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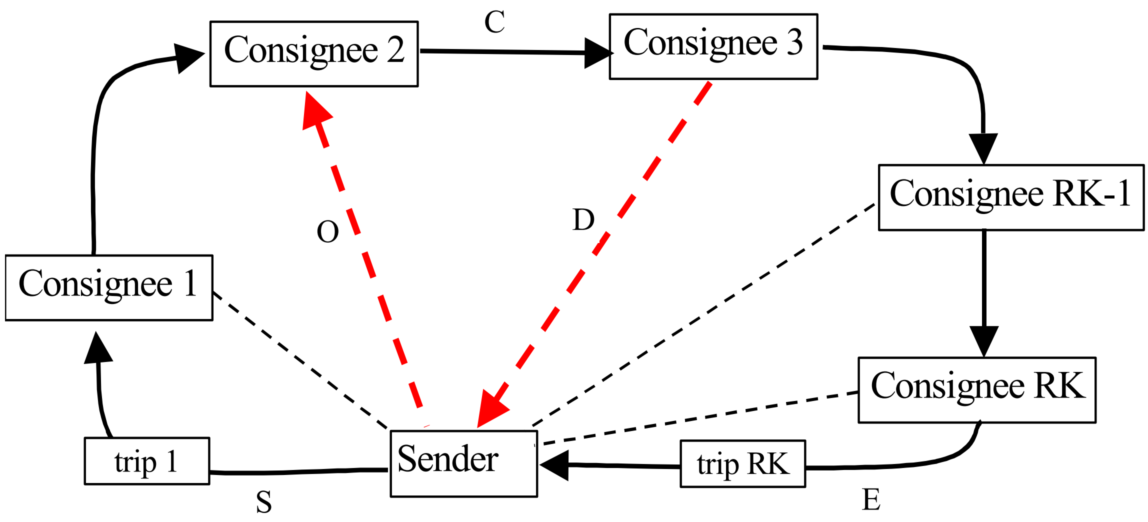

Freight Modelling: Data Issues, Survey Methods, Demand and Network Models

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Freight Modelling: Data Issues, Survey Methods, Demand and Network Models

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Abstract

The paper discusses requirements for freight modelling and presents specific approaches concerning freight surveys, demand and network modelling, rail freight optimisation and freight assignment including:

- Surveying methods for collecting road based demand data.
- WIVER/VISEVA: a demand modelling system for urban and regional commercial transport.
- SPIN: a multimodal network model for intermodal freight transport in Europe.
- VISUM Cargo: a tool for optimising rail freight transport
- Freight assignment: discussion of unimodal and intermodal assignment

Keywords

Freight Modelling, Demand Model, Network Model, International Conference on Travel Behaviour Research, IATBR

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1. Introduction

Forecasting the developments of future transport is essential for transport policy planning. For this purpose it is common practice to apply transport models for developing and analysing policy options. Transport models for passenger transport are applied regularly for regional, national and international transport studies. These models distinguish private passenger transport systems (passenger cars, bikes, etc.) and public transport systems (bus, tram, rail, etc.). For modelling passenger transport the transportation planner can select from a variety of commercial software packages which provide methods for network editing, demand calculations and traffic assignment. Freight transport shows some similarities to passenger transport especially since passenger and freight vehicles use the same network. This may imply the use of modified passenger models for freight modelling. However, there are significant differences between passenger and freight transport that should be taken into account in freight modelling (see for example British guideline for multimodal studies [3] or Ortúzar and Willumsen [13]):

- Freight is entirely passive and therefore may require specific infrastructure for loading and unloading.
- Many freight vehicles are specifically designed for a particular type of goods.
- The items being transported range from an urgent single parcel to non-urgent bulk shipments of thousands of tonnes.
- In the freight transport market several actors (consignor and consignee, freight forwarder and carrier, driver) influence the travel itinerary of freight items.
- A supply network for freight consists not only of nodes and links but also of terminals nodes (freight hubs, logistic centres, shunting yards, warehouses) with specific characteristics concerning capacity and transfer delay time.
- Service frequency and transport costs for shipment are often undefined until a potential sender makes an enquiry.

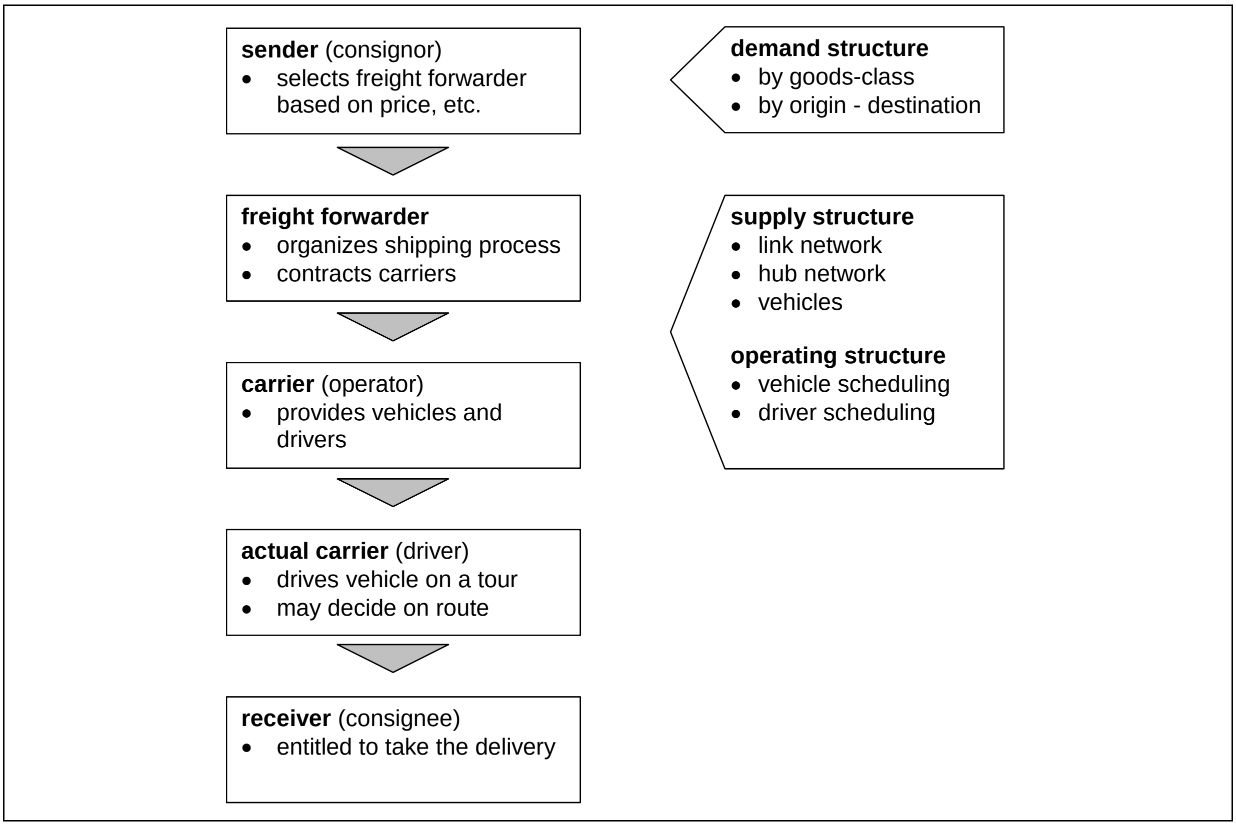
Figure 1 shows the process steps and decision levels in freight transport as defined in the terminology on combined transport [6]. At each decision level specific decisions concerning the movement of goods are required:

- The *sender* (shipper, consignor) demands the transport of goods-units and puts these goods-units in the care of others (freight forwarder, carrier) to be delivered to a consignee. The sender will decide on a freight forwarder based on price and other factors like temporal constraints or reliability.
- The *freight forwarder* organizes the shipping process. It will provide and schedule unimodal or intermodal transport chains for shipping the goods. For this it may subcontract carriers or provide an own carrier service.

- The *carrier* is responsible for the carriage of goods. The carrier will provide the vehicles required for the transport along a unimodal section of the transport chain. The vehicles operate on the link infrastructure connection origin, hubs and destination.
- The *driver* steers the transport vehicle along a predefined tour. In case of road transport the driver may decide on the route between two points of the tour.
- The *consignee* is entitled to take delivery of the goods.

Transport and logistic structures provided by the freight forwarder and the carrier (hubs, vehicles, tours) are established in a long- or medium-term planning horizon and cannot be changed at short notice. The short term planning task only attempts to adopt or optimise the structures to the current freight volume.

Figure 1: Process steps and decision levels in freight transport

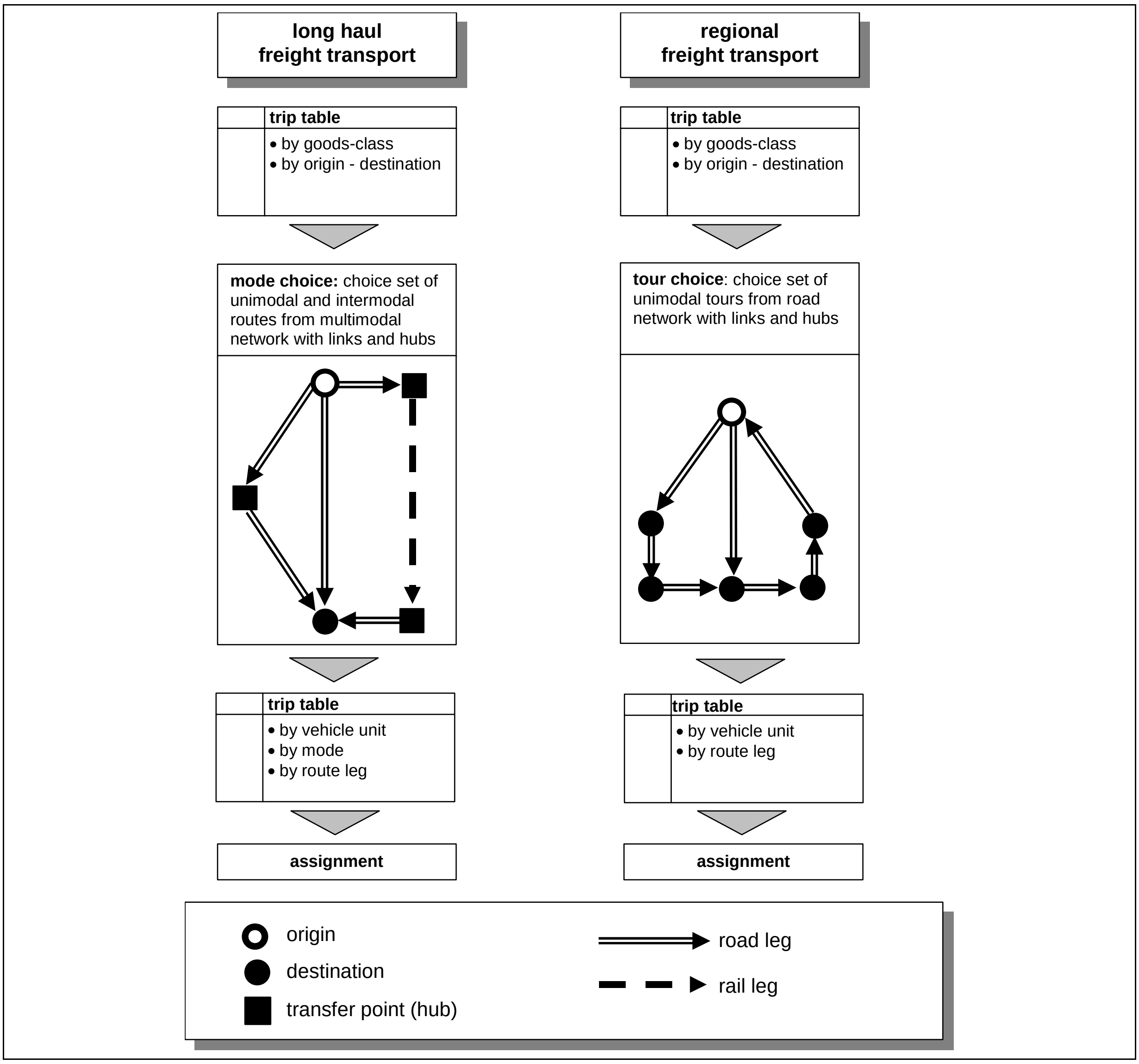


The complex interactions between the actors is one reason why it is more complicated to model the decision process in freight transport compared to passenger transport. Another important reason results from the fact that the number of decision units in freight transport is significantly smaller. As a result the decisions of a single sender, e.g. a big company may have a direct impact on the demand. One the contrary, in passenger transport the unit of decision is the individual traveller. Passenger demand combines the result of numerous individual decisions which makes it relatively easier to estimate the parameters of choice models.

On the network side freight models need to reflect the specific supply structure of freight networks. In order to provide a good basis for mode choice and assignment a network model which provides the location of hubs is vital. Even in unimodal road freight transport the vehicles frequently do not take the direct route between origin and destination but are routed through hubs. Figure 2 shows choice sets for long haul and regional freight transport. In both cases the location of the hubs as transfer point between vehicles of the same or alternative modes is fixed. In long haul transport a set of unimodal or intermodal routes compete with each other. Routes are built from one or more route legs, i.e. route sections connecting hubs to hubs as well as to origins and destinations. This reflects the transport chain in hub and spoke networks. In regional transport the choice is usually not between modes but between road vehicles of different size and between different tours.

For the final assignment step, it seems to be appropriate to apply the same methods for passenger and freight transport, if the trip tables reflect the hub structure of the network. For this the assignment does not distribute origin – destination flows, but flows one the level of route legs. As passenger cars and freight road vehicles share the same road space a simultaneous assignment of passenger and freight demand is desirable. In case of rail assignment it may be necessary to distinguish between freight transported with fixed scheduled trains and demand actuated trains. Like in road traffic there are also interdependencies between passengers and freight trains which should be considered.

Figure 2: Choice sets in long haul and regional freight transport



This paper does not intend to give an overview of existing freight models. Such an overview can for example be found in a recent paper by de Jong et al [5]. Instead the paper focuses on selected modelling approaches for freight transport which address some of the problems described above. These are:

- Surveying: methods for collecting road based demand data.
- WIVER/VISEVA: a demand modelling system for urban and regional commercial transport.
- SPIN: a multimodal network model for intermodal freight transport in Europe.
- VISUM Cargo: a tool for optimising rail freight transport.
- Freight assignment: discussion of unimodal and intermodal assignment.

2. Survey of road based demand data for national, regional and urban freight models

2.1 Urban and regional surveys of commercial trips - the Munich example

Consistent and extensive behaviour surveys of regional commercial transport are rare. The following describes an exemplary three-part survey which was performed in Munich in 1995 as part of an extensive analysis of the regional commercial transport, as well as some of the results of that survey. The survey consisted of three parts

1. Written postal behaviour survey
2. Questioning of singular transport generators
3. Questioning of drivers on the roads

Similar surveys were performed before and afterwards in Berlin, Hamburg, Dresden, Madrid, Rome and in other regions. All of these studies work with the definition of commercial transport as the trips which are generated by drivers during their jobs. The Munich survey is the most extensive of all and is the survey which is best included in the analysis of the entire transport system. The gross random sample of the written postal behaviour survey included 3881 businesses. By making frequent telephone contact with a named contact person at the firms selected for the survey, high participation was achieved, which could be clearly shown in a reply rate of 58%. The survey was based on a key date concept and was performed in waves.

Part 1: Written postal behaviour survey

This survey was performed during the period from April to July 1995 with two types of questionnaires:

1. *Paper A – Questions on workplaces* (Figure 3) asks questions on the number of employees, number of vehicles and number of received deliveries. The questions are answered by a contact person from the firm.

2. *Paper B – Questions for the employees* (Figure 4) is designed as a trip diary asking the mobile employees (actively travelling on the key date) for details on the vehicle used, destinations and their loads etc.

Figure 3: Questionnaire A: employees, vehicles and received deliveries by firm.

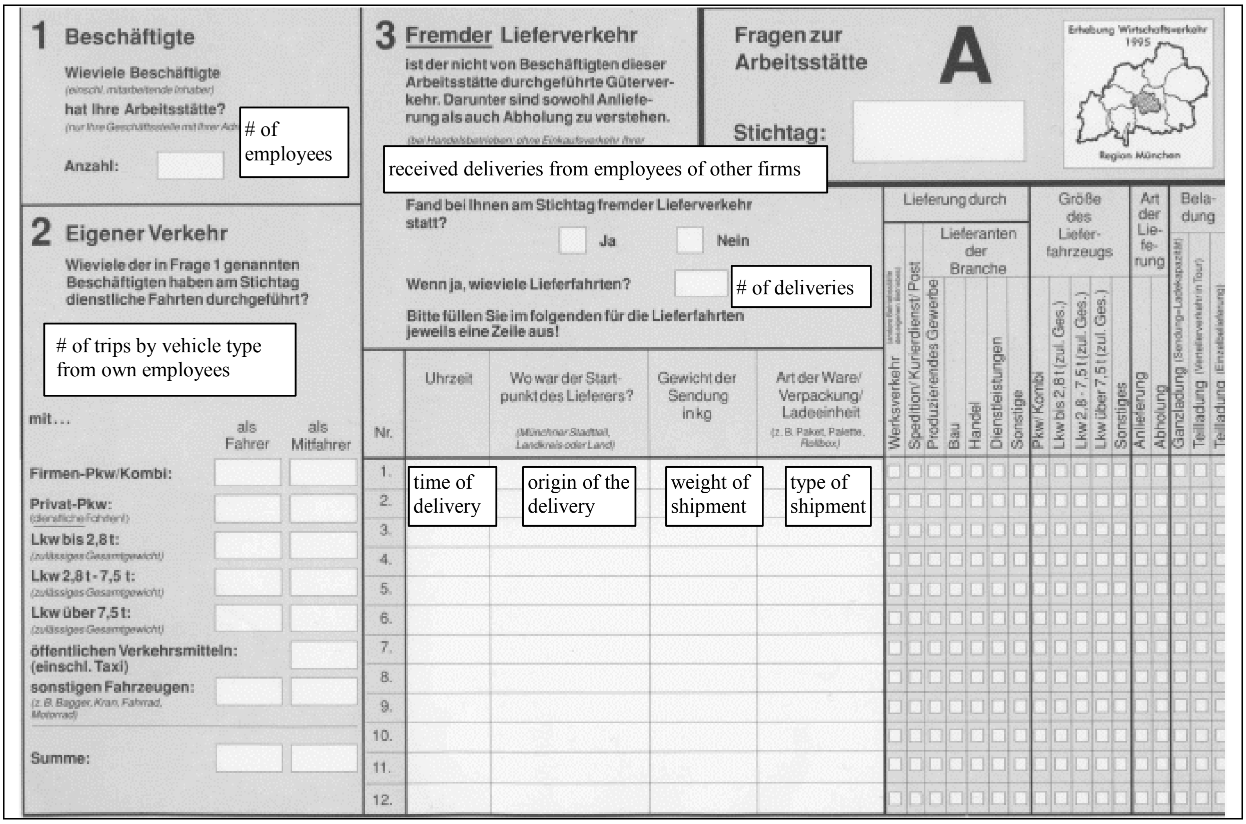
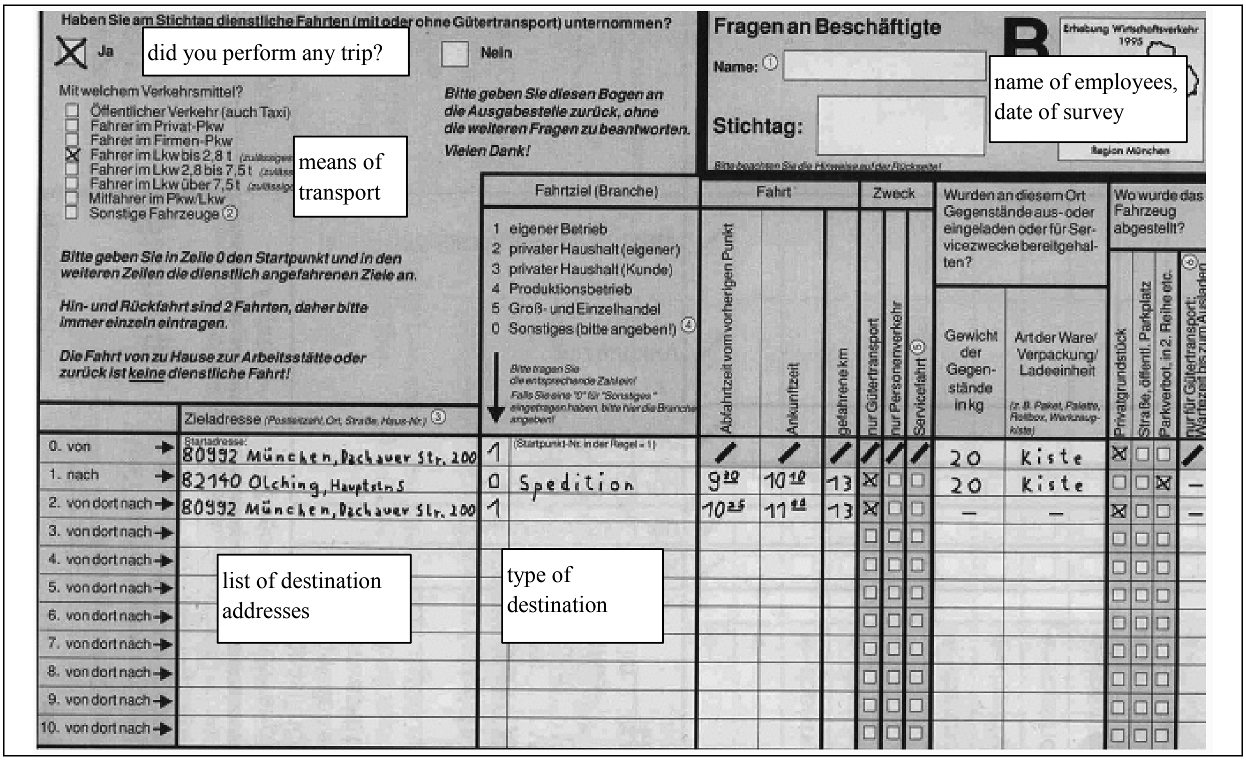


Figure 4: Questionnaire B: commercial car/truck driver trip diary



Part 2: Questioning of singular transport generators

In order to exactly replicate traffic flows dependent on the behaviour of individual, large traffic generators as well as flows resulting from the remaining commercial transport, an extra survey "Singular transport generators" was performed to accompany the main survey. This included freight forwarders and the flows of the remaining commercial transport by taxis, busses, emergency services, fire brigade, police etc.:

- The group *freight forwarders* consisted of 19 major Munich freight forwarders and businesses that operate central logistics points. Their survey was intended to compare the results of the general survey with the actual behaviour of the freight forwarder branch and to improve the quality of the results for these traffic zones.
- The *remaining commercial transport* consists of taxis, busses, postal transports, emergency services, the police and the local authorities. The objective of that part of the survey was to estimate the kilometres travelled.

A total reply rate of 79% of all questionnaires was achieved. The following results on the workday kilometres travelled by the remaining commercial transport in the region of Munich were gained from the survey.

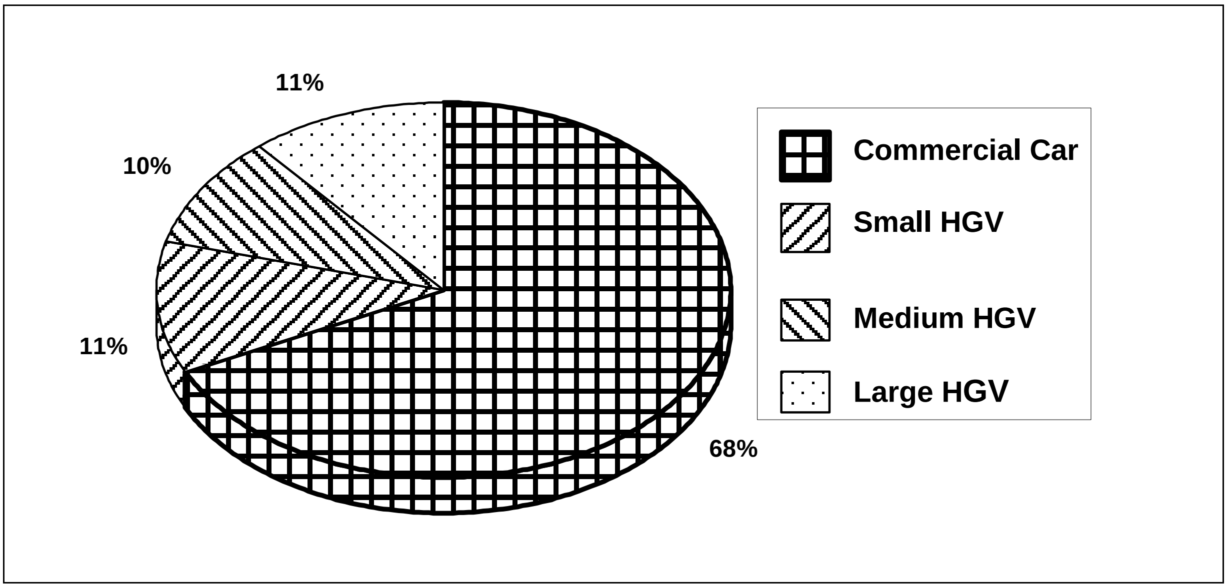
Figure 5: Kilometres travelled by the remaining commercial transport on a workday

Category	Workday kilometres travelