total freight transport demand in an area (or a given OD matrix with total freight flows between origins and destinations) over the available transport modes. What the modes are, depends on the spatial scale.

Most modal split models in freight transport have been developed for interurban (or interregional) transport flows (this includes most national freight models in Europe, state-level models in the US, and even models for Europe or the US as a whole). The modes from which one can choose for this spatial context usually include road and rail transport. Depending on the topography of the study area, inland waterway transport and short-sea shipping can also be choice alternatives (for some of the OD pairs).[1] In a modal split model applied at the OD level, the choice set of available alternatives does not have to be the same for all OD combinations. Good practice in modal split modelling is to exclude infeasible alternatives (such as road transport between an island and the mainland, or inland waterway transport for locations far away from an inland port) from the set of available alternatives.

For the urban context, the only available transport mode usually is road transport. Here it may make sense to distinguish between various types of road transport vehicles (sometimes called 'vehicle choice' as opposed to mode choice).

For intercontinental flows, the available modes are sea and air transport. In terms of tonnes transported, the share of air transport is very small, but it has a substantial share in terms of the value of the goods or the costs of the transport services.

7.1.2 Relevance of modal split

Modal split modelling is not only a vital component of the overall four-or-more-step freight transport model, it is also an important explanatory factor for the emissions of freight transport. Sea and inland waterway transport have generally lower emission rates (though there often is considerable of scope for improvements within these modes) per tonne-kilometre than rail transport, which in turn has a lower rate than road transport (air transport having the highest rate). Examples can be found in Maibach et al. (2008) and Ricardo AEA (2014). But also the requirements on public funding and accident rates vary greatly between modes.

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[1] In principle also pipelines, but because the use of pipelines is so commodity- and location-specific this is hardly ever included in a mode choice model (more often pipeline transport is excluded beforehand).

In many freight transport models, the modal split is the most policy-sensitive demand component, in the sense that it reacts more to changes in transport time and cost than transport generation and distribution (which in some models are not sensitive to policies at all). Network assignment/route choice on the other hand might be more sensitive to such changes. However, a discussion of the possible policy effects in freight transport should not be restricted to modal split, as sometimes happens. International and regional trade flows might be also be sensitive to changes in transport time and costs, and some of the choices that are often ignored in freight transport modelling, such as shipment size choice and the loading rates of the vehicles, can be influenced by transport time and cost. We will come back to these impacts of changes in transport time and costs when discussing the literature on elasticities in freight transport in chapter 7. Some other choices in freight transport, which can be combined with mode choice, are mentioned below.

7.1.3 Dependent and independent variables

The dependent variable in mode choice can be a discrete choice (one of the modes is chosen the other modes are not chosen), when the analysis is carried out at the level of the individual shipment, or a fraction (modal share) within a certain geographic area of for a specific OD flow, when the analysis is carried out at a more aggregate level.

The explanatory variables for modal split can be: transport cost of the available modes (including loading, and unloading cost), their transport time, (sometimes combined into generalised transport costs), the number of trans-shipments, reliability (referring to the degree of on time delivery), flexibility (ability to handle short-term requests), probability of damage during transport, tracking and tracing of the cargo, the harmful emissions and transport frequency offered. However in practice, many modal split models only contain variables on transport costs and time, or even only cost (but including time-based costs). The sensitivity of the modal split to these attributes of the modes can for instance differ between different commodity types (e.g. bulk versus general cargo), shipment sizes, industries, firm sizes, transport equipment used (e.g. containers) and geographic distance.

7.1.4 Disaggregate and aggregate mode choice models

A key distinction in freight mode choice modelling is that between aggregate and disaggregate models. In fact in the context of aggregate models one often speaks about ‘modal split’ and within disaggregate models about ‘mode choice’, but here we use both terms as synonyms.

By ‘disaggregate’ we mean here that the unit of observation is the individual decision-maker (travellers in passenger transport; firms in freight transport) as opposed to ‘aggregate’ models where the units of observation are aggregates of decision-makers, usually geographical zones.

Disaggregate models are much less common in freight transport than in passenger transport (and even in passenger transport many practical models are aggregate). The main reason for this difference is the lack of publicly available disaggregate data on freight transport, which in turn is too a large extent due to the commercial nature of such data. Firms involved in freight transport are often reluctant to disclose information on individual shipments, mode chosen, transport cost, etc...

Within disaggregate freight transport models, the decision that has been modelled most is clearly the mode choice. For this reason, and because a single mode choice yields a relatively easy model, we present he disaggregate choice modelling theory as part of this chapter (section …), using mode choice as the relevant context. The types of models for a single discrete choice that are used most in practice (multinomial logit and nested logit) are described here. For more sophisticated models (ordered generalised extreme value, cross nested logit, mixed logit, latent class, as well as deviations from utility maximisation), we refer to Chapter 6 of Tavasszy and de Jong (2014).

However, the aggregate mode choice model, especially the aggregate logit model, is the most commonly used model for mode choice in freight transport. We think it is best to see this as a pragmatic approach, not as a model based indirectly on a theory of individual behaviour, that however regularly leads to satisfactory results (elasticities, forecasts) at relatively low effort (especially in data collection).

In section 6.2 we discuss disaggregate mode choice models in theory and practice. Section 6.3 treats aggregate modal split models, also with practical examples. In section 6.4 we discuss models that combine mode and route choice at the aggregate level (multimodal assignment models). Section 6.5 discusses some specific models at the European scale. Section 6.6 deals with the interaction between available data and model form and section 6.7 with choice of model form for answering specific questions.

7.2 The disaggregate mode choice model

7.2.1 Cost functions and utility functions

As in most disaggregate mode choice models, we'll start by assuming that the decision-maker is the shipper, a firm that needs to send goods to a receiving firm and therefore has a demand for transport services. Shippers then have a choice to carry out the transport themselves or to contract it out to carriers (or more generally to logistics service providers, that also include firms that integrate services of different carriers for their customers). In practice, these firms in turn can also have a say in the mode choice. So, often in freight transport several firms (shipper, receiver, carriers, intermediaries) are involved in decision-making about the same shipment[1]. Instead of assuming that one of these firms takes the (mode choice) decisions, one could also try to model the interactions between the different parties involved, as joint decision-making. This is a relatively new area in freight transport modelling.

The shipper that we assume decides, makes mode choice decisions for shipments. A shipment is defined as a number of units of a product that are ordered, transported and delivered at the same time. It doesn't necessarily correspond to a vehicle load, because there maybe be several (small) shipments in the same vehicle (consolidation of shipments), whereas a large shipment may require several vehicles.

The alternatives in mode choice can be road transport, rail transport, inland waterway transport, sea transport, air transport and pipeline transport. Furthermore, one could distinguish several vehicle or vessel types within these modes (vehicle type choice). An essential characteristic of all these alternatives is that these are discrete alternatives (as opposed to both continuous choice variables and ordered choice alternatives). The model for this is the discrete choice model.

Discrete choice models at the disaggregate level have originally been developed in passenger transport, where the dominant choice paradigm and theoretical foundation is that of random utility maximisation, RUM (McFadden, 1974, 1978, 1981). The basic equation of the RUM model is:

$$U_{ik} = Z_{ik} + \varepsilon_{ik} \qquad (7\text{-}1)$$

[1] Additionally, lorry drivers often have some freedom to choose the route, or adapt the route when facing congestion.

In which:
U_{ik}: Utility that decision-maker k derives from choice alternative i (k= 1,..K ; i = 1,…,I)
Z_{ik}: observed utility component
ε_{ik} : random utility component.

Utility maximisation belongs to the economics of consumer behaviour, and seems at first sight inappropriate for explaining the behaviour of the firm, where the standard economic paradigm is that of profit maximisation or costs minimisation. However, we can apply the random utility framework to freight transport choices by simply using minus the total generalised transport costs[1] as the observed component of utility and including one or more random costs components to this function:

$$U_{ik} = -G_{ik} - e_{ik} \qquad (7\text{-}2)$$

In which:
G_{ik}: observed component of generalised transport cost
e_{ik}: random cost component.

In eq. (7-2) random costs minimisation becomes random utility maximisation. For the standard discrete choice models with an independent error term and without heteroskedasticity, one might just as well write a + sign in front of e_{ik} .The mode choice mode for freight transport can then be estimated using the same software as for the RUM model in passenger transport. One only has to take into account that an increase in costs leads to a reduction in utility, but is also how transport cost works in the passenger transport model. If one assumes negative coefficient signs for the costs variables, one can also write + G_{ik} in eq. (7-2), as we will do below.

More specifically, for the choice of mode for a specific shipment by decision-maker k, between three alternatives (road, rail and inland waterways IWW), one might specify the following linear[2] utility functions: [3]

$$U_{road} = \beta_0 + \beta_1 \,.\, COST_{road} + \beta_2 \,.\, TIME_{road} + \beta_3 \,.\, REL_{road} + e_{road} \qquad (7\text{-}3a)$$
$$U_{rail} = \beta_4 + \beta_1 \,.\, COST_{rail} + \beta_5 \,.\, TIME_{rail} + \beta_6 \,.\, REL_{rail} + e_{rail} \qquad (7\text{-}3b)$$
$$U_{IWW} = \beta_1 \,.\, COST_{IWW} + \beta_7 \,.\, TIME_{IWW} + \beta_8 \,.\, REL_{IWW} + e_{IWW} \qquad (7\text{-}3c)$$

In which:

[1] The generalised transport costs are the direct monetary costs of transporting goods plus the influence of other qualitative characteristics of the modes (transport time, reliability, etc.) expressed in money units. In a model that also includes inventory considerations (such as the choice of shipment size) one could even generalize further and use total logistics costs (comprising amongst others transport and inventory costs).
[2] Non-linear specifications of the utility function, such as functions with logarithmic or quadratic attributes, translog costs functions (e.g. Oum, 1989) or Box-Cox transformations (e.g. Picard and Gaudry, 1998) , are also possible.
[3] Strictly speaking there is also a 'scale' parameter, which reflects the variance of the random component of utility and is used for normalising the model. It is called 'scale' parameter, because it scales the β parameters in (7-3a) – (7-3c); a higher random variance leads to lower estimated β's.

$COST_i$: transport cost of mode i; this could include both the distance-dependent costs $f_i \cdot DIST_i$ (such as fuel costs), where f is the transport cost per km and DIST the distance in km, and the time-dependent cost $g_i \cdot TIME_i$ (such as transport staff and vehicle cost), where g is the costs per hour.
TIME: transport time of mode i in hours.
REL_i: transport time reliability of mode i; this could be measured as the standard deviation of transport time or as the percentage of shipments delivered on time.
β_0, β_1, …, β_8: coefficients to be estimated; we expect negative signs for β_1,… β_3 andβ_5, … β_8, the sign for β_0 and β_4 can be positive or negative.

In equations (7-3a) – (7-3c), the utility that would be obtained when choosing road transport depends on the transport cost and time for that shipment by road transport and its reliability, and likewise for the other two modes. The values for COST, TIME and REL by mode, may come from skimming networks for these modes, but also might be provided by the decision-makers themselves (often they find this hard for non-chosen modes, and there could be perception errors) or have been postulated in a 'what if' fashion by the researcher in a stated preference survey.

The βs are coefficients for which numerical values are determined by estimating the model on data for various decision-makers and corresponding individual shipments (which may vary in terms of origins and destinations, leading to variation in distance and time within modes but over shipments). β_0 and β_4 are so-called 'alternative-specific constants', ASCs. There can only be N-1 ASCs in a model, N being the number of available choice alternatives, because in a utility maximisation model only differences in observed utility matter. In the example above, we have excluded an ASC for the inland waterways alternative, which means that for this alternative, the constant is normalised to 0. For the same reason, we can only include attributes as explanatory variables that differ between alternatives. Attributes of the decision-maker (e.g. the size of the firm) or of the shipment (e.g. containerised or not) can only be included by interacting these variables with characteristics of the modes (for instance by making certain firms less cost-sensitive or including containerisation only for rail, expressing that container transports are more likely to be transported by rail).

Coefficients can be generic, such as β_1 for cost above, or alternative-specific, such as the other coefficients in equations (7-3a) – (7-3c). Which is best is largely an empirical matter, which means that various forms should be tested and compared against each other. In the above model specification we have used generic coefficients for costs (but not for the other variables), which has the additional advantage that one unit of money paid for road transport has the same value as one unit of money paid for rail or inland waterways transport ('a euro is a euro' or 'a dollar is a dollar').

The decision on mode choice by decision-maker k could be influenced by other variables than the three attributes included above. For instance the flexibility of a mode, the service frequency and the probability of damage to the goods might also play a role. But the researcher that is constructing the mode choice model may not have any data on these influencing variables, or only data measured with some error. This is a key reason[1] for including the error components e_{road}, e_{rail} and e_{IWW} to the utility functions: they represent variables that affect the utility of the decision-maker, but are not observed by the researcher (or observed only with measurement errors).

[1] There are other reasons in the discrete choice literature for including the error terms.

Discrete choice models estimated on stated preference (SP) data only should not directly be used for forecasting (including the derivation of elasticity values), since the SP data will have a different variance for the error component than real world data, which will affect the choice probabilities. This happens because in the experimental set-up of the SP many things that can vary in reality are kept fixed, and vice versa. Therefore, for forecasting it is better to use revealed preference (RP) data or combined SP/RP data where the variance of the SP is scaled to that of the RP. Models estimated on SP data can directly be used to derive ratios of coefficients (such as a value of time or a value of reliability) because in calculating these ratios, the SP error component drops out.

In order to deal with the error components, the researcher assumes these are random variables (with a mean of zero and some variance). By making different specific assumptions on the probability distribution of the error components, different discrete choice models can be derived. These models are probability models, because they do not generate a certain choice, but probabilities for each of the available alternatives. The two choice models that are used most in practice, the multinomial logit (MNL) model and the nested logit model are discussed in Annex 1. Annex 2 discusses some models that combine mode choice with other choices (joint models).

7.2.2 Practical examples of disaggregate mode choice models

A practical example of an MNL model estimated on disaggregate freight data for mode choice is Nuzzolo and Russo (1995). This is the mode choice model within the Italian national freight model system for intercity freight flows. It contains three choice alternatives (road, rail and combined road-rail transport) and was estimated on interview data (RP) with producers/shippers. This model includes transport costs and time by mode as well as some shipment characteristics.

Some practical examples of nested logit mode choice models in freight transport are:

- Jiang et al. (1999): a model for the choice of mode (more specifically: own account transport versus a nest with three contract out options: road, rail and combined road-rail transport) estimated on the French shippers survey of 1988. The model includes attributes of the firms and of the shipment, but not transport time and cost (distance however was included).

- De Jong et al. (2001) used RP information and data from SP mode choice experiments (and from SP abstract or 'within-mode' alternatives) among shippers in the French region Nord-Pas de Calais to estimate a mode choice model. Nested logit was used to allow simultaneous SP/RP estimation. The explanatory variables in the model include transport time and costs by model, reliability, flexibility and frequency of the mode, as well as attributes of the shipments and the shipper.

- The German model for federal infrastructure project assessment (BVWP model) was estimated as a disaggregate mode choice model (road, rail and inland waterway transport), partly on stated preference data (ITP and BVU, 2007).

7.3 Aggregate mode choice models

As discussed in section 7.2, the standard disaggregate choice model (MNL), and many extensions of it, can be based on the theory of utility maximisation by individual decision-makers. There also is an aggregate form of this model (often called 'aggregate logit') where the observations usually refer to summations of shipments for the same origin-destination (OD) zone pair.[1] More specifically these modal split models are estimated on data for the market share of each mode over different OD pairs. The aggregate modal split model can indirectly be based on the theory of individual utility maximisation (all decision-makers on the shipments for an OD pair carrying optimising their subjective utility, but only under very restrictive assumptions. These assumptions basically boil down to assuming that all variation in characteristics of the decision-makers and of the goods belongs to the error component of the utility function. This would be such a far-reaching assumption, that it is better to see aggregate logit models as pragmatic models (that have shown to be able to yield plausible results) instead of models based on a theory of behaviour.

The aggregate logit models are often selected because disaggregate data are not available and all we have are the tonnes by OD zone pair and mode (or tonnes by PC pair and main mode). The aggregate logit can easily be estimated (both with software for linear regression models and for discrete choice models), produces an intuitively appealing S-shaped market shares curve and market shares, which are always between 0 and 1. Because of these advantages, the aggregate logit model still is the single model specification used most in practical freight mode choice modelling. [2]
A typical formulation is the 'difference form':[3]

$$\log \frac{S_i}{S_j} = \beta_0 + \beta_1 (P_i - P_j) + \sum_w \beta_w (x_{iw} - x_{jw}) \qquad (7\text{-}4)$$

In which:
S_i/S_j is the ratio of the market share of mode i to the market share of mode j.
P_i and P_j are the transport costs using these two modes.
X_{iw} - X_{jw} are w (w=1,…, W) differences in other characteristics of the two modes.

This model can be estimated using specialised discrete choice estimation software (the same as used for estimating disaggregate models), but also by standard regression analysis of the log-ratio above on its explanatory variables.

Aggregate modal split models are mostly binomial (two available modes) or multinomial logit models (three or more available modes). Since they only give the market share of a mode, not the absolute amount of transport (tonnes) or traffic (vehicles), the elasticities from such models are conditional elasticities (conditional on the quantity demanded).

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[1] The observations might also be summations of shipments to form data per business sector or time series for some region.
[2] In practice it is often even difficult to obtain plausible transport time and costs coefficients when estimating on aggregate data. Prof. Moshe Ben-Akiva once suggested here to assume a value of time distribution to allow for heterogeneity between shipments.
[3] An alternative for the difference form is the 'ratio form' where the right-hand side has P_i/P_j and x_{iw}/x_{jw}, which has the disadvantage that the choice of the base mode (in the denominator of the dependent variable) affects the estimation results and the elasticities from the model. The difference form does not have this disadvantage.

Practical examples of aggregate modal split models are:

- Blauwens and van de Voorde (1988) modelled the choice of inland waterways versus road transport in Belgium.
- The modal split model within the NEAC model for Europe (NEA, 2000) explains the choice between road, rail and inland waterway transport.
- The French national freight transport model MODEV (MVA and Kessel+ Partner, 2006) has an aggregate logit model with road, rail, combined road-rail and inland waterways as modal alternatives.
- The current EU transport model system Transtools (Tetraplan, 2009) includes a modal split component for freight by road, rail and inland waterway transport that is an aggregate logit model. The same goes for the previous version of Transtools (NEA, 2007).
- The LEFT model (Fowkes et al., 2010) for the choice between road and rail for seven commodities and nine distance bands also works at the aggregate level.
- The new 'back to basics' Dutch freight transport model BasGoed also is an aggregate logit model, estimated on shares by zone pair for the modes road, rail and inland waterway transport (de Jong, et al, 2011). The level-of-service inputs come from uni-modal assignments for these modes.
- The strategic freight transport model for Flanders contains an aggregate nested logit model for mode choice between road, rail and inland waterways as well as the choice of vehicle/vessel type (e.g. Grebe, 2014).
- The following aggregate models in a way go beyond the aggregate logit model in that they model the budget share of a mode in total transport cost. This type of input demand function can be derived from a production cost function for a firm that also includes the cost of transport services by mode, using Shephard's Lemma from the standard micro economic theory of the firm. This too however, is a relation that applies for a single firm; transfer to a sector or region is not straightforward.
    - Oum (1979) had aggregate time series data on modal split in Canada and estimated various aggregate models on this.
    - Friedlaender and Spady (1980) analysed the mode choice at the level of 96 economic sectors in five regions in the US (so the data are not by OD pair, but by sector and origin region).
    - Oum (1989) used aggregate models with different cost specifications (linear, loglinear, Box-Cox and translog) explaining the modal split for transport flows between Canadian regions.

7.4 Multi-modal network models for aggregate mode and route choice

The multi-modal network modelling provides one way to handle transport chains.[1] In a transport chain, several modes are used consecutively for a door-to-door shipment. An example is to use a lorry first from the zone of the sender to the port, then use short sea shipping, then rail transport and finally lorry delivery to the zone of the receiver. Assignment to such combinations of modes in a transport chain can take place if the network not only includes links and nodes for each mode, but also multi-modal nodes that connect one network to another network. Such nodes can be ports or rail and inland waterway terminals for trans-shipment between modes. In other words, a multi-modal network (or super-network) is created, where inter-modal transfer nodes for instance link road, rail and inland waterways networks

The aggregate mode and route choice model (multi-modal assignment) has been used in a number of cases:

- Even in a relatively small network, many route-mode combinations can be chosen for a specific OD combination and a cost minimisation algorithm is used to find the least-cost combination. The cost function that is minimised in multi-modal assignment can contain several attributes, including transport time components and terminal cost. In most cases all traffic for an OD pair is assigned to the single optimal alternative: all-or-nothing assignment, but for instance the Dutch SMILE+ model (Tavasszy et al., 1998) uses stochastic multi-modal assignment.

- One of the commercial software packages for multi-modal network assignment is the STAN package (Crainic et al., 1990), which has been used in the previous freight transport models in Norway (NEMO) and Sweden (the previous SAMGODS model), and also in Canada and Finland. The WFTM freight model for the Walloon Region uses a similar multi-modal network assignment, but this is implemented in the NODUS software (Geerts and Jourguin, 2000; Beuthe et al., 2001). The selection of the optimal mode-route combination is done separately for different commodity groups, because different goods will have different handling requirements and values of time, and therefore the coefficients in the cost functions (e.g. for trans-shipment costs and time costs) will differ between these goods.

- In the European model SCENES (SCENES Consortium, 2001) and The Great Britain Freight Model GBFM (MDS Transmodal, 2003) a multi-modal network assignment takes place. Worldnet (Newton, 2008), that was also developed for the European Commission, and covers Europe, but also intercontinental sea and air freight, contains a multi-modal transport chain builder. Furthermore it also includes an aggregate logit model to choose between the different uni-modal and multi-modal transport chains.

7.5 Some specific models at the European scale

This section 7.5 considers three, related families of freight models:

- STEMM/GBFM

[1] The other way is to have a disaggregate or aggregate model for the choice from a choice set containing different uni-modal and multi-modal **transport chains** (as discussed in Annex 2).

- NEAC, TRANSTOOLS
- WorldNet, NEAC10

STEMM/GBFM

STEMM (1996-1998; Baxter Eadie et al., 1998) aimed to develop a freight model that could be tested and applied on different European corridors. One of the relevant case studies carried out, was the cross-Channel market, and the opening of the Channel Tunnel, which had prompted a high degree of interest in the question of how much (if anything) freight companies and exporters would be prepared to pay for a faster cross-Channel link. One of the key methodological inputs used in STEMM was Tweddle et al. (1995).

This study had used stated preference techniques (hypothetical questions) to see how companies would react to the opening of the Channel Tunnel, in terms of their willingness to pay for new or improved transport options. It was an interesting case study because of the wide range of routes available, the high degree of competition amongst the existing ferry operators, and the fact that the clearest difference between the ferries and the Channel Tunnel shuttles (lorries on trains) was (and still is) the crossing time between Dover/Folkestone and Calais. Eurotunnel's business case rested on the assumption that the Channel Tunnel services could gain a market-leading share of traffic, and achieve higher yields per crossing, whereas the received wisdom in the ferry industry was that these were mutually exclusive aims. Three categories of interviewees were identified in the survey:

1) Manufacturers
2) Freight forwarders, and
3) Hauliers

These categories were distinguished in order to account for the different interpretation of value of time, and the different role in the decision making process, depending upon the perspective of the interviewee.

The data from the stated preference interviews produced the following results:

Table 7-1: Valuation of service attributes (% of freight rate)

	Per Time Unit* (%)
Manufacturers	7.4%
Freight Forwarders	6.1%
Hauliers	3.8%
Total Sample	4.9%

Source: Tweddle et al. (1995)

**A time unit was defined to be a two-hour period in the daytime and a four-hour period at night; hence there are nine time units per 24 hours.*

On this basis, a haulier would be willing to pay 3.8% more for a sea-crossing normally costing around €180-€250 in order to save one time unit, or two daytime hours. This suggests a value of time saved of about €4 per hour, per lorry-load of cargo, with respondents quoted as saying that they would not pay a significant premium for the faster, Channel Tunnel services. Values of time for manufacturers and freight forwarders were estimated to be higher (6.1% to 7.4% of the freight rate), reflecting the fact that they expected to benefit from any productivity saving made during the transport operation, and from the inventory-related savings.

Following on from these findings, the STEMM models (cross-Channel and trans-Alpine) were constructed according to the principle that the best way to explain route and mode choices would be to have a good estimation of direct, out-of-pocket transport costs, including the time-based transport costs such as drivers' wages and equipment hire, with a relatively small inventory-related value of time added.

This approach was later taken further in GBFM (MDS-Transmodal, 2004) – the model developed by the UK department for Transport and consultants, MDS-Transmodal, as part of the National Transport Model. In GBFM, the choice model reacted to estimates of generalised cost, comprising:

- Out of pocket costs
- Door-to-door travel time, and
- Variability of travel time (reliability)

The carrier's value of time related to the more efficient use of drivers and equipment is captured in the 'out-of-pocket' costs, and the inventory value of time (for the consignee/consignor) is added, using a rate of:

- 1.04167% of the freight rate per lorry load per hour.

Reliability (variability of travel time) was valued at 5.0% of the freight rate per lorry load per 1% late (1% late means for instance an increase in late deliveries from 10 to 11%).

In later model versions (see GBFM v5.0), the same (low) value of time was used (1.04167%), implying that most of the observed transport behaviour could be simulated by being able to estimate out of pocket costs with reasonable accuracy. One of the additional contributory factors was that GBFM used detailed networks of rail services, differentiating between unitised and bulk services. This helps to identify which types of rail service, with which cost structures, were available for which commodities. Another important consideration was that the model rarely needed to compare extreme time savings, such as between intercontinental air and sea freight. Without the air-freight option, road is generally the fastest option available, but since road captures high proportions of both highly time sensitive and moderately time sensitive traffic, there was no need to differentiate between the two.

NEAC/TRANSTOOLS

NEAC (Chen and Tardieu, 2000) is a model and database developed by NEA (now Panteia) during the 1990s, for analysing multimodal freight flows at a European level. It was used as the main freight model for the project TEN-STAC (NEA et al., 2004) for analysing the impact of European transport projects[1].

It contains two main modules, dealing with trade forecasting and mode choice, with the mode choice module as the main area where there are interactions with respect to transport time. The formulation of the mode split function is shown below in equation (1). It is essentially a pivot-point structure, calculating

[1] TEN-STAC additionally used value of time estimations for its impact analysis, based on the 2001 project, UNITE, ranging from approximately 25€/vehicle hour to around 90€/vehicle hour depending upon the nationality.

changes in modal split in response to changes in the ratios of cost and time, calculated for different pairs of modes.

$$P^{p}_{m=1,i-j} = P^{b}_{m=1,i-j} \cdot \left(\frac{RC^{p}_{m=2}}{RC^{b}_{m=2}}\right)^{\beta} \cdot \left(\frac{RC^{p}_{m=3}}{RC^{b}_{m=3}}\right)^{\chi} \cdot \left(\frac{RT^{p}_{m=2}}{RT^{b}_{m=2}}\right)^{\delta} \cdot \left(\frac{RT^{p}_{m=3}}{RT^{b}_{m=3}}\right)^{\varphi} \cdot \left(\frac{V^{p}_{i-j}}{V^{b}_{i-j}}\right)^{\gamma} \qquad (7\text{-}5)$$

where:

$P^{p}_{m=1,i-j}$	Probability of selecting mode (1) for the O/D relation i-j in the *predicted* scenario. (Mode 1 is road)
$P^{b}_{m=1,i-j}$	Probability of selecting mode (1) for the O/D relation i-j in the *base* scenario.
$RC^{p}_{m=2}$	Ratio of Transport Cost (door to door transport tariffs including terminal, collection/distribution and line haul); ratio of the cost of mode 1 (road) to the cost of mode 2 (rail) in the *predicted* scenario.
$RC^{b}_{m=2}$	Ratio of Transport Cost (door to door transport tariffs including terminal, collection/distribution and line haul); ratio of the cost of mode 1 (road) to the cost of mode 2 (rail) in the *base* scenario.
$RC^{p}_{m=3}$	Ratio of Transport Cost (door to door transport tariffs including terminal, collection/distribution and line haul); ratio of the cost of mode 1 (road) to the cost of mode 3 (waterway) in the *predicted* scenario.
$RC^{b}_{m=3}$	Ratio of Transport Cost (door to door transport tariffs including terminal, collection/distribution and line haul); ratio of the cost of mode 1 (road) to the cost of mode 3 (waterway) in the *base* scenario.
$RT^{p}_{m=2}$	Ratio of Transport Time; ratio of the trip time of mode 1 (road) to the trip time of mode 2 (rail) in the *predicted* scenario.
$RT^{b}_{m=2}$	Ratio of Transport Time; ratio of the trip time of mode 1 (road) to the trip time of mode 2 (rail) in the *base* scenario.
$RT^{p}_{m=3}$	Ratio of Transport Time; ratio of the trip time of mode 1 (road) to the trip time of mode 3 (waterway) in the *predicted* scenario.
$RT^{b}_{m=3}$	Ratio of Transport Time; ratio of the trip time of mode 1 (road) to the trip time of mode 3 (waterway) in the *base* scenario.
V^{p}_{i-j}	Total annual tonnage for the O-D relation *i-j* in the predicted scenario.
V^{b}_{i-j}	Total annual tonnage for the O-D relation *i-j* in the base scenario.
$\beta, \chi, \delta, \varphi, \gamma$	Coefficients

The transport time ratio (RT) between road and rail, for example, can be re-arranged as (Kawabata, 2006):

$$\frac{RT^{p}_{m=2}}{RT^{b}_{m=2}} \overset{(4)}{=} \frac{T^{p}_{road}/T^{p}_{rail}}{T^{b}_{road}/T^{b}_{rail}} = \frac{T^{p}_{road}}{T^{b}_{road}} \cdot \frac{T^{b}_{rail}}{T^{p}_{rail}} = \frac{Ch_{road}}{Ch_{rail}} \qquad (7\text{-}6)$$

If the road time changes, and all other factors stay the same, the predicted road probability will become the base year probability multiplied by the result of equation (6-6) expressed to the power of the parameter delta (see equation 1). A decrease in road time will cause equation (6-6) to be less than one, so a negative value of delta (coefficient *δ)* will result in a higher probability share for road. In practice, different delta values have been calculated per market segment, typically ranging from +2 to -2. Thus, there are different values of time being applied, some positive, some negative, and many set at zero (no effect).

An important difference compared to STEMM/GBFM is that the NEAC mode split coefficients which determine the importance of time and cost in determining modal split were calculated by fitting the function to available data. In STEMM/GBFM they were pre-set. NEAC was later used as the main template for the design of freight module for the DG-MOVE network model, TRANSTOOLS. In the TEN-STAC era NEAC formulation, as explained above, the mode split function handles the value-of-time related calculations using time and cost ratios. Following criticism of this method (see Smies, 2003 and Van der Leest, 2005) the mode split module was replaced in TRANSTOOLS by a more conventional multinomial (aggregate) logit function (TNO, 2006). In the prototype versions of TRANSTOOLS, the logit function shown in equation (7-7) was used to assign probabilities across modes.

$$P_{m|cij} = \frac{e^{V_{m|cij}}}{\sum_{l \in M} e^{V_{l|cij}}} \qquad (7\text{-}7)$$

$$with: V_{m|cij} = \beta_{m0} + \sum_{k} \beta_{mk} x_{cijmk}$$

Where:

M:	Set of available modes.
$P_{m\|cij}$:	Choice probability of mode *m* given commodity group *c* and OD relation *ij*.
$V_{m\|cij}$:	Systematic utility of mode *m* given commodity group *c* and OD relation *ij*.
x_{cijmk}:	Level of service *k* for mode *m* given commodity group *c* and OD relation *ij*.
β_{mk}:	Logit parameter for mode *m* and level of service *k*.

The utility function for mode *m* (V_m) in the prototype TRANSTOOLS mode split model was:

V_m = $Amode_m$ + $Bcost*Cost_m$ + $\mathbf{Btime*Time_m}$ + $Broad*Road_m$ + $Brail*Rail_m$ + $Bsea*Sea_m$ + $dom_m*Domestic$ + $Bdist_m*Distance$ + $Bton_m*Totalton$.

This contains a transport cost item ($Cost_m$), which includes time-based cost elements (e.g. drivers' wages) as well as a specific transport time item ($Time_m$), as well as mode specific constants, amongst others. The cost item ($Cost_m$) is in turn based on a function which includes distance-based, time based, and fixed cost items, with different parameters for each NST category (See van der Leest, 2005, Appendix II). Since it is not immediately evident that transport costs depend on the product being carried, this methodology which results in some commodities appearing to travel more slowly than others, might also be seen as a way of calibrating valuations of time, although this is not explicitly described.

However, this cost function turned out to be unsatisfactory (Kawabata, 2009), so the utility function was simplified to include only three items:

- Cost per mode (fixed cost per hour, waiting cost per hour, variable cost per km, fuel cost per km, toll cost per km, total fixed cost, total variable cost, total waiting cost, total fuel cost, total toll cost and total time)

- Existence of service per mode
- Border resistance per mode (dummy variables)

The transport time element (per mode) was therefore removed as an explanatory variable. Note that time based costs (e.g. driver's wages) are still included in the cost model, but no specific time variable (the value of time for the owner of the cargo, over and above the cost of the transport) was entered in the model.

During the first calculation runs in TRANSTOOLS, the time parameter ($Time_m$) was not significant in most cases. Table 7-2 shows the relative size of the inventory costs (purely time based costs) to the transport cost. Two O/D pairs are compared, covering 105 Km and 1189 Km respectively, for road and rail.

Table 7-2 Comparison between transport costs (EUR/t) and Inventory Costs

orig	*dest*	*distance (kms)*	*mode*	*tpt cost/ tonne*	*total time*	*inv. cost/ tonne*	*inv. cost/ tpt cost*
				(euros)	*(hrs)*	*(euros)*	*(%)*
NL	D	105	road	17.69	4.98	0.08	0.45%
			rail	23.98	24.49	0.39	1.62%
AT	GR	1189	road	206.91	57.70	0.91	0.44%
			rail	68.25	55.33	0.88	1.28%

For a 105 Km trip, taking only 4 hours by road, including an allowance for loading and unloading, the inventory cost is only 0.45% of the transport cost for a typical commodity in product group 8 (chemicals) with a value of 1386 Euros per tonne, using a discount rate of 10%. For longer trips (e.g. 1189 kms, estimated to take over 50 hours by rail) the ratio rises, but remains below 2% of the transport cost. It is therefore clear that the impacts of a policy to speed up transport by a particular mode is adequately covered by the cost model, and that the additional time parameter is not required.

This simplified utility function was applied in later versions of TRANSTOOLS (v2.5[1] onwards) and in the project MODEV (Kiel, 2007), and continue to be used in the mode split function of the 2010 updated versions of the NEAC10 model (Newton et al., 2015). In NEAC10 out-of-pocket costs (including time-based costs) are calculated using a network model, described later under the heading NEAC10 cost functions. These are primarily based on the ETIS projects (ETIS-BASE and ETIS-PLUS).

Regarding the value of time, the conclusion of projects such as NEAC and TRANSTOOLS was remarkably similar to the separate work carried in STEMM and GBFM. While it was considered theoretically necessary to include a value of time, over and above time-based transport costs (the carrier's value of time), it has been found difficult to quantify it statistically in a simple mode choice model structure. The relatively small market segments which are highly time sensitive are hard to identify as statistically significant quantities by simply measuring modal split and only considering surface modes of transport. Flows for

[1] As used in the (DG-MOVE) TEN-CONNECT studies.

which the consignors and consignees exhibit high values of time may well exist, but they are subsumed into road transport.

WORLDNET

WORLDNET (NEA et al., 2009) was a successor project to TRANSTOOLS, which aimed to develop elements related to long distance freight flows, and which formed the basis of current models such as NEAC10. Two aspects of WORLDNET are relevant for value of time:

- Mode Chain Builder: The development of a model structure for estimating long-distance multimodal chains, and
- Air Cargo Trade Flow Model: The estimation of a binary choice model for selecting air cargo flows from trade data.

The Mode Chain Builder was essentially a development of the STEMM methodology, but applied pan-Europe, using detailed, bottom-up generalised cost estimations (including a pre-set value of time) within a choice function for fitting cargo flows across a multimodal network. The air cargo model was an econometric model to determine the proportion of a trade flow which would use air cargo, rather than surface modes.

WORLDNET Mode Chain Builder

The mode chain builder was developed as a tool for converting trade data (imports and exports) into multimodal chains, routed via seaports and inland terminals. It uses a multimodal network to generate multimodal paths connecting origins and destinations, and a logit model to assign shares of the traffic amongst the most efficient chains. Path efficiency is estimated using a generalised cost function. Like STEMM it used detailed networks and detailed transport costs (pre-determined, not statistically estimated) to estimate out-of-pocket costs (including time-based haulage costs). Generalised cost is calculated by adding a consignor/consignee value of time to these out-of-pocket costs.

In the Mode Chain Builder, the value of time is 5 Eurocents per lorry-load per minute, or €3 per lorry-load per hour, i.e. similar to the figure estimated by Tweddle, Fowkes and Nash (1995). Note that the model is calibrated with shadow weights applied per country, per product and per mode to fit available data, but the value of time parameter is held constant across. Thus the calibration is responsible for ensuring that the profiles of route and mode choice can differ across different product categories; something that might otherwise be explained by variation in value of time.

WORLDNET Air Cargo Trade Flow Model

The objective of this modelling exercise was to be able to extract likely air cargo flows from trade data, using a large sample of flows from Eurostat's extra-EU trade database in which mode of transport is recorded. Compared to the other modelling exercises described above, which focused on modal shares of surface transport, without paying close attention to product sectors likely to exhibit high values of time, this part of the study was potentially more likely to reveal examples where consignee/consignor values of time would be high enough for it to be the dominant factor in transport route and mode choice; companies choosing the fastest option and discarding the low-cost options.

For intercontinental freight, the choice between sea-freight and airfreight is quite clear. A maritime 20' container containing e.g. 8,000Kg of freight, with a total value of €70,000 might pay around €1500 to be transported between Europe and the Far East. This works out to be 0.19€ per Kg for the transportation cost, and a consignment value per Kg of 8.75€/Kg. Voyage time from the Far East to Europe by sea would be around 30 days.

An airfreight consignment on the other hand might have a value of around 40€/Kg (4.5 times higher) and would pay around €5 per Kg (about 26 times more). Flight time would be approximately one day (about 30 times lower).

This is a real example, based on COMEXT trade data, referring to trade in NST3 979 (Other manufactured articles), between the Netherlands and China in 2011. The airfreight accounted for 5% of this particular trade by weight, but close to 20% of the trade by value, and the most logical explanation is that the consignments that went by air, paying 26 times more than the sea freight rate, did so because the relatively high value of the goods translated into a high value of time for the consignor/consignee.

The model was designed to estimate the proportions of European trade that would use air cargo services. A binary logit function was fitted to the trade data:

The dependent variable was calculated as logarithm of air tonnage percentage:

$$LN\_p\_air = \ln\left(\frac{p\_air_{ton}}{1 - p\_air_{ton}}\right)$$

with:

$$p\_air_{ton} = \frac{air\_tonnes}{total\_tonnes}$$

The estimation of air percentages are calculated as follows:

E_percentage = exp(e_value)/(1+exp(e_value))

and

*e_value = constant + coeff1*kmrange+ coeff2*(vrange)*

where
kmrange: is the distance band
vrange: is the value density range (€ per kg)

The function was modelled for ten different NSTR categories, and the variables were found to be significant, with positive signs, indicating that higher value consignments travelling longer distances are more willing to pay for faster air freight services.

Taking NST9 (manufactures), and looking at long distance transport (>9500km) this function would estimate that 0.1% of the cargo in the lowest value category (up to 10€/kg), 2% of the cargo in the middle range (<16€/kg), but 29.11% of cargo in the highest category (>16€/kg), would choose air transport.

The obvious difference between this model and the more general mode split models is that it uses value per kg as an explanatory variable, and instead of using transport cost it uses distance as a proxy for either surface transport cost of journey time. However it only shows a valuation of time at one end (premium freight) of the spectrum, so the results cannot be generalised in order to estimate values of time for the 95% of the market which chooses surface transport.

NEAC10
NEAC10 is the latest incarnation of the NEAC model. As explained above, it uses outputs from the WORLDNET Mode Chain Builder as inputs, and it contains both the original NEAC mode split model (time and cost ratios) and the TRANSTOOLS v2.5 (simplified) mode split function. Normally the TRANSTOOLS v2.5 approach is used. In this structure, time is handled as an integral part of the function calculating out-of-pocket costs, and there is no additional (consignor/consignee) value of time in the utility function.

7.6 Data availability and modelling approach

7.6.1 Introduction

In this chapter, we first review the available data sources for freight transport modelling (section7.6.2). Since we focus on models for modal split, we will not discuss the data sources that are only used for other model components, such as trade statistics, input-output data and make and use tables (these are described in Tavasszy and de Jong, 2014).

Many data are collected by the national statistical offices (e.g. statistics Norway). International statistical offices, such as Eurostat for the EU, but also the statistical offices at the UN, depend to a large degree on the national statistical offices of the member countries for their information.

Most of the data in freight transport are at the annual level (e.g. in tonnes transported per year). Official data sources are usually collected each year and then published in the form of yearly figures. Data on time intervals shorter than a year (weeks, quarters, months, working days) are very scarce, but some of the underlying data (trade statistics, transport statistics, traffic counts) is collected all year round and could be used (if access would be granted) to generate distributions of freight transport patterns over the year.

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

In section 7.6.3 we link the data sources from section 7.6.2 to model components and model specifications in freight transport modelling (focussing on mode choice models) for which these data can be used.

In section 7.6.4 we further discuss the relationship between model form and data availability.

7.6.2. Overview of different data sources for freight transport modelling

Transport statistics
Transport statistics such as roadside surveys providing information on vehicle origins and destinations. Whereas the trade statistics provide information on the locations of production and consumption of the goods (that can be used to build PC matrices, see chapter 2 of this report, the transport statistics provide information about the locations where the vehicle flows started (point of loading) and ended (point of unloading). This information can be used to build OD matrices. When the transport from the producer to

the consumer is a direct transport, the PC and OD flow will be the same. A difference occurs when the transport from the producer to the consumer uses a transport chain with several modes in a sequence (e.g. road first, then sea, then rail, then road). In this case one PC flow leads to multiple OD flows (in the example given to four OD flows), since the goods are unloaded and loaded (lifted) several times, unto several modes. In some cases the published transport statistics may not distinguish between different vehicle types of the same mode that are used consecutively, so that a transport chain LGV-HGV-LGV would just be one OD flow by road transport. In more detailed statistics cases these could be three OD flows.

The transport statistics consists of various parts: different modes have their own sources. The publication is usually carried out by the national statistical offices, but the data collection may originally have been done by others (e.g. ports and airports). Common characteristic is that these data are at the OD level, in terms of tonnes, the use of commodity classifications like NSTR and NTS2007 and that information on the mode is an integral part (since the data are gathered by mode). Transport statistics thus include the following mode-specific statistics:

<u>Road transport statistics</u>. This information needs to come from road haulage carriers (firms offering transport services by road) and shippers doing own account transport by road. Physical transport of goods (whether domestic or international) is accompanied by some paperwork required by the national authorities: consignment bills. The direct use of these bills as a research data source is discussed later, but this is not available for the national statistical offices. Therefore, they have to organise interviews with carriers and own account transports to get a picture of the transport flows by road. In the EU countries, information on origin, destination, commodity type, and the load is collected from a sample of firms with trucks over 3.5 tonnes, under the responsibility of the national statistical offices, which report to Eurostat on this, following guidelines from Eurostat. This sample survey is expanded to the population and leads to published aggregate statistics on road transport volumes in tonnes (and tonne km as well as vehicle km).
The survey only deals with transports carried out by firms based in the home country (sometimes also focusing on transport by domestic firms on the national territory). In principle surveys with firms in their home country can also give information on transports in other countries. Some statistical offices have added interviews with foreign firms to their data.

The road transport statistics are generally only available in aggregate form (zone-to-zone data). In some cases it has been possible to use the underling micro-data on the server of the national statistical office (e.g. in the PhD work of Abate (2013) in Denmark).

<u>Seaport statistics</u>. The national or international statistical offices do not publish a data base of maritime flows between seaports (though there are some commercial data bases with data at this level, but more often focusing on the movements of ships). They base themselves on statistics on the use of specific seaports (usually also collected by these seaports) and then publish data by port (or all the ports in a country together) on ingoing and outgoing transport, in tonnes, sometimes by country where the goods came from or went to, and by mode of appearance (containers, dry bulk, liquid bulk, roll on-roll off). For Europe, the ETISplus project has constructed maritime OD matrices on these data, also using information from the trade data (www.etisplus.eu). Port statistics often not only give tonnes but also the amount of sea containers (TEU). The tonnes can be split over commodity types (e.g. NSTR), the TEU usually not.

<u>Inland waterway statistics</u>. This data mainly comes from national statistical offices (international organisations publish only very limited information on inland waterway flows), and of course only in a few countries this mode is of major relevance. The information is available at the OD level, but only provides

tonnes (not containers) for a coarse classification of the commodities and of the zones abroad for international flows.

Railway statistics. Goods flows by rail are recorded by the railway companies that carry out these transports (possibly also by the clients of the railway companies) and the rail authorities record the train movements . Nevertheless, there often is hardly any information on rail freight flows available for transport research, especially now that many of the operators are private firms and are not obliged to provide information on this. As a result, information is only published for some of the years (e.g. every five years), and for instance the Eurostat data either has OD flows (tonnes) without commodity distinctions, or total volumes by country with a commodity classification. No comparable information on containers is available.

Airport statistics. As for seaports, the available base data are not organised in the form of OD flows, but as statistics of the incoming and outgoing flows of specific airports. The ETISplus project produced a –partly synthetic- OD matrix for air freight flows in/to/from the EU (in tonnes, no commodity distinction).

Shipper surveys
Shipper surveys are interviews with shipping firms (e.g. producers of goods). Unlike the databases mentioned above, these are not data that are collected regularly by most of the national statistical offices in the world. Only some countries (mostly their national statistical offices do this) have carried out shipper surveys, and these are done with larger time intervals, not every year, sometimes on an ad hoc basis. The shippers are asked to provide information about a sample or their outgoing (sometimes also incoming) shipments of goods.

Well-known examples are the US Commodity Flow Survey (CFS; several years; see Vanek and Morlok, 1998), the French and Dutch shippers surveys of 1988, the Swedish CFS (2001, 2004-2005 and 2009; see SIKA, 2003), the Norwegian CFS and the French ECHO survey of 2004 (see see Rizet and Guilbault, 2004).
The information that is gathered includes the location and sector of the producer and consumer, the value and weight of the goods and the transport chains used (possibly multiple modes). The French ECHO survey goes beyond the other shipper surveys in that also the receiver and carrier firms involved in a number of specific shipments of the selected shippers were interviewed as well (extending it to a shipper-carrier-receiver survey). About 10,000 shipments in total could be reconstituted this way, with detailed information (modes, transhipment locations) about the different OD flows of these chains. The US and the Swedish surveys contain considerably less information per shipment, but millions of shipments in total.

Under certain conditions, some shipper surveys have been made accessible to transport researchers not only at the aggregate but also at the micro-level, for use in research projects.

Specific project-based interview data (especially stated preference data)
Several research projects in freight transport found that the existing data are not sufficient for their purposes and carried out their own interviews with shippers and/or carriers firms, focussing on one or more individual shipments. This happens regularly especially for projects that should provide freight values of time (or other service quality attribute values) or develop mode choice models for freight transport. The interviews can be revealed preference (observed choices), stated preference (choices between hypothetical alternatives) or a combination of both. In the former case, the survey is equivalent to a shipper survey.

Consignment bills and RFIDs

Most of the information on individual shipments that researchers now get from shipper surveys, could also be obtained (and also for many more shipments) from the administrative documents that need to be completed for shipments (consignment bills) and from RFIDs, which are electronic tags for tracking and tracing the shipments. The consignment bills are now often completed and handled electronically and the tracking and tracing data is by nature electronic data. However, neither of this data is publically available. For use in transport research, permission from the private firms involved would be needed. A related possibility would be if a transport researcher would be allowed to have its own (additional) tags on the shipments of a certain carrier or shipper and read out the data on where the shipments goes from this.

Traffic count data

Traffic counts in road transport can be both manual and automated (using induction loops in the road surface) counts. Both result in numbers of road vehicles on some road link, that usually distinguish between trucks (buses) and cars. The induction loop data can also be used to calculate travel times, but in these data there usually is no distinction between trucks, buses and cars. Counts of trains, ships and airplanes is in principle also possible, but the collection and use of such data is uncommon outside major hubs such as railway stations, airports or seaports. With new technology becoming available, traffic counts for all modes of transport can be based on approaches such as satellite observation, GPS location services, traffic cameras, Bluetooth communication and cellular phones. This opens up now possibilities to create a complete picture of traffic flows in areas that were previously difficult to map.

Transport safety inspection data

Transport safety inspectorates collect some data that might also be of use in freight transport modelling. Their main forms of inspection are usually roadside inspections and firm inspections, both checking whether working and driving time regulations and cargo weight regulations are being followed. This includes checking the working and driving times recorded by on-board units and the cargo plus vehicle weight at specific weighting sites or on the road itself (weigh-in-motion measurements).

Network data

These are the standard transport engineering data on links, link capacity, nodes, distances and transport times. They can be organised by mode (road, rail, waterways, etc., networks) or be combined in a multimodal network that would also include transhipment links.

Apart from this, there can also be timetables for transport services that operate at fixed times, such as liner services in sea transport, shuttle trains, etc..

Cost functions

Transport cost functions are usually given by mode, but sometimes also for different vehicle types within a mode. They might depend on the shipment size (e.g. lower unit rates for bigger shipments). The costs functions are sometimes based on data from a sample of firms (e.g. quoted freight rates or survey data on cost), but can also simply be based on assumptions provided by experts. Apart from transport costs information, logistics costs also consist of information about for instance order, storage and capital costs. More detail on costs functions can be found in chapter 6 of this report.

Terminal data

These are data on seaports, inland ports, airports, rail terminals and consolidation and distribution centres within road transport on attributes such as the location, types of goods, throughput, and costs.

7.6.3 Which data sources can be used in which type of model?

In Table 7-3 we repeat the overview of data sources from section 7.6.2 and add for each source its possible uses in freight transport modelling.

Table 7-3. Different data sources and how they can be used in freight transport modelling that is related to mode choice

Data sources	Use in freight transport modelling for mode choice
Transport statistics	Estimation of OD matrices for the base-year
	Estimation of gravity-type models for generation and distribution at the OD level (less appropriate than at the PC level)
	Estimation of aggregate mode choice models
	Load factors (cargo weight to vehicle capacity)
	Aggregate port choice models
	Models for road vehicle type choice, tour formation and empty driving/load factor if micro-data available
Shipper surveys	Estimation of PC matrices for the base-year
	Estimation of disaggregate mode choice models
	Estimation of transport chain choice models
	Estimation of disaggregate shipment size choice models
	Estimation of disaggregate joint models (mode-shipment; mode-supplier)
	Value-to-weight ratios
Stated preference surveys	Estimation of disaggregate mode choice model
	Estimation of route choice models
	Estimation of transport chain choice models
	Estimation of disaggregate shipment size choice models
	Estimation of disaggregate joint models (mode-shipment; mode-supplier)
	Monetary value of service attributes (e.g. value of time)
Consignment bills and RFID data	Estimation of OD matrices for the base-year (possibly PC, if tags stay on after transhipment or if combinations of tags registered at transhipment)
	Estimation of disaggregate mode choice models
	Estimation of disaggregate shipment size choice models
	Estimation of disaggregate joint models (mode-shipment; mode-supplier)
Traffic count data	Estimation of OD matrices for the base-year
	Estimation of route choice models
	Calibration data
Traffic safety inspection data	Load factors
Network data with costs functions	Direct input for the estimation of aggregate and disaggregate mode choice models and joint models
	Indirect input for aggregate distribution models
	Direct input for the estimation of route choice models
Terminal data	Direct input for the estimation of transport chain choice models

Table 7-3 can also be read from right to left: given that one wants to develop a certain model, base matrix or set of conversion factors in the context of freight transport modelling, the data sources that can be used for this are in the left-hand side column. This is also further discussed in the next section.

7.6.4 Discussion on data availability and model form for modal split

The estimation of aggregate mode choice models calls for transport statistics data by mode. These are available in most countries. The information that is required for the estimation of disaggregate mode choice models, shippers surveys, stated preference surveys or consignment bill data, is not so often available. The same data could be used for joint models of mode and shipment size (or shipment size by itself), but especially stated preference surveys are also often carried out to obtain monetary values of service attributes such as transport time and reliability.

If the generation and distribution model would be at the PC level, the corresponding consistent mode choice component would be a transport chain choice model. In principle, this could be both an aggregate or a disaggregate transport chain choice model. However, aggregate information on actually used transport chains is very scarce and limited to records of transhipment activities at intermodal terminals and in some cases statistics of access and egress movements related to intermodal terminals. The limited direct observations that we have of transport chains comes from disaggregate shipper surveys (including commodity flow surveys). In this case, it doesn't make much sense to aggregate the disaggregate transport chain information so that an aggregate transport chain model can be estimated. Better use of the data (with less aggregation bias) then would be to use the disaggregate data to estimate disaggregate transport chain choice models (that can be used for aggregate predictions). In all cases for a transport chain model one also needs network data (time and cost by mode), cost functions and data on the terminals for transhipment.

Information on observed use of different routes from traffic counts can be used to estimate network assignment models (alternatively in SP interviews one can collect information about stated route choices). Typically however, network assignment models do not use information on observed choices or market shares, but use a deterministic rule to assign vehicles to a shortest path (possibly also using information about link and node capacities). The only information required then is network data, in some cases with information about the value of time versus cost. In some cases traffic counts are used to calibrate parameters in the route choice model.

The same modelling philosophy that is routinely used in network assignment can also be used for other choices where information on observed choices is missing. In the absence of information about transport chains, one might use a deterministic model that predicts the transport chain choice on the basis of minimisation of the full logistics costs (Ben-Akiva and de Jong, 2013). However, the outcomes of this are normative, not necessarily realistic (the latter problem can be reduced by a calibration of the predictions to other data, such as mode shares at the OD level from transport statistics).

For building the conversion modules, data can come from trade statistics (value-to-weight ratios for export and import), and shipper surveys (export, import and domestic flows), provided that they record both the values and the weights. Questions on the volumes (m^3) might also be asked in shipper surveys and could be used as explanatory variables in mode choice and transport logistics choices (especially on the load factor). For observed information on the load factor the transport statistics (especially the OD-based interviews with the truck operators) can be used, but also the vehicle and load weight data from traffic safety inspections (though there might be a bias towards overloaded vehicles).

Aggregate port choice models can be based on port statistics (together with network information at the sea and the hinterland side). Aggregate vehicle type choice models (not ownership of the vehicles, but their use) need information on the vehicle type use shares, preferably per OD. Disaggregate vehicle type choice models are also possible, but for estimation need micro-data from interviews with the truck operators. For modelling tour formation and the amount of empty driving and the load factor of trucks at the disaggregate level, one also needs to have access to micro-data from interviews with firms that are operating the trucks.

Many transport models use the pivot-point method: the models are only used to give changes in the flows between the base year and a future year, and these changes (usually in the form of ratios, sometimes in the form of differences) are applied cell-by-cell to the base matrices (that represent the situation for the base-year, as much as possible based on observed information). Pivotting can be done at the OD level as well as at the PC level (even in the same model system both can occur). PC base matrices can be based on trade statistics, national account data and shipper surveys. OD base matrices can be established on information from transport statistics, consignment bills and RFID data and traffic counts.

7.6.5 Concluding remarks on data

Data availability is key for modelling. There is a long tradition of data acquisition for freight transport, through statistics for trade and freight trips by all modes of transport. Also, traffic counts distinguish between freight and passenger movements. At the same time, there are areas which are unobserved and notoriously difficult to map, due to the fact that current statistical systems are not developed enough, or due to the proprietary nature of business information. These include:

- Costs of freight transport and related logistics processes (loading/unloading, cross-docking, transhipment, storage, production, administration).
- Content of transport units, be it vehicles or containers. These are observed as “boxes” with a content that may be recorded in bills of lading but is seldomly transferred into statistical systems. Trade statistics may have this detailed information but lack the specificity of transport statistics in terms of spatial detail or mode of transport.
- Consumer choices that have an indirect influence on freight but can have a strong impact, such as temporal or spatial choices in shopping behaviour, or in e-commerce.

In general, disaggregate data is hard to obtain on a systematic basis and for larger populations, without a special arrangement about confidentiality and level of detail (anonymous and generally only aggregate) in dissemination. In the past, governmental statistical offices were the ones who had exclusive infrastructures in place to create statistics for the public or to carry out unique, large scale surveys. Currently, this field is changing quickly. Firstly, data capture is becoming digital to an increasing extent (from paper based surveys to web based, further towards capture from operational transport management systems). This implies that potentially the flow of data can increase at no additional costs (or even, at lower costs). Secondly, as the transport world is entering the digital age, data sources are no longer isolated (by mode, firm or jurisdictional area) but can be exploited to the full as it covers entire global supply chains. This implies that transport data repositories will be created that cover entire supply chains or transport chains. Thirdly, there is a strong drive towards sharing data across supply chains and extending the reach of data availability outside the conventional business relations to new communities.

The challenge for transport modelling research is to follow these technological developments and create safe environments for experimentation, to allow development of models based on as much data as possible, and more data than was ever available. The consequences of these “big data” developments can be huge. One could speculate that the heterogeneous nature of freight would not be an important unknown factor, as it is now in many models, but would be known in all detail. Big data analytics could also lead to the discovery of new explanatory patterns that help us to understand the drivers of freight transport demand and supply. Potentially, it could break new ground, replacing our present causal models and theories by correlations and associations between data that provide a better explanation of how freight moves.

7.7 Choice of modelling approach

7.7.1 Introduction

The choice of the best freight transport model in a specific situation depends on many criteria, data availability (as discussed in the previous chapter) being only one of these.
The relevant criteria can be decomposed into two groups;

- The demand side: the objectives on the model and related to that the questions the model is intended to answer. But also criteria like transparency of the model for the user can be grouped here.
- The supply side: what is technically possible, including considerations of data availability, what different modelling techniques have to offer, but also the available know-how, time and money budgets for model development and runtime of the model in application?

Often different model types need to be combined in a single model system to answer specific questions. The four-stage transport models and their freight-transport-specific extensions consist of several model types (e.g. I/O models, aggregate modal split models and network assignment) that are all needed to give the impacts on transport of adding new links to the transport networks.

A single type of model or model system that is best on all relevant criteria does not exist. Even if one would only consider the criterion of which policy questions the model should be able to answer, this would already lead to a mix of different models. The most comprehensive and complex model is not always the best model. A model should not be more complicated than is necessary to answer the questions asked (this rule is sometimes called ‘Occam’s razor’, after the medieval philosopher who first proposed this rule). On the other hand, a model should also not be so simple that its answers will be a too inaccurate reflection of reality, which usually is very complex.

However, it may also not be wise to develop separate models for every separate policy question. Such models may be optimal on the specific criterion of providing the best possible answers to policy question, but may require much heavier investments in model development than a limited number of multi-purpose models. Moreover, especially in the context of societal cost-benefit analysis (and/or multi-criteria analysis) it can be considered an advantage if several proposed transport projects and policies have been appraised using the same model, so that the outcomes will be more comparable than with different models. Multi-purpose models can also have components that can be turned on/off for answering specific questions.

So advantages of multi-purpose models are comparability of the outcomes and a more solid justification of the model development cost. But multi-purpose is not the same as all-purpose. In our view, the best choice on the criteria on model form in most situations will lead to a combination of different freight transport models for the same study area (which could be linked to each other).

In section 7.7.2 we will first discuss the need to have both relatively simple models with a wide scope and comprehensive models that focus on depth of detail. Then in section 7.7.3 the importance of the model objectives and the research questions on the choice of model form is discussed. The second group of criteria on model choice, the supply-side criteria, is discussed in section 7.7.4. Finally in section 7.7.5 we provide some concluding remarks on comprehensive versus simplified models.

7.7.2 High- and low-resolution models

In de Jong et al. (2004a) first a review of the model types at the national and international level[1] available at the time is given, followed by a recommendation to develop an integrated family of mutually consistent models at two different levels of resolution:

- A detailed, high-resolution, model system for spatial planning
- A fast, low-resolution, policy analysis model.

The main reason for having these two different family members is that each of them can handle different questions. The low resolution model can be used for policy analysis, which is about distinguishing between promising and unpromising policy alternatives, in an uncertain world where many issues are interrelated. This should only give first order approximations, which can then be worked out into specific project proposals and subsequently be simulated in the high-resolution model to assist the actual decision-making about transport projects and policies.

Other reasons for having two sets of freight transport models at the same time for a state, country or group of countries are that the high-resolution model may be expensive and time-consuming to run for many possible policy actions, whereas accuracy requirements and need for detail in the initial stages are lower. Finally decision-makers in different stages may have different cognitive needs and may therefore require information at different levels of detail.

Figure 7-1 shows how the low-resolution model system and the high-resolution model provide different levels for the model's scope (the breadth of the model in terms of the number of factors or markets included) and the model's depth of detail (the amount of detail for the factors that are included. Models that are neither wide nor deep are not particularly interesting. Policy analysis models (low-resolution) will preferably include a wide range of factors (e.g. not just the freight transport market, but also land use, emissions, the economy), but for each of those factors limited detail will be included. High-resolution models for project appraisal and spatial planning will focus on freight transport, taking factors such as the economic conditions and land use as given (possibly through scenarios), but with more detail on freight transport itself in terms of commodity types, number of zones and size of the transport networks. Models with a lot of factors and a lot of detail per factor have also been attempted. Even though modern

[1] To this family of two can be added urban freight models for cities within the national or international study area.

computing technology is able to handle much larger computational problems that in the past, 'models of everything' are not commendable. They often become highly non-transparent (the same changes can be caused by different factors) and unstable because so many things are treated as endogenous and so little is taken as exogenous.

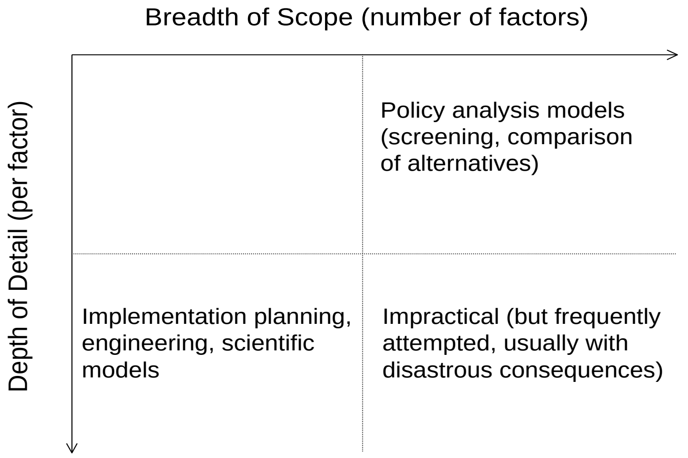

Figure 7-1. Different types of models with different scopes and levels of details (from de Jong et al., 2004a)

The types of low-resolution models that come to mind for policy analysis are elasticity-based and trip-rate based models (e.g. de Jong et al., 2004b; or the HIGH TOOL model that is now being developed for the European Commission) and system dynamics models (e.g. ASTRA consortium, 2000). SCGE models (see chapter 2) also cover a considerable breadth of scope (various interconnected markets, such as for transport services, land use, labour and goods), without treating (freight) transport in detail, and might also be used for policy analysis purposes, provided that they remain relatively simple in structure and fast (and easy) in application.

A high run time for a model is in practice often caused by equilibration processes which require that the same calculations are made over and over again to find or at least approach an equilibrium situation (iterative model applications). An example is network assignment with capacity constraints, or a model with feedbacks in the form of OD transport times from assignment to transport demand. For a policy analysis model a better choice may well be to ignore such constraints and feedbacks or to approximate them within a single model run.

A low-resolution model can be developed independently, but it can also be based on one or more high-resolution models. In the latter case it becomes a 'repro-model' or 'simplified model'. One way of achieving this is to do a systematic set (but only once and for all) of runs with the detailed model, and then to estimate a repro-model on the outcomes of the detailed model, so that the low-resolution model will have basically the same response characteristics as the high-resolution model and becomes a fast and approximate version of it. One might also pull out basic equations from the detailed model and leave out equations, variables and feedbacks that are of lesser importance.

7.7.3 Model objectives and policy questions and their impact on model form

Freight transport models are used to assess the impacts of different types of autonomous developments and policy measures, such as changes in national regulations and taxes or infrastructure investments in specific links, nodes and corridors. A wide range of models and model systems are applied by public agencies. Furthermore, a lot of freight transport modelling takes place at universities and at the individual firm level. Models to optimise transport and logistics within a specific firm or supply chain are not discussed in this chapter. Nevertheless, there are many things that models for government agencies or models in scientific research can learn from models for the private sector.

Freight transport models for public agencies are used for assisting decision-making on the following transport policy measures:

- Changes in national regulations (e.g. on working and driving hours and maximum allowed vehicle loads) and taxes;
- Infrastructure investments in specific links, nodes and corridors (new roads, railway lines, canals, ports, multi-modal terminals, locks, but also extensions of the current infrastructure in these respects);
- Traffic management, such as variable message signs, on-ramp metering, variable speed limits, peak hour and reserved lanes, priorities in road and rail (e.g. freight trains versus passenger trains) traffic;.
- Pricing measures, such as road pricing per location and time-of-day, or railway infrastructure charges.
- Spatial and temporal planning measures, such as restrictions on locations for manufacturing or warehouses, low or zero emission zones or delivery time windows for retailers.

Furthermore, there is an interest in the impact of autonomous developments (e.g. economic development, population change, employment, oil prices, ...) on transport.

For policy questions about the influence of autonomous factors and about the impact of changes in regulations and taxes and uniform pricing measures, rather general models (like the low resolution models discussed above) might be sufficient; detailed zoning systems and networks are not required, unless outcomes for specific zones and links would be asked.

However for policy questions about the transport impacts of infrastructure investment projects, traffic management, charging by location and time-of-day and spatial planning measures, detailed network models are indispensable. Especially for traffic management measures, a detailed representation of the flows on the network is needed. For evaluating the impact of time-period-specific pricing measures and temporal policies, the network model needs to be supplemented by a freight transport departure time choice model (which is very uncommon in freight transport modelling, but might be done on stated preference data).

Decision-makers may want to know the impact of the above policy measures and autonomous developments (in various combinations) on transport, in the short, medium and long run, at different spatial scales. Different timescales and different spatial scales call for different types of models.

For the short run (say up to 1 year) and also the medium run (a couple of years), there is more scope for time series models, that start from the current patterns and focus on the changes over time[1], especially if the changes are relatively small and few. For the long run (5-30 years ahead), cross-sectional models (aggregate models such as gravity or I/O models as discussed in chapter 2; or disaggregate models such as logit models for individual mode choice as discussed earlier in chapter 7) that explain transport 'from scratch' may be more appropriate.

If outcomes are only required for the study area (such as a state or country) as a whole, relatively simple and fast models (such as the policy analysis models above) may be sufficient. Should outcomes be needed for a large number of zones within the study area, a high-resolution model enters the picture. An example is the appraisal of new infrastructure links, where one needs to predict an OD matrix that is assigned to the network with and without the new link to obtain the impact of the transport project on transport.

Another relevant consideration is the type of output indicators that are required. In the case of freight transport this may be:

- Transport volumes in tonnes and tonne km (by mode);
- Vehicle km (by mode);
- Number of vehicles on specific routes;
- Number of vehicles by route and time period.

In order to get predictions for the number of tonnes and tonne km by mode one needs models of generation, spatial distribution (including inventory chains) and mode choice (or transport chain choice). But for the number of vehicle km one also needs to model the shipment size distribution, the allocation of vehicles to shipment sized and the empty backhauls (though often this is simply done by assuming fixed load factors and empty trip factors).

To generate vehicle intensities per link of the network, assignment procedures are needed. Often these are the most time-consuming parts of a model run.

Apart from the impacts of autonomous developments and policy measures on transport itself, public decision-makers often want to know the impact of these through transport on the economy and employment (the 'indirect effects of transport') and on fuel use, local and greenhouse gas emissions, safety, nature (the 'external effects of transport'). This either requires the use of unit rates for these effects (that are combined with outcomes on transport) or of specific models or model components on these issues (such as atmospheric pollution models for the spread of harmful emissions from traffic). In both cases, for CBA one also needs monetary values for these units.

[1] This also holds for doing pivot–point analysis: this is more important for medium run forecasts than for long run predictions, since the further away one gets from the present, the less important it becomes to start from a good representation of the current patterns.

7.7.4 Approaches for simplification

In this section we discuss several modelling options for simplifying high resolution models. This section discusses the specific choice situations around high resolution models that regularly occur in practice. We see three strategies for simplification:

- Simplification by omission of sub-models
- Simplification by integration of sub-models
- Simplification by a reduced data need

Simplification by omission of sub-models

In this report were we focus on options that are directly relevant for modal split. In chapter 11 of Tavasszy and de Jong (2014) are also options for omitting input-output based approaches.

Simplification by integration

A second strategy for simplification concerns the combination of parts of the framework into integrative models. Note that this approach, in contrast to the one above, does not eliminate parts of the framework, but mainly simplifies the *structure* of the model by combination of sub-models. Figure 7-2 shows two simplifications, one occurring in the upper third of the figure (one integrative model for the market of goods), the other in the lower third of the figure (one integrative model for transport network choice). Integrating network assignments of different modes in a supernetwork approach is useful as it provides additional information on possible intermodal transport movements. Besides this improvement in consistency and information content, the advantage of this freight model architecture is also the good fit with current policy questions in logistics (Tavasszy et al. 2003).

Multimodal network modelling requires less data on observed transport outcomes than aggregate choice models. In the model, transport chains with different modes in a sequence and transhipment locations can be found by searching for the shortest (fastest or cheapest) path in a multimodal network, and all that is required is this multimodal network. For validation purposes, however, additional data is required as the model generates transhipment flows. The downside of a deterministic assignment is that the researcher has little scope for controlling this optimisation process (e.g. through calibration parameters), because there are hardly any such parameters. In reality mode-route alternatives may be chosen in quite different proportions than obtained from the costs minimisation in the multimodal assignment, because decision-makers also take other factors into account (e.g. reliability, flexibility, perceptions on certain modes). In stochastic (e.g. random utility) models of mode choice such influences are accounted for in modal constants and error terms[1]. Furthermore, deterministic multi-modal assignment might lead to overreactions to exogenous changes, because of the all-or-nothing character of the underlying mechanism.

[1] In some stated preference models these factors have been made explicit as attributes of the modes.

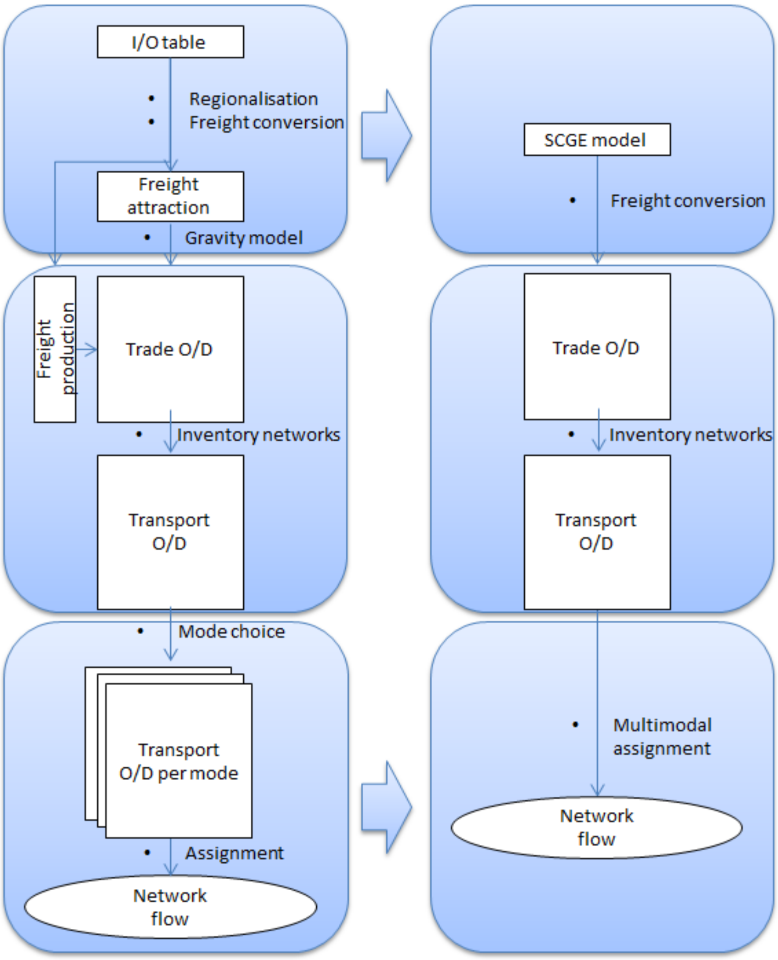

Figure 7-2. Options for simplification of the structure of freight models through combination

Our recommendation is to handle mode choice, and if possible transport chain choice in a probabilistic model. This can either be a probabilistic discrete choice model (aggregate or disaggregate) or a probabilistic multimodal assignment (all these models were discussed in section 6). If one would include the mode choice in a larger model system as a discrete choice model, the subsequent assignment can be uni-modal. In case of a discrete choice transport chain model, the assignment still needs to determine the optimal transhipment locations for every type of transport chain (e.g. which ports are optimal for road-sea-road?), as well as the best route for each uni-modal leg of the transport chain (two road legs and one sea leg in the example just given).

Simplification by reduced data need

A third strategy for model simplification concerns the reduction of the specification of sub-models (and, in particular, the choice models) by using aggregate instead of disaggregate data. We explore this strategy for the choice model where these choices have been most debated: the mode choice model.

Aggregate modal split models require for estimation only data on the shares of the mode by OD or PC pair (combined with cost and/or time by mode), if possible by commodity type. For disaggregate models, micro-data about the mode choice for specific shipments are needed. Disaggregate models have as advantages that they have a more direct base in a theory of individual or company behaviour and that it becomes possible in these models to include more attributes, such as those related to the shipper, the receiver, the carrier or the shipment as a explanatory variables in the model. The main advantage however is that they do not assume that there is an optimisation of mode choice at the zone-to-zone level, but at the level of individual shipments (though possibly allowing for consolidation of individual shipments).

So, if a sufficiently large sample of micro-data on individual shipments is available, it remains hard to argue in favour of aggregate models, and the researcher is recommended to treat mode (or transport chain) choice in a disaggregate fashion. In the absence of such data, there are still possibilities for developing a deterministic micro-level model, but this would be lacking a direct empirical basis. An aggregate modal split model would be a perfectly justifiable choice under such circumstances.

7.8 Concluding remarks on comprehensive versus simplified models

Our preferred answer to the question whether one should have a comprehensive or a simplified model is to have both types of models. The simplified model can be used for initial screening of policy options and projects and for the impact of more general (not location- and time-specific) measures). The comprehensive model then is the most appropriate model to use for assisting project appraisal, traffic management and policy measures that are location- and/or time-specific.

Modal split is only one of many components of a freight transport model. In terms of policy/project effects it is likely to be the most important but not the only one (also see the elasticities in the next chapter).

The choice of model type in specific situations (e.g. choice of a generation/distribution model or choice of a modal split model) not only depends on data availability, but also on theoretical considerations, the question how many and which explanatory variables one wants to include and the question whether one wants to represent links with other sectors (e.g. the wider economy) or not.

In terms of types of models for modal split, there seems to be a divide between proponents of disaggregate and of aggregate models. However, there is wide support for the following model choice rule: when disaggregate data are available, these should be used for a disaggregate model and when there are no disaggregate data (which will almost always be the case in JASPERS countries), then it will usually be more efficient to develop aggregate models than to collect new disaggregate data.

8. Freight transport elasticities

Chapter 8 of this report is mainly based on Tavasszy and de Jong (2014), chapter 9 and VTI and Significance 2010).

8.1 Derivation of elasticities from transport models

Practically all elasticities that can be found in the literature (published and grey) are derived from models. Elasticities from direct observation of the situation before and after a price or time change are extremely uncommon (and in such cases the issue always is how to decompose the observed changes into changes that would have happened anyway and changes that are the result of the policy under investigation.

Elasticities can be used in simple elasticity models, but can also be used as reality check when building transport models (e.g. logit models). Applying elasticity models in practice is not always straightforward, it might for instance be difficult to determine the % change in transport time from an absolute time gain (what is the appropriate transport time in the base case?).

The advantage of elasticities is that they are dimensionless, i.e. a change in the unit of measurement (for instance from kilometres to miles) does not affect the elasticities. Elasticities give the ratio of a percentage change in demand or supply (e.g. road tonne-kilometres) to a percentage change in one of the factors explaining demand or supply (e.g. price of road freight transport). Model coefficients (that give the reaction of model outputs to model input variables, such as transport costs) are not dimensionless, so it is very hard to compare these across models. Moreover, for logit models it is not appropriate to compare a single coefficient, such as the cost coefficient, between different models, since the choice probabilities are affected by all variables in the model and the random utility component. However, ratios of coefficients, such as the value of time (time coefficient divided by costs coefficient) can be compared across models, and so can direct elasticities calculated from the models. An example of estimated cost coefficients for an aggregate multinomial logit model (the modal split model in TRANSTOOLS) is given in Annex 3, together with the implied elasticities.

In this chapter, we use the following **general definition** of elasticity:

An elasticity gives the impact of a change in an independent (or stimulus) variable on a dependent (or response) variable, both measured in percentage changes.

Elasticities are defined using the 'ceteris paribus' condition: they are valid under the assumption that all other things (e.g. other independent variables) do not change.

An elasticity can be positive or negative. If an elasticity (in absolute values) exceeds 1, the dependent variable is called 'elastic' (e.g. elastic demand) w.r.t. the independent variable

Some basic distinctions

A first distinction is between point elasticities and arc elasticities. A point elasticity measures the proportionate change in the dependent variable resulting from a very small proportionate change in the independent variable. The price (P) elasticity of demand for commodity Q in terms of a point elasticity is:

$$E_p = (dQ/Q) / (dP/P) = (dQ/dP) . (P/Q) \qquad (8\text{-}1)$$

In this formula dQ/dP is the derivative of the (ordinary or Marshallian[1]) demand function w.r.t. P (the slope of the demand function).

An arc elasticity is applicable if the change in the independent variable is not very small, whereas point elasticities are appropriate for small changes. An arc elasticity is defined as:

$$e_p = (\Delta Q/\Delta P). (P_1 + P_2)/(Q_1 + Q_2) \qquad (8\text{-}2)$$

In which the subscripts 1 and 2 represent the situation before and after the change in price. Whether an arc elasticity will be higher or lower than a point elasticity depends on the shape of the demand function (e.g. concave or convex).

Another distinction is between own and cross elasticities. If for instance we are studying mode choice, the own (or direct) elasticity gives the impact of an attribute of some mode on the demand for that same mode, e.g. the road transport cost elasticity of road freight tonne kilometres. A cross elasticity measures the impacts on other modes, e.g. the road transport cost elasticity of rail freight tonne kilometres.

We use transport price and cost as synonymous here; most freight transport markets have small profit margins.

A disaggregate elasticity measures the reaction of an individual (can be an individual firm). Such elasticities can only be derived from disaggregate models, e.g. the (logit) mode choice models discussed below. For policy-making, aggregate elasticities are mostly more interesting. They refer to the responsiveness of a group of individual firms (possibly the entire market). Aggregate elasticities can be derived from aggregate models and from disaggregate models. Elasticities that are calculated from a model depend on initial situation and/or the amount of change in the stimulus variable. In other words: the elasticity from a model can vary. There is one exception to this rule, which is called the 'Constant Elasticity of Substitution' CES or 'double-logarithmic' function.

For instance the (own) elasticity from a logit model with a linear utility function is given by:

$$E_{x_{rik}}^{ik} = \beta_r x_{rik} (1 - P_{ik}) \qquad (8\text{-}3)$$

In which:

[1] Practically all elasticities in freight (and passenger) transport modelling are 'ordinary' elasticities, meaning that they contain a substitution and an income effect of a price change, as opposed to 'compensated' elasticities that keep income constant (using the Hicksian demand function). Also see Oum et al. (2008).

E stands for the elasticity for the impact of a change in the r'th independent variable x_{rik} that is part of the utility function for alternative i for individual (firm) k on the probability P_{ik} of k choosing alternative i.
β_r: the estimated coefficient for the r'th independent variable.

Because of the presence of the P_{ik} term in eq. (8-3), all coefficients of the model affect the elasticity, not just the one for the r'th variable. The elasticity from an aggregate or disaggregate logit model (after sample enumeration) only gives the impact of the change in the independent variable on the distribution of a given total over the alternatives (such as the modal shares). This does not include an impact of the change in price or time on the total demand (over all modes), that is included in ordinary demand elasticities (Oum et al., 2008).

The double logarithmic form is:

$$\ln(y_k) = \ldots\beta_r \ln(x_{rk}) + \ldots. \tag{8-4}$$

In which:
Y_k: dependent variable (of a continuous nature), with observations k = 1, …, K.
X_{rk}: the r'th independent variable.

The elasticity for a change on x_{rk} is constant at β_r.

Elasticities usually come from models, estimated on empirical data, but in some cases, elasticities can be calculated from direct observations of the impact of a change (e.g. introduction of a toll), from before and after studies. The data used for model estimation can be time series data, cross section data or panel data. If a time-series model contains lagged parameters, the model can distinguish between short and long term effects. Whether the effects from a cross-section are short or long term depends on a judgement on the nature of the behavourial mechanisms included (e. g. location decisions are regarded as long run). In general, long run elasticities are larger than short run elasticities, because in the long run more response mechanisms are available.[1]

8.2 Differences in elasticities

Very often considerable heterogeneity in elasticity values has been found. There are two basic explanations for this:

1. Different elasticities seem to be referring to the same thing, but are taking into account different response mechanisms, that may be working at different timescales. The response mechanisms for rail freight transport are discussed in chapter 2.
2. Price elasticities can be different because they refer to:
    a. Different market segments (e.g. commodity classes, distance classes, geographic markets), with different substitution possibilities: if two goods are close substitutes, the cross-price elasticity (e.g. effect of road transport prices on rail demand) can be expected to be high

[1] This is assuming that all response mechanisms, short and long run, have the same sign. This is usually the case, but there could be exceptions, e.g. when the price of a high-capacity mode or vehicle type goes up, this could also lead to lower frequencies and bigger shipments, which by itself favours large capacity modes and vehicle types.

and the own-price elasticity (in absolute terms) will also be higher if close substitutes exist.

b. Different components of total transport costs (e.g. infrastucture fees, energy cost or fixed vehicle costs).
c. Price increases versus decreases; according to prospect theory, decision-makers will react more strongly to losses than to gains, so elasticities for price increases could be larger than for price reductions (however, most models used in practice do not take this into account).
d. Price changes of different magnitude (this refers to the distinction between point and arc elasticities, but also arc elasticities for changes of different magnitude can be different); if the slope of the inverse demand function decreases with increasing price (reflecting satiation), then large price changes will lead to smaller elasticities than small price changes.
e. Different definitions of a transport mode (e.g. trip mode versus main mode of transport chain).

Furthermore, especially cross-elasticities can be very different depending on the market shares of the modes in the base situation. This also means that cross elasticities are not really transferable from one country to the other if these countries have different mode shares. In this project we will not provide estimates for cross-elasticities.

8.3 Tonne kilometre price elasticities

Changes in tonne kilometre prices may result in various responses of rail operator, forwarder and shipper. These were discussed in detail in chapter 2. The literature does not distinguish all these response mechanisms separately. On the basis of the literature, the following composite response mechanisms may be distinguished:

- *Change in mode;* substitution to and from road, inland shipping and (short) sea shipping.
- *Changes in transport demand;* due to the changes in tonne-kilometre prices shippers may choose other supplier/receivers or other production locations. These decisions may lead to changes in total transport demand (without changes in tonnes shipped).
- *Changes in commodity demand;* if the shippers cannot 'internalise' the transport price changes by themselves, they have to increase the price of the goods they offer. As a consequence consumer demand can fall and thereby total transport demand.

Based on the results of the literature review we will first discuss the price sensitivity of these three effects separately. The rail tonne-kilometre price elasticities are in Table 8-1.

Table 8-1. Overview of rail tonne-kilometre price elasticities

Study	Country	Period	Dependent variable	Response mechanisms[a]	Elasticity
Effect on rail tonne-kilometres					
Beuthe et al. (2001)	Belgium	1995	Tkm	9	-1.1 to -1.3
Björner & Jensen (1997)	Denmark	1967-1990	Tkm	9/10/11/12	-0.9 (manufacturing)
				9	-0.8(manufacturing) 1.1 to -1.5 (other)
				10/11/12	-0.1 (manufacturing)
Friedlaender & Spady (1980)	USA	1972	Tkm (ton-miles)	9/10/11/12	-1.45 to -3.55
Inabe & Wallace (1989)	USA	1984	Tkm	5/9/12	-0.1 to -1.1
De Jong (2003)	EU (Scenes)	90ties	Tkm	9	-2.66
	Belgium	90ties	Tkm	9	-1.40
	Norway	90ties	Tkm	9	-3.87
	Sweden	90ties	Tkm	9	-1.95
	EU (Expedite)	90ties	Tkm	9	-1.48 to -1.73
Oum (1989)	Canada	1979	Tkm	5/9/10/11/12/13	-0.60[b] (-0.64 to -1.52)[b]
				9	-0.54
				5/10/11/12/13	-0.06
Effect on rail tonnes					
Abdelwahab (1998)	USA	1977	Tonnes	5/9/13	-0.91 to -2.49
Beuthe el al. (2001)	Belgium	1995	Tonnes	9	-1.3 to -1.8

Study	Country	Period	Dependent variable	Response mechanisms[a]	Elasticity
Chiang, Roberts & Ben-Akiva (1981)	USA	70ties	Tonnes	5/9/12	-0.00 to -2.4
De Jong (2003)	EU (Scenes)	90ties	Tonnes	9	-1.97
	Belgium	90ties	Tonnes	9	-0.87
	Italy	90ties	Tonnes	9	-0.82 to -1.51
	EU (Expedite)	90ties	Tonnes	9	-1.09 to -1.21
NEA (2007)	Europe (Transtools)	Around 2001	Tonnes	9	-0.07 to -1.08; average: -0.40
Picard and Gaudry (1998)	Canada	1979	Tonnes	9	-0.42 to -0.76
Windisch (2009)	Sweden	2003-2004	Tonnes	5/9	-0.68 to -3.2
Winston (1981)	USA	1975-1977	Tonnes	9	-0.02 to -2.68
Effect on mode choice for rail					
De Jong & Johnson (2009)	Sweden	2001	Mode choice	5/9	-2.42[c]
				9	-0.13
McFadden, Winston & Boersch-Supan (1985)	USA	1977	Mode choice	5/9/10/11/12/13	-1.16
Nam (1997)	Korea	1988-1989	Mode choice	9	0.62 to -0.76

[a] The response mechanisms are:

1. change in energy efficiency by using more energy-efficient trains;
2. change in fuel efficiency of driving;
3. optimizing allocation of wagons/trains to shipments;
4. change in number and location of depots;
5. change in shipment size;
6. change in consolidated shipments;
7. change in empty driving;
8. change in trip length;
9. change in mode;
10. change in production technology;
11. change in production volumes per location;
12. change in suppliers/customers (change in PC patterns);
13. change in commodity demand.

[b] This value is for the most flexible functional form (translog); the values between brackets give the range for more restrictive functional forms (log-linear, linear, Box-Cox and logit).

[C] This value, that includes substitution between shipment sizes, is for the shipment size 15-30 tonnes. So it gives the effect of a price change for rail transport for this shipment size category. Substitution can be to other modes and other shipment sizes.

Mode change

In terms of the types of models (focussing on mode choice) discussed in chapter 6:

- Beuthe (2001) are aggregate models of mode and route choice (multimodal assignment);
- Björner and Jensen (1997) is an aggregate MNL mode choice model coupled with a trade model;
- Abdelwahab (1998), Windisch (2009), de Jong and Johnson (2009) and McFadden et al. (1985) are disaggregate models of mode and shipment size choice;
- Chiang et al. (1981) is a disaggregate model of mode shipment size and supplier choice;
- De Jong (2003) reports on a multimodal assignment model for Belgium and one for Europe (within SCENES), a model with disaggregate mode choice (MNL model) for Italy and an elastity-based meta-model for Europe (EXPEDITE); The elasticities for Norway and Sweden in de Jong (2003) were derived from older versions of the national freight models NEMO and SAMGODS, using the STAN software. The EXPEDITE model described in De Jong (2003) gives an average value for Europe for the modal split effect of around -1.6.
- NEA (2007) refers to an aggregate MNL model for mode choice (within the Transtools 1 model for Europe), and so does Picard and Gaudry (1998);
- Winston (1981) and Nam (1997) are MNL models of mode choice on disaggregate data;
- Friedlaender and Spady (1980) are Oum (1989) and models for transport demand (expressed as a share of total production cost) on aggregate data.

Several studies included in the literature review pay attention to the effect of changes in tonne-kilometre prices on the modal split in isolation (measured in tonne-kilometres): Beuthe et al. (2001), Björner and Jensen (1997), De Jong (2003), Oum (1989). These studies find price elasticities that range from -0.5 to -3.87. This is of course a very wide range, given that the definitions of the input and output variables are similar and we are only looking at modal split as a response mechanism. A substantial part of the differences can probably be explained by differences in the market share of the modes in the different studies. The literature contains little information on the variation of elasticities by market share of the modes. However, elasticities are different at different starting points in terms of market shares, and this is taken into account in the models (most of the models are logit models that have an S-shaped reaction function to changes in price, with smaller elasticities at low and high market shares and higher elasticities in between)[1]. In our view some of the absolutely high elasticities are less relevant for future guidance because they come from multi-modal assignment models. In such models mode choice is modelled together with the usually much more flexible route choice, within a model framework that contains only a few user settings to represent the observed patterns (this goes for the models by Beuthe and the SCENES model and the models for Belgium, Norway and Sweden that are referred to in de Jong (2003). Most of these models have been superseded by other models. In disaggregate or aggregate (logit) choice models many parameters are statistically estimated to reproduce the data as well as possible (without having to mode route choice at the same time). In our view, this should usually produce more reliable modal split elasticities. Friedlaender and Spady (1980) also produce high absolute elasticities, but these are less relevant because they are based on old data (1972) for the US.

[1] An extreme but realistic example is a mode share of close to 100% (e.g. coal transport by rail in several countries). The own elasticities will be quite low here. This also shows that some differentiation by commodity type and/or mode share might be indispensable.

In Table 8-1 also tonne-kilometre price elasticities with regard to mode change measured in tonnes are presented: Beuthe et al. (2001), De Jong (2003), NEA (2007), Picard and Gaudry (1998) and Winston (1981). Winston (1981) finds a wide range of elasticities, which depends heavily on the type of goods considered. Elasticities for the effect on tonnes can be lower (in absolute values) than the elasticities for mode change measured in tonne-kilometres, when mode shifts especially take place in long distance transport (provided the long distance elasticities are larger than those for small distances). In long distance transport, rail and inland shipping can be a competitive alternative for road transport; on short distance transport they usually cannot. This is what we found from the SCENES and Expedite models, but for rail this does not happen in Beuthe et al. (2001). The authors explain this from the very small market share of rail in Belgian short distance transport.

Finally, in Table 8-1 the results of some studies of the tonne-kilometre price elasticities on mode choice, measured as the modal shares in the total number of shipments, are presented. De Jong and Johnson (2009) find a small mode choice elasticity for Sweden (but large shipment size changes) and Nam (1997) finds relatively small values for Korea (including some positive values, which must be wrong). However, it is questionable whether the latter elasticities can be applied on European freight transport.

Changes in transport demand

The effects of changes in tonne kilometre prices on total transport demand are only investigated separately by two studies: Björner and Jensen (1997) and Oum (1989). Björner and Jensen (1997) find an elasticity of transport demand of -0.1 for manufacturing goods. The transport demand effect for rail price changes is much smaller than for road price changes, because rail transport only accounts for 14% of the transport costs in the Danish manufacturing industry (Björner and Jensen (1997). So a change in the price of rail transport will have a smaller effect on overall transport costs (all modes together) and therefore a smaller effect on transport demand than a change in the road transport prices. Oum (1989) provides similar elasticities of rail transport demand in Canada: -0.06[1].

Changes in commodity demand

No studies are found that consider separately the effect of tonne-kilometre price changes for rail on commodity demand. But we expect that the elasticity with regard to this effect will be small (< 0.1). The main reason for this low transport price sensitivity of commodity demand is that rail transport costs account for only a very small part of total commodity prices.

Total effect: changes in tonne-kilometres

Several studies have estimated tonne-kilometre price elasticities with regard to tonne-kilometres including both mode change, transport demand and/or commodity demand in the analysis. This gives a very wide range of tonne-kilometre price elasticities (-0.1 to -3.6). The lower bound (-3.6) of this range is determined by elasticities from Friedlaender and Spady, which refer to freight transport in the USA. Furthermore, this is a rather old study by now. Compared to the studies with regard to European freight transport (e.g. Bjorner & Jensen, 1997) these estimates are relatively high in absolute values. Also Abdelwahab (1998) presents elasticities for the USA (tonne price elasticities with regard to tones) which are relatively high (-0.9 to -2.5). These results suggest that tonne-kilometre price elasticities are higher in the North America than in Europe. Inabe and Wallace (1989), however, present elasticities for the USA which are comparable

[1] This elasticity includes also shipment size effects and changes in commodity demand. Therefore, the actual elasticity of transport demand will be even smaller.

with the elasticities found for European freight transport. The same holds for Oum (1989) with regard to Canadian transport. Moreover, Windisch (2009) found a wide range for rail price elasticities for domestic transports in Sweden. Hence, the literature review do not provide unambiguous evidence that tonne-kilometre price elasticities differ between Europe and North America.

In general, the results on the total effect correspond reasonably well to the elasticity estimates found for the separate effects (mode change, transport demand and commodity demand). The body of evidence (using the 80-20% rule) from the studies reviewed points at a tonkilometre price elasticity for total rail freight between -0.9 and -1.7, of which -0.1 is for transport demand and the rest for modal shift (from Björner and Jensen (1997) we then only use the values for manufacturing goods), using 0 for the impact on commodity demand. Therefore, we recommend to use -0.9 to -1.7 as values for the tonne-kilometre price elasticities with regard to tonne-kilometres.

8.4 Train kilometre price elasticities

Most price elasticities in freight transport refer to changes in the price per tonne-kilometre (see section 3.1). Results for changes in the price per train kilometre are very scarce (see Table 8-2). A change in the train kilometre price can have an impact on transport efficiency (logistics) and transport volumes, and can affect the output dimensions tonnes, trainkm and tkm).

Table 8-2. Overview of train kilometre price elasticities

Study	Country	Period	Dependent variable	Response mechanisms	Elasticity
Ecorys	Netherlands	2002	Trainkm	4/6/7	-0.15
				3	-0.15
				3/4/6/7	-0.30

[a] See below Table 8-1 for a description of the various response mechanisms

The estimate of -0.3 (two times -0.15) for the transport efficiency effect (3/4/6/7) in Table 7-2 was an expert guess (not a model outcome) of Ecorys (together with the Transport Research Centre of the Dutch MoT). We agree that it seems a plausible value. It does not include the effect of longer trains, only the effect of using the wagons more efficiently.

We expect that an x% change in the vkm price will lead to smaller mode and transport demand effects than an x% change in the tkm price. This is because shippers and especially rail transport operators can avoid changes of mode and in transport demand by changing the load of the rail vehicles (the number of tonnes per wagon and number of wagons per train), until the vehicle capacity will be reached. These are the transport efficiency effects discussed above. Changes in vkm prices will be an incentive to change the transport efficiency. Also there will be an incentive to revise the modal and transport demand choices, but not as much as for changes in the tkm price.

8.5 Segmentation of elasticities

Most studies either give elasticities for all commodities together or segment by commodity group (sometimes focussing on one or a few of those). The EXPEDITE study (de Jong, 2003) also distinguished elasticities by distance class for some countries, as well as between conventional rail and combined road-rail. Most studies find relatively higher rail transport price sensitivities for general cargo compared to bulk products (e.g. solid fuel, petroleum, iron ore, fertilisers, stones, wood). This can be a transport demand effect (irrespective of the mode): in general there are more potential suppliers and receivers in general cargo products than in bulk products so it's easier to substitute to nearby suppliers and shorten distances for general cargo. Furthermore, road transport is a better substitute for general goods than for bulk goods – a mode choice effect. Also the general picture is that the elasticities for short distance transport are

Table 8-3. Overview of rail tonne or tkm price elasticities by commodity type

Study	Country	Effect	Commodity type	Response mechanisms included[a]	Elasticity
Abdelwahab (1998)	USA	Tonne or tkm price on tonnes	Food	5/9/13	-1.3 to -2.3
			Textile		-1.6
			Chemicals, Petroleum, coal		-1.1 to -2.0
			Rubber, plastic, leather		-1.2
			Metal products		-0.9 to -2.5
			Electrical and transportations equipment		-1.2 to -2.2
			Stone, clay, glass, concrete		-1.0
			Wood and paper products		-1.3 to -2.1
Beuthe et al (2001)	Belgium	Tkm price on tkm	Agricultural products and animals	9	-2.87
			Food		-1.05 to -1.24
			Solid fuel		-0.18 to -0.55
			Petroleum		-0.02 to -0.14
			Iron ore and scraps		-0.17 to -0.53
			Metallurgical products		-0.89 to -1.10
			Minerals and building materials		-0.82 to -1.11
			Fertilisers		-0.09
			Chemical products		-0.80 to -0.95
			Diverse products		-1.56 to -1.57

Study	Country	Effect	Commodity type	Response mechanisms included[a]	Elasticity
Friedlaender and Spady (1980)	USA	Tkm price on tkm	Food products	9/10/1/12	-1.78 to -4.00
			Wood & Wood products		-1.45 to -2.18
			Paper, plastic, rubber products		-1.56 to -2.06
			Stone, clay, glass products		-1.61 to -1.81
			Iron and steel products		-1.86 to -2.78
			Fabr. metal products		-2.16 to -8.66
			Nonelectrical machinery		-1.99 to -2.77
			Electrical machinery		-1.66 to -5.06
Nam (1997)	Korea	Tkm price on mode choice	Textile	9	-0.004
			Paper		-0.759
			chemicals		-0.264
			Basic metal		-0.540
			earthenware		0.620 (!)
			Electrical houseware		0.154 (!)
			high value goods		-0.03
Oum (1989)	Canada	Tkm price on tkm	Fruit and vegetables	5/9/10/11/12/13	-0.80[b] (-0.39 to -0.80)
				9	-0.69
				5/10/11/12/13	-0.11

Study	Country	Effect	Commodity type	Response mechanisms included[a]	Elasticity
De Jong (2003)	Belgium	Conventional and combined tkm price on tonnes	0-100 km, conventional rail	9	-0.61
			100+ km, conventional rail	9	-2.04
			All distances, conventional rail	9	-1.87
			100+ km, combined road-rail	9	-1.05
		Conventional and combined tkm price on tkm	0-100 km, conventional rail	9	-0.61
			100+ km, conventional rail	9	-1.41
			All distances, conventional rail	9	-1.40
			100+ km, combined road-rail	9	-0.76
	Italy	Conventional rail tkm price on tonnes	Conventional rail	9	-0.82 to -1.51
			Combined road-rail	9	0.04 to 0.06
		Combined road-rail tkm price on tonnes	Conventional rail	9	0.02 to 0.04
			Combined road-rail	9	-0.42
	Norway	Tkm price on tkm	25-100 km, conventional rail	9	-2.03
			100+ km, conventional rail	9	-3.88
			Al distances, conventional rail	9	-3.87
	Sweden	Conventional rail vkm price on vkm	<50 km, conventional rail	9	-0.06 to -0.10
			>50 km, conventional rail	9	-1.49 to -1.95
			All distances, conventional rail	9	-1.49 to -1.95
		Combined road-rail vkm price on vkm	<50 km, combined road-rail	9	0
			> 50 km, combined road-rail	9	-0.84 to -1.71

Study	Country	Effect	Commodity type	Response mechanisms included[a]	Elasticity
De Jong (2003)	EU (Expe-dite)	Tkm price on tonnes	Bulk	9	-1.11
			petroleum products		-1.22
			general cargo		-1.09
		Tkm price on tkm	Bulk	9	-1.56
			petroleum products		-1.73
			general cargo		-1.48
NEA (2007)	Europe (Trans-tools)	Tkm price on tonnes	Agricultural products	9	-0.69
			Foodstuffs		-0.28
			Solid mineral fuels		-0.07
			Ores, metal waste		-0.21
			Metal products		-0.79
			Building minerals & material		-0.18
			Fertilisers		-0.36
			Chemicals		-0.21
			Machinery & other manufacturing		-1.08
			Petroleum products		-0.11
Winston (1981)	USA	Tonne or tkm price on tonnes	Unregulated agriculture	9	-1.1
			Regulated agriculture		-0.29
			Textiles and fabricated textiles		-0.56
			Chemicals		-2.25
			Leather, rubber and plastic products		-1.03
			Stone, clay and glass products		-0.82
			Primary and fabricated metals		-0.02
			Machinery including electrical machinery		-0.61
			Transport equipment		-2.68
			Paper, printing and publishing		-0.17
			Petroleum and petroleum products		-0.53
			Lumber, wood and furniture		-0.08

[a] See below Table 8-1 for a list of the various response mechanisms.

[b] This value is for the most flexible functional form; the values between brackets are for more restrictive functional forms. Elasticities for all commodities together from Oum (1989) are in Table 8-1.

small and that combined road-rail transport elasticities are somewhat smaller than conventional rail elasticities (however this is not consistent with the finding of a higher sensitivity for general cargo).

The ranges over the commodities of the elasticities for changes in the tonne-kilometre price are presented in Figure 8-1. Most studies give elasticities in the range between 0 and -3 for all commodities. Exceptions are:

- Nam (1997, with some positive own price elasticities, which must be wrong;
- Friedlaender and Spady (1980), which we do not regard as an important source for future reference, since the data are for 1972 for the US;
- de Jong (2003), with an elasticity close to -4 from the Norwegian model, which at the time was a multimodal assignment model, a model type that could give overly large elasticities.

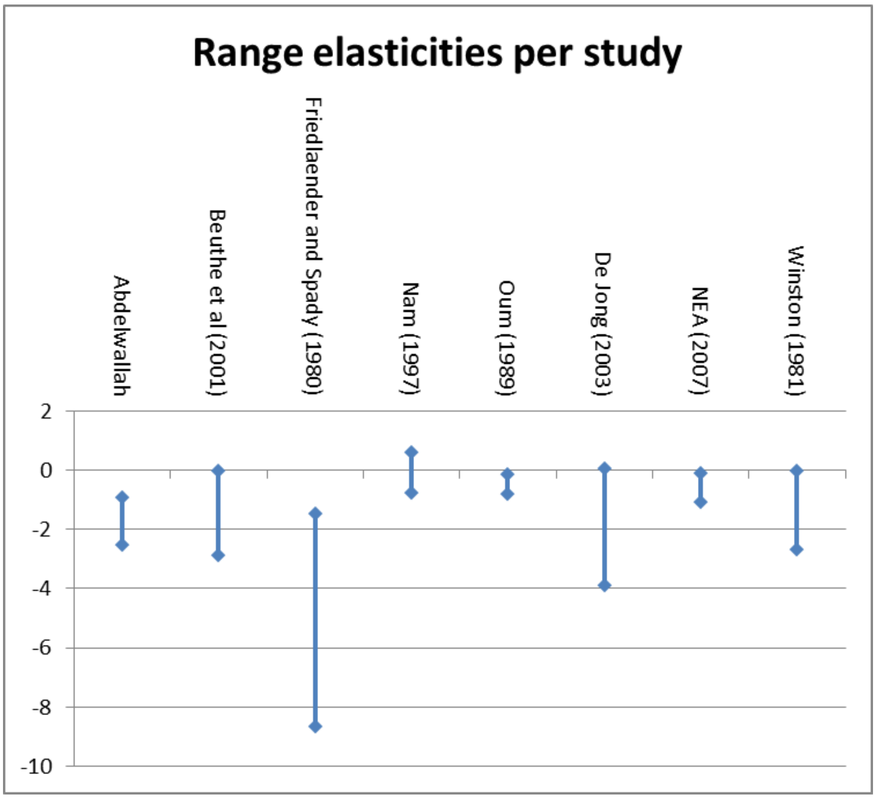

Figure 8-1: Range over commodities for tkm price elasticities per study

8.6 Conclusions on elasticities

Elasticities in transport usually come from models; elasticities coming directly from empirical observations have not been found in the literature. The most commonly used models for modal spit that produce implied elasticities are aggregate logit models, aggregate multimodal assignment models and disaggregate logit models. In the literature we studied were no elasticities from specific models estimated on data in Eastern Europe.

The main conclusions from the literature review on own-price elasticities for rail transport are summarized in Table 8-4. The ranges in this table reflect about 80% of the elasticities found; the remaining 20% is regarded here as 'outliers'. Notice that especially the values presented with regard to vehicle kilometre price change are characterized by high uncertainties due to the additional assumptions that had to be made to derive these elasticities. Rail operators internalise a part (here we assume: 30%; also based on Ecorys, 2005) of a rail costs increase by increasing the transport (logistics) efficiency and pass the remainder on to their customers. These react to the price changes largely by adjusting the modal split, but about -0.1 of the -0.9—1.7 range is for changes in total transport demand (such as choosing different suppliers or customers for the commodities). These transport demand effects are considerably smaller than for road transport, since the share of rail transport in the total transport cost for all commodities is much smaller than for road transport. For the same reason we expect that there will be no change in commodity demand when rail prices change.

Table 8-4. Results from the literature review on rail own-price elasticities

Impact on: Price change	Tonnes	Train kilometres	Tonne kilometres
Price per train kilometre	-0.5 to -1.1 derived from vkm price elasticity of tkm; using -0.1 for transport demand effect	-0.9 to -1.5 derived from vkm price elasticity of tkm; using -0.3 for transport efficiency effect	-0.6 to -1.2 derived from tkm price elasticity of tkm and assuming train operators internalise 30% of a trainkm price change by transport efficiency changes
Price per Tonne kilometre	-0.8 to -1.6 derived from tkm price elasticity of tkm; using -0.1 for transport demand effect	-0.9 to -1.7 derived from tkm price elasticity of tkm	-0.9 to -1.7 "recommendation" (see above)

For practical studies that will use these above elasticities as an indication of the likely impact of a price change in rail transport, we recommend to carry out a sensitivity analysis, using different values from the range given, including the upper and lower bound.

Finally, we also analysed the literature on rail price elasticities for different commodity types, distance classes and train types, in as far as available in the literature. We find:

- Several studies where rail transport price sensitivities are larger for general cargo compared to bulk products (e.g. solid fuel, petroleum, iron ore, fertilisers, stones, wood), but some studies find the reverse.
- The price elasticities for short distance rail transport are smaller than for long distance rail transport.
- At small and high market shares elasticities are smaller than in between.

In Task 4, we will investigate to which degree a joint segmentation by commodity type, distance class and current market share is possible, and if not, which of these dimensions should best be kept.

9. Preliminary conclusions on modelling approaches and unit values

9.1 Conclusions on the VOT

The distinction between the cargo component and the transport cost component of the effects of changes in transport time in freight transport is relatively new in the literature, but there is not really any disagreement on it. Different national guidelines for CBA and different researchers have put forward different views on whether the transport cost component should be part of the value of time (VOT) or of a separate transport cost component in the CBA. There is a common view that the cargo component should be included in the VOT (or be the VOT). Also there is consensus that the distance-based cost (such as energy and access cost), should not be in the VTT but treated as a separate variable or operating costs component in the CBA.

A key result from older and more recent studies is that the transport service component of the VOT will be (especially in the long run) more or less equal to the cost of producing the transport services (the sum of the staff and vehicle cost per hour including overheads, but not including distance-dependent cost). It is therefore not really needed to do new SP research to get these values, one can simply use the factor costs method to find this component. This component will hardly or not vary between commodity types, but it will vary between modes. However, for the first ten years of a project it seems better to assume a gradual move towards these long term values.

The cargo component of the VOT cannot so straightforwardly be derived from the factor cost. If possible, specific SP surveys are recommended. If these are not possible, one could use for the cargo component of the VOT in rail freight surcharge on the factor costs, which might be commodity-specific. Variation between commodity types (which one would expect for the cargo component) can be derived from the French, German or UK results in Table 4-1 (but the German values are higher than the values other studies, and as such rather an outlier).

VOTs for freight have been researched considerably less than VOTs in passenger transport, and within freight the focus has mostly been on the road sector and less so on rail.

There is a large knowledge gap concerning VOTs for Eastern Europe: empirical studies that produce VOTs in freight transport have practically all been carried out in Western Europe or other OECD countries, not in Eastern Europe. So to get values for Eastern Europe, researchers have been using transfer methods, based on estimated or assumed VOT elasticities of GDP per capita.

9.2 Conclusions on the VOR

As discussed in de Jong and Bliemer (2015) and several other papers and reports, there are two groups of operational definitions for reliability:

- Reliability as a measure of dispersion of the travel distribution (usually the standard deviation, sometimes the variance, range or measures based on percentiles);

- Expressing the consequences of reliability as the expected number of minutes early or late relative to the preferred arrival time.

There is a reasonable degree of consensus among the experts that for road transport the former definition is to be preferred for use in practical applications in the coming years. This leads to the definition of the reliability ratio, which is the value of reliability expressed as the standard deviation divided by the value of time. For rail transport (and other scheduled services) some argue for the standard deviation as well, others prefer to use deviations relative to the timetable. A measure which has elements of both approaches is the standard deviation of lateness (relative to the schedule). This can also be included in a reliability ratio.

Similarly to what was said for the cargo component of the VOT, for the VOR the preferred method is to carry out a specific SP study. This is the clearly dominant the view in the literature. The overall impact of reliability on the carriers has been found by some recent studies to be very limited (not significantly different from 0). But a significant impact on the shippers (comparable to the cargo component of the VOT) has been found. The relative size of this shipper VOR to the shipper VOT (the reliability ratio) and of the total VOR to the total VOT (cargo plus transport cost component) varies a lot between studies and presumably between commodity types, but a conservative estimate would be a reliability ratio (for the total VOR and VOT) of 0.2 for rail transport (or 0.8 for the shipper component of VOR and VOT).

This conservative estimate (that is in line with the latest Dutch results on the VOR) could be used here to give a reliability surcharge on the time benefits (e.g. as a last resort), but using the German results might be more attractive (should they not be considered too high or too low, which requires testing for specific projects as examples in task 4), since: they provide more distinction between commodities, use variables that the sector can provide and understand (% on time and hours delayed) and it would be good to distinguish between projects that focus on time savings and projects that focus on reliability (i.e. not assume these are proportional). The Norwegian results (for two commodity groups) for the value of expected delay could also be used here, but these values seem to be unusually high.

The empirical material on the VOR in freight transport is more limited than for the VOT (fewer studies). The comments on focus on road and OECD countries that we made above when discussing the VOT also apply for the VOR.

9.3 Conclusions on transport costs

Transport cost functions are available for several countries, either for monitoring/guideline purposes or as input for transport modelling. There is no serious disagreement in the literature on form of the transport cost functions and its components. The numerical values however vary considerably, also for relatively comparable countries and even within countries. It is not clear whether this reflects differences that exist in practice or that these differences are die to the methods used in the various studies. In this report we have presented various approaches and outcomes for the EU and for The Netherlands and Belgium. In the CBA of transport projects one has to take care that all relevant components of costs are included but also that these benefits or costs do not overlap with time benefits (through the VOT). A possible mistake would be to include the savings in terms of staff time and vehicle use in both the transport cost savings and the time savings.

9.4 Conclusions on model approaches to modal split

Our preferred answer to the question whether one should have a comprehensive or a simplified model is to have both types of models. The simplified model can be used for initial screening of policy options and projects and for the impact of more general (not location- and time-specific) measures). The comprehensive model then is the most appropriate model to use for assisting project appraisal, traffic management and policy measures that are location- and/or time-specific.

The choice of model type in specific situations (e.g. choice of a generation/distribution model or choice of a modal split model) not only depends on data availability, but also on theoretical considerations, the question how many and which explanatory variables one wants to include and the question whether one wants to represent links with other sectors (e.g. the wider economy) or not. This view is widely held.

There is a clear distinction between the disaggregate approach (using data at the level of individual decision-makers and shipments) and the aggregate data (using data at the zonal level) in modelling modal split in freight transport. The model type used most in freight transport analysis is the aggregate logit model. Given the data availability situation in most countries this seems a plausible choice as one of the components of the comprehensive model. In task 4 we will provide advice for which situations relatively simple models, such as elasticity-based models, will be sufficient and where more detailed models are required.

9.5 Conclusions on elasticities

Again, the numerical outputs in the literature almost always refer to OECD countries, and there is a knowledge gap for Eastern Europe (though there are some transport models that cover the EU or Europe as a whole). There is considerable agreement in the literature on which types of effects could occur of transport cost or time change, but much less on the absolute of relative importance of these various effects. However, if we make proper distinctions between the types of price changes and types of outputs used, it is possible to give a range, after eliminating the 20% most extreme values as outliers. The main conclusions from the literature review on own-price elasticities for rail transport are summarised in Table 9-1. Please note that especially the values presented with regard to vehicle kilometre price change are characterized by high uncertainties due to the additional assumptions that had to be made to derive these elasticities. Rail operators internalise a part (here we assume: 30%) of a rail costs increase by increasing the transport (logistics) efficiency and pass the remainder on to their customers. These react to the price changes largely by adjusting the modal split, but about -0.1 of the -0.9—1.7 range is for changes in total transport demand (such as choosing different suppliers or customers for the commodities). These transport demand effects are considerably smaller than for road transport, since the share of rail transport in the total transport cost for all commodities is much smaller than for road transport. For the same reason we expect that there will be no change in commodity demand when rail prices change.

Table 9-1. Results from the literature review on rail own-price elasticities

Impact on: Price change	Tonnes	Train kilometres	Tonne kilometres
Price per train kilometre	-0.5 to -1.1 derived from vkm price elasticity of tkm; using -0.1 for transport demand effect	-0.9 to -1.5 derived from vkm price elasticity of tkm; using -0.3 for transport efficiency effect	-0.6 to -1.2 derived from tkm price elasticity of tkm and assuming train operators internalise 30% of a trainkm price change by transport efficiency changes
Price per Tonne kilometre	-0.8 to -1.6 derived from tkm price elasticity of tkm; using -0.1 for transport demand effect	-0.9 to -1.7 derived from tkm price elasticity of tkm	-0.9 to -1.7 “recommendation” (see above)

For practical studies that will use these above elasticities as an indication of the likely impact of a price change in rail transport, we recommend to carry out a sensitivity analysis, using different values from the range given, including the upper and lower bound.

Finally, we also analysed the literature on rail price elasticities for different commodity types, distance classes and train types, in as far as available in the literature. We find:

- Several studies where rail transport price sensitivities are larger for general cargo compared to bulk products (e.g. solid fuel, petroleum, iron ore, fertilisers, stones, wood), but some studies find the reverse.
- The price elasticities for short distance rail transport are smaller than for long distance rail transport.
- At small and high market shares elasticities are smaller than in between.

In Task 4, we will investigate to which degree a joint segmentation by commodity type, distance class and current market share is possible, and if not, which of these dimensions should best be kept.

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Annex 1. The multinomial logit model and the nested logit model

Different distributional assumptions lead to different discrete choice models. The most common assumption for the error components e, both in passenger and freight modelling, is that they are independently and identically (i.e. same variance across observations) distributed following the extreme value distribution type I (or Gumbel distribution). This leads to the multinomial logit (MNL) model with the choice probabilities:

$$P_{ik} = \frac{e^{G_{ik}}}{\sum_i e^{G_{ik}}} \qquad \text{(A1-1)}$$

The MNL model can be estimated by Maximum Likelihood methods that do not involve any simulation. Several software packages contain MNL estimation (sometimes called 'conditional logit').

After having estimated the model, one can apply the estimated coefficients on a sample of firms (shipments) to calculate probabilities for each choice alternative for each observation. If this sample is representative of the population studied, one can then simply sum the probabilities (this method is called 'sample enumeration') over all observations in the sample to get the market shares for the alternatives (e.g. the share of road transport in the total for toad, rail and inland waterways) as predicted by the model. For non-representative samples[1], one can do a weighted summation with the population to sample fractions for each observation as weights. Different zones in a study area or different horizon years might even have different sets of weights. Such applications can give the impact of changing a single variable at a time (which can be expressed in the form of elasticities), but can also predict what would happen in case of an input scenario with changes for several (possibly all) variables in the model.

A well-known restriction of the MNL model is that the cross-elasticities are the same: if in the mode choice model in equations (6-3a) – (6-3c) (see the main text) the cost of road transport increases, substitution will occur to rail and inland waterways in proportion to their current market shares, so that the road cost elasticities of demand for rail transport and for inland waterway transport will be the same. Another manifestation of basically the same phenomenon (which is due to the independence of the error terms) is the independence from irrelevant alternatives (IIA) property: the ratio of the choice probabilities between two alternatives does not depend on any other alternative. These properties may be at odds with reality. In practice, there could for instance be more substitution between rail and inland waterways than between any of these alternatives and road transport. A relatively easy way to accommodate for this is the nested logit model (e.g. Daly and Zachary, 1978) in which rail and inland waterways would be grouped in a nest, allowing correlation between these alternatives.

[1] MNL models can be estimated consistently on a sample that is non-representative with regards to the exogenous variables. If the sample is non-representative with regards to the choice variable (e.g. with an overrepresentation of rail transport), and the model has N-1 ASCs and M other coefficients, all M coefficients can still be estimated consistently using standard methods, and only the N-1 ASCs will be biased. These ASCs can simply be corrected after esti mation on the basis of the observed market shares (McFadden, 1981).

Mathematically, the easiest representation is to distinguish two probabilities (as for instance in Train, 2003), linked to each other by the logsum variable.

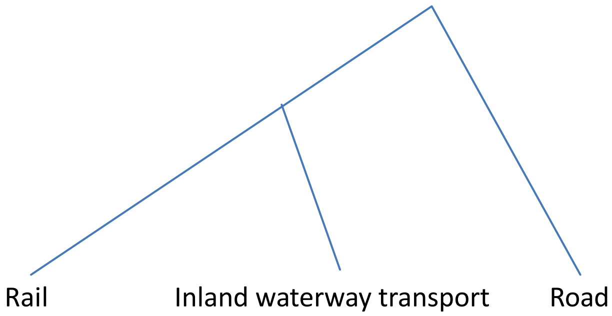

Figure A1-1. Nested logit structure for freight mode choice

$$P_{B_l k} = \frac{e^{G_{lk} + \lambda_l l_{lk}}}{\sum_l e^{G_{lk} + \lambda_l I_{lk}}} \quad \text{(A1-2a)}$$

$$P_{\langle ik | B_l \rangle} = \frac{e^{H_{ik} / \lambda_l}}{\sum_{i \in B_l} e^{H_{ik} / \lambda_l}} \quad \text{(A1-2b)}$$

$$I_{lk} = \ln \sum_{i \in B_l} e^{H_{ik} / \lambda_l} \quad \text{(A1-2c)}$$

The first probability (A1-2a) gives the chance that decision-maker k chooses an alternative within nest B_l. This depends on the generalised cost G of l plus a coefficient λ_l times the expected cost from the alternatives in the nest, represented by I_{lk}, the so-called 'logsum' variable, relative to the same kind of costs for the all alternatives at the nesting level.

The second (conditional) probability gives the change of choosing alternative i given that nest B_l has been chosen. This depends on the generalised cost of this alternative relative to those for all alternatives in the nest.

Now the unconditional probability that decision-maker k will select alternative i is:

$$P_{ik} = P_{\langle ik | B_l \rangle} P_{B_l k} \quad \text{(A1-1d)}$$

The coefficient λ_l is the 'logsum coefficient' which gives the degree of correlation between the error components of the alternatives in nest B_l: the higher this coefficient, the lower the correlation. In estimation, this is an extra parameter to be estimated. The estimated value must be between 0 and 1 for global consistency (meaning: across the entire range for the exogenous variables) with RUM. If a value above 1 is found, this often is an indication that a different (especially a reversed) nesting structure would work better and be consistent with RUM.

Nested logit can also be used to combine two choices in a joint model (such as shipment size and mode choice, or mode and supplier choice) and for joint estimation on a combination of data sets (e.g. stated preference and revealed preference data, Bradley and Daly, 1997).

Both MNL and nested logit are members of a family of models, the GEV family (McFadden, 1978; Daly and Bierlaire, 2006) which contain more members (and sometimes new members are discovered), all of which are consistent with random utility maximisation. Most of these have only seen a limited number of applications in passenger transport and none or almost none in freight transport, though they offer more flexibility in terms of substitution patterns between alternatives than MNL or nested logit.

Annex 2. Mode choice coupled with closely related choices

Mode choice is usually studied in isolation, i.e. as a single endogenous variable. Also in most regional, national or international freight transport forecasting systems the modal split is determined independently from the trade volumes and the level-of-service from the networks acts as one or more exogenous variables in mode choice. However, there is much to be said for freight model systems with multiple dependent variables that allow for simultaneous choice-making on mode choice and other choices. Some other choices in freight transport are closely connected to that on the mode, and sometimes also modelled in a simultaneous fashion:

- A series of mode choices in the form of a transport chain choice model. Mode choice can be studied for an origin-destination (OD) flow, which has the advantage that the choice alternatives can be simple and the choice set limited. However, it often happens in practice that the use of a specific mode is combined with the use of other modes in a transport chain. A transport chain is a sequence of modes and trans-shipment locations that are all used to transport shipments from the sender to the receiver (e.g. road-rail-road). So transport chains refer to the PC (production-consumption) level, not to the OD level. An example of a transport chain would be road-rail-road, which decomposes into two road OD flows and one rail OD flow. We think that modelling transport chain choice at the level of the PC flows is a qualitatively superior strategy to mode choice at the OD level, especially because the latter might lead to suboptimal solutions at the PC level. However, in practice, data might not be available for a transport chain choice model, since transport data are usually collected at the OD level. In a transport chain choice model, the choice alternatives are sequences of modes (including direct transport using a single mode all the way) instead of modes. A simplified way of modelling transport chain choice is to define a main mode at the PC level and model the choice between available main modes. This definition could be based on the longest distance or on a modal hierarchy (e.g. inland waterway is the main mode if it is used somewhere in the chain, otherwise rail is the main mode if it is used somewhere in the chain and if not, the main mode is road transport). The explanatory variables for inland waterways and rail could then include road transport costs of getting to and from the inland port or rail terminal and corresponding trans-shipment cost. The choice models in section 7.2 can be regarded as OD mode choice models or PC main mode choice models.
- Mode choice and shipment size choice model (usually measured in tonnes). Smaller shipment sizes are almost always transported by road, and larger shipments have an increased probability of being transported by a non-road mode (e.g. rail, inland waterway transport). This by itself could be a reason to include shipment size as an exogenous variable in mode choice (e.g. Jiang et al., 1999). But one could go one step further and model two-way interactions where mode choice also influences shipment size choice. Holguín-Veras et al. (2011) carried out economic experiments with groups of students that were playing shippers and carriers, where the shippers knew the inventory costs function and the carriers knew the transport cost functions by mode. The carriers had to compete with each other to supply transport services to the shipper and did this by submitting a sealed bid (containing a price and a mode) to the shipper. This was repeated a number of times. These experiments rather soon converged to the joint optimum in terms of modes and shipment size, as predicted by game theory. The assumption that freight mode choice is an independent decision was not supported, and a joint mode and shipment size choice model is preferred. This leads to disaggregate models in which the mode choice decision is embedded in

a larger inventory-theoretic and logistics framework, so that shipment size optimisation can be covered as well.

- Models for the choice of mode and supplier (in the sense of the origin zone for the transport flow). In passenger transport modelling one sometimes comes across joint models of mode and destination choice, where a traveller chooses between combinations of destination zones and modes to that destination, given the origin. In freight transport modelling, mode-destination choice does not seem a very sensible option, since it would amount to client choice by the suppliers. A more realistic option would be to take the viewpoint of the receiver of the goods (a firm that processes incoming goods, or a wholesaler or retailer) and model his choice of supplier jointly with the mode from that supplier (sender) to the given location of the receiver.

- Mode and route choice models. This includes disaggregate models that combine mode and route choice in freight transport in a simultaneous decision-making framework as well as aggregate multi-modal network models. The multi-modal network modelling provides another way to handle transport chains.[1] In a transport chain, several modes are used consecutively for a door-to-door shipment. An example is to use a lorry first from the zone of the sender to the port, then use short sea shipping, then rail transport and finally lorry delivery to the zone of the receiver. Assignment to such combinations of modes in a transport chain can take place if the network not only includes links and nodes for each mode, but also multi-modal nodes that connect one network to another network. Such nodes can be ports or rail and inland waterway terminals for trans-shipment between modes. In other words, a multi-modal network (or super-network) is created, where inter-modal transfer nodes for instance link road, rail and inland waterways networks

Mode and shipment size choice are only modelled at the disaggregate level (that is for individual shipments). The other three joint choices can be modelled both at the aggregate and the disaggregate level, and especially mode and route choice is indeed mostly done at the aggregate level. Transport models for regional and national authorities and international organizations often have large networks, that include so many mode and route choice alternatives (with difficult correlation structures, e.g. routes partly overlap), that a disaggregate joint mode and route choice model is usually not considered a feasible option (but this may change in the future). However, within a certain corridor, and especially for crossing a certain screenline (such as a sea strait or mountain range), there may only be a very limited number of route alternatives, and joint mode and route choice (both a discrete variables) is not cumbersome at all.
Examples of joint models (aggregate and disaggregate) of mode choice and related choices are described below.

Some practical disaggregate freight transport models that simultaneously deal with mode choice and logistic choices are the following.

1) Models with discrete mode (or transport chain) choice, jointly with discrete shipment size choice (after dividing shipment size into a number of classes):

[1] The other way is to have a disaggregate or aggregate model for the choice from a choice set containing different uni-modal and multi-modal **transport chains** (as discussed above).

- Chiang et al. (1981) modelled the choice of shipment size, mode and the location of supplier (supply zone).
- De Jong and Ben-Akiva (2007), using data from the Swedish Commodity Flow survey (CFS) 2001, estimated a joint model of mode and shipment size choice.
- Habibi (2010) estimated models for discrete shipment sizes and transport chains for the commodity 'domestic steel products' on the CFS 2004/2005.
- Windisch et al. (2010) used the CFS 2004/2005 to estimate models of (discrete) shipment size and transport chain choice.

These models have as choice alternatives combinations of a mode m (i=1 , …, I) and a shipment size class s (s=1, …, S), with a choice set that could be as large as I.S alternatives. The econometric models used are MNL, nested logit (with more substitution between shipment size classes than between modes) and mixed logit.

2) Models with discrete mode choice jointly with continuous shipment size choice:

- McFadden et al. (1985) developed a model for shipment size and mode choice and applied it to agricultural goods.
- Abdelwahab and Sargious (1992) and Adelwahab (1998) estimated a mode choice and shipment size model on the U.S. Commodity Transportation Survey.
- De Jong and Johnson (2009) and Johnson and de Jong (2011) used the CFS 2001 to estimate discrete-continuous (continuous shipment size) models, following the specification that Holguín-Veras (2002) developed for road vehicle type and shipment size choice. In these papers, discrete choice models (both mode and shipment size treated as discrete variables) were estimate on the same data, allowing a comparison of both models.
- Combes (2010a, b) developed models of shipment size and mode choice on the national French shippers survey ECHO.
- Liu (2012) estimated models for discrete mode and continuous shipment size in the CFS 2001 for four different commodity groups.

These discrete-continuous models are usually estimated in two steps (one for the discrete and one for the continuous step) with selectivity correction terms to correct for the simultaneity bias.

Models that include the joint choice of mode and supplier are:

- The model by Chiang et al. (1981) also falls in this category, since the dependent variables are shipment size, mode and the location of supplier (represented by supply zone).
- Another disaggregate model where a receiver of the goods chooses the supplier to buy from is Samimi et al. (2010). Their utility function includes receiver characteristics (quantity required, budget, modes) and supplier characteristics (capacity to produce/stock, price, geographic location).

Examples of disaggregate joint mode and route choice (both a discrete variables) models are:

- The freight transport model developed for the Öresund screenline between Sweden and Denmark (e.g. Fosgerau, 1996), where three types of trucks, unaccompanied trailer, rail, and intermodal road-rail were combined with different ferry routes and a fixed link route, using a combination of SP and RP data.
- A similar model for the Fehmarn Belt corridor between Denmark and Germany (Fehmarn Belt Traffic Consortium, 1998), also on SP and RP data.

Annex 3. Utility functions, estimated coefficients and elasticities in the revised Transtools model

The modal split model in TRANSTOOLS is an aggregate logit model, following the basic multinomial logit specification. Below we report the modal split model as it was re-estimated by NEA, in cooperation with Significance (the description is based on NEA, 2011).

According to this specification, the choice probabilities of the available modes per commodity group for every OD relation are determined by the following formula:

$$P_{m|cij} = \frac{e^{V_{m|cij}}}{\sum_{l \in M} e^{V_{l|cij}}}$$

$$\text{with}: V_{m|cij} = \beta_{m0} + \sum_k \beta_{mk} x_{cijmk}$$

Where:

M:	Set of available modes.
$P_{m\|cij}$:	Choice probability of mode *m* given commodity group *c* and OD relation *ij*.
$V_{m\|cij}$:	Systematic utility of mode *m* given commodity group *c* and OD relation *ij*.
x_{cijmk}:	Level of service *k* for mode *m* given commodity group *c* and OD relation *ij*.
β_{mk}:	Logit parameter for mode *m* and level of service *k*.

The following levels of service, given commodity group *c* and OD relation *ij,* are the explanatory variables in this model:

- Cost per mode (fixed cost per hour, waiting cost per hour, variable cost per km, fuel cost per km, toll cost per km, total fixed cost, total variable cost, total waiting cost, total fuel cost, total toll cost and total time)
- Existence of service per mode
- Border resistance per mode (dummy variables)

Note that time based costs (e.g driver's wages) are included in the cost model, but no specific time variable (the value of time for the owner of the cargo, over and above the cost of the transport) has been entered in the model.

The database that has been used for the calibration of the new model is the ETIS freight flow database as was used for the calibration of the original model.

The market segmentation that has been used in the calibration phase is not intended to explain the modal split but to allow for differences in coefficients (and elasticities). The market segmentation used is by commodity group (10 groups: NSTR level 1).

The set of estimation runs were executed to include the maximum number of relevant explanatory variables, where the aim was to have besides the mode specific constants at least the cost variable in the utility function. The mode specific constants are determined dependent on the type of relation (intra Western European countries, intra Eastern European countries and between Western and Eastern European countries).

During the first calculation runs, the time parameter was not significant in most cases. Table A3-1 shows the relative size of the inventory costs (purely time based costs) to the transport cost. Two O/D pairs are compared, covering 105 Km and 1189 Km respectively, for road and rail.

Table A3-1. Comparison between transport costs (EUR/t) and Inventory Costs

orig	dest	distance (kms)	mode	tpt cost/ tonne	total time	inv. cost/ tonne	inv. cost/ tpt cost
				(euros)	(hrs)	(euros)	(%)
NL	D	105	road	17.69	4.98	0.08	0.45%
			rail	23.98	24.49	0.39	1.62%
AT	GR	1189	road	206.91	57.70	0.91	0.44%
			rail	68.25	55.33	0.88	1.28%

For a 105 Km trip, taking only 4 hours by road, including an allowance for loading and unloading, the inventory cost is only 0.45% of the transport cost for a typical commodity in product group 8 (chemicals) with a value of 1386 Euros per tonne, using a discount rate of 10%. For longer trips (e.g. 1189 kms, estimated to take over 50 hours by rail) the ratio rises, but remains below 2% of the transport cost. It is therefore clear that the impacts of a policy to speed up transport by a particular mode is adequately covered by the cost model, and that the additional time parameter is not required.

The utility functions

The definition of the utility functions per transport mode is given below:

U(road) =
ArailE*dcrailE + AiwwE*dciwwE + AseaE*dcseaE
+ ArailWE*dcrailWE + AiwwWE*dciwwWE + AseaWE*dcseaWE
+ b_road*road
+ bcost*totcost
+ bcroadE*costE
+ bcroadWE*costWE

U(rail) = a_rail
+ ArailE*dcrailE + AiwwE*dciwwE + AseaE*dcseaE
+ ArailWE*dcrailWE + AiwwWE*dciwwWE + AseaWE*dcseaWE
+ b_rail*rail

```
   + bcost*totcost
   + bcrailE*costE
   + bcrailWE*costWE

U(inlww) = a_inlww
   + ArailE*dcrailE + AiwwE*dciwwE + AseaE*dcseaE
   + ArailWE*dcrailWE + AiwwWE*dciwwWE + AseaWE*dcseaWE
   + bcost*totcost
   + bciwwE*costE
   + bciwwWE*costWE

U(sea) = a_sea
   + ArailE*dcrailE + AiwwE*dciwwE + AseaE*dcseaE
   + ArailWE*dcrailWE + AiwwWE*dciwwWE + AseaWE*dcseaWE
   + bcost*totcost
   + bcseaE*costE
   + bcseaWE*costWE
   + bc5sea*c5sea
```

List of coefficients (to be estimated):

a_rail	Constant
a_inlww	Constant
a_sea	Constant
ArailE	dummy rail, East Europe
AiwwE	dummy inland waterways, East Europe
AseaE	dummy sea, East Europe
ArailWE	dummy rail, inter Europe (W <-> E)
AiwwWE	dummy inland waterways, inter Europe (W <-> E)
AseaWE	dummy sea, inter Europe (W <-> E)
b_road	dummy road parameter
b_rail	dummy rail parameter
Bcost	generalized cost parameter
bcroadE	specific cost parameter for road, East Europe
bcrailE	specific cost parameter for rail, East Europe
bcinlwwE	specific cost parameter for inland waterways, East Europe
bcseaE	specific cost parameter for sea, East Europe
bcroadWE	specific cost parameter for road, inter Europe (W <-> E)
bcrailWE	specific cost parameter for rail, inter Europe (W <-> E)
bcinlwwWE	specific cost parameter for inland waterways, inter Europe (W <-> E)
bcseaWE	specific cost parameter for sea, inter Europe (W <-> E)

bc5sea extra cost parameter for port regions (Table A3-1)

List of explanatory variables:

dcrailE dummy constant for rail, East Europe. Value is 1 if origin and destination are both in area 2 (East Europe) and transport mode is rail. Otherwise value is 0.

dciwwE dummy constant for inland waterways, East Europe. Value is 1 if origin and destination are both in area 2 (East Europe) and transport mode is inland waterways. Otherwise value is 0.

dcseaE dummy constant for sea, East Europe. Value is 1 if origin and destination are both in area 2 (East Europe) and transport mode is sea. Otherwise value is 0.

dcrailWE dummy constant for rail, inter Europe (W <-> E). Value is 1 if origin is in West Europe (W) and destination in East Europe (E), or vice versa (origin in E, destination in W). and transport mode is rail. Otherwise value is 0.

dciwwWE dummy constant for inland waterways, inter Europe (W <-> E). Value is 1 if origin is in West Europe (W) and destination in East Europe (E), or vice versa (origin in E, destination in W). and transport mode is inland waterways. Otherwise value is 0.

dcseaWE dummy constant for sea, inter Europe (W <-> E). Value is 1 if origin is in West Europe (W) and destination in East Europe (E), or vice versa (origin in E, destination in W). and transport mode is sea. Otherwise value is 0.

Road dummy road parameter (border resistance): Dummy for waiting times at EU (including Norway + Switzerland) outside borders for road transport; Value is 1 if origin EU and destination non-EU or if origin is non-EU and destination is EU and mode is road, otherwise value is 0.

Rail dummy rail parameter (border resistance): Dummy for gauge-width differences for rail transport; Value is 1 if origin and destination region have different gauge-widths, otherwise value is 0.

Standard gauge:	All TRANSTOOLS regions in the countries: AL, AT, BE, BA, BG, CZ, CH, DK, DE, FR, GR, HR, HU, IT, MD, NL, NO, PL, RO, SE, SI, SK, TR, UK (except 15230000 = UKN) and YU.
Irish gauge:	In the TRANSTOOLS regions: 9000100, 9000200 and 15230000 (= IE and UKN).
Iberian gauge:	All TRANSTOOLS regions in the countries: ES and PT.
Russian gauge:	All TRANSTOOLS regions in the countries: BY, EE, FI, LT, LV, MD, RU and UA.

Totcost Total cost

costE specific cost variable for East Europe transport. costE = totcost if origin and destination are both in East Europe. Otherwise value is 0.

costWE specific cost variable for inter Europe transport. costWE = totcost if origin is in West Europe (W) and destination in East Europe (E), or vice versa (origin in E, destination in W). Otherwise value is 0.

c5sea extra cost variable for port regions. c5sea = totcost, if origin or destination region is a port region (see table A3-1) and distance > 500, zero otherwise.

Estimated coefficients

During the calibration the best set of parameters was determined for each commodity group (nstr0 to nstr10) except for nstr3 (crude oil). This was done by selecting the acceptable configuration which meets the restrictions on significance and the signs of the parameters. The results are presented in table A3-2.

Table A3-2. Estimation results per NSTR1

	nstr0	nstr1	nstr2	nstr4	nstr5	nstr6	nstr7	nstr8	nstr9	nstr10
A_RAIL	-1.9225	-3.1145	-1.0756	-1.6209	-0.8901	-2.7242	-2.6939	-2.3372	-1.8668	-1.3862
A_INLWW	-2.0620	-2.6490	-0.4265	-1.4461	-2.7086	-1.2998	-0.8092	-2.9036	-3.7000	-0.9052
A_SEA	-0.4138	-0.4076	0.6971	0.0731	0.5149	0.0063	-0.5515	0.2736	0.0835	0.9607
ARAILE	5.2743	2.8520	1.7196	1.0463	3.4922	3.1458	2.5742	3.1979	2.0749	2.4966
AIWWE	-2.1590		-4.2746	-4.5100	-1.0760	-3.1421				
ASEAE	-1.7732	-1.7764	-2.3677		-2.6656	-2.1006		-1.4949	-2.2051	-1.0672
ARAILWE	5.2397	2.5573	3.8239	3.7283	2.9102	2.0834	3.9495	4.0129	0.6811	2.3404
AIWWWE	-0.6044						1.9336	-0.8149	-1.5599	
ASEAWE	0.3403		1.5127		-0.8794		2.9763	-0.0936	-0.9325	0.4747
B_ROAD		-0.6850							-0.3768	
B_RAIL	-1.4129	-0.7757	-2.5009	-2.4415	-0.7071	-1.2590	-1.7007	-1.2655	-0.7522	-1.5663
BCOST	-0.0061	-0.0048	-0.0051	-0.0143	-0.0041	-0.0093	-0.0257	-0.0044	-0.0052	-0.0061
BCROADE	-0.0079	-0.0084	-0.0304	-0.0205	-0.0163	-0.0216		-0.0057	-0.0067	
BCRAILE	-0.0306	-0.0237	-0.0503	-0.0265	-0.0159	-0.0879		-0.0260	-0.0052	-0.0388
BCIWWE										
BCSEAE	x	x	x	x	x	x	x	x	x	x
BCROADWE					-0.0062	-0.0027				
BCRAILWE	-0.0334	-0.0334	-0.1266	-0.1364	-0.0147	-0.0697	-0.0897	-0.0603	-0.0047	-0.0606
BCIWWWE						-0.0661				
BCSEAWE	x	x	x	x	x	x	x	x	x	x
BC5SEA	-0.0083		-0.0411		-0.0074	-0.0092	-0.0321	-0.0108	-0.0163	

Implied elasticities

Table A3-3 presents the cost elasticities by NSTR level 1 classification and mode of transport (based on the final model estimation results). The cost elasticities refer to the change in volume (tonnes) transported by mode.

The table does not include *cross*-elasticities as these depend on the market shares. As a consequence of the MNL model structure the cross-elasticities will be similar for all modes.

Table A3-3. Cost elasticities by NSTR1 and transport mode

NSTR	Name	road	rail	inlww	sea
NSTR0	Agricultural products	-0.263	-0.686	-0.049	-0.044
NSTR1	Foodstuffs	-0.158	-0.283	-0.047	-0.028
NSTR2	Solid mineral fuels	-0.29	-0.073	-0.033	-0.014
NSTR4	Ores, metal waste	-0.66	-0.208	-0.109	-0.033
NSTR5	Metal products	-0.234	-0.788	-0.047	-0.033
NSTR6	Building minerals & material	-0.423	-0.18	-0.53	-0.039
NSTR7	Fertilisers	-1.102	-0.355	-0.178	-0.097
NSTR8	Chemicals	-0.235	-0.213	-0.047	-0.026
NSTR9	Machinery & other manufacturing	-0.224	-1.078	-0.069	-0.039
NSTR10	Petroleum products	-0.574	-0.118	-0.033	-0.025

IMC Worldwide Ltd
64-68 London Road
Redhill,
Surrey, RH1 1LG
Tel: +44 (0)1737 231400
Fax: +44 (0)1737 771107
www.imcworldwide.com

iMC worldwide
Development | Management | Infrastructure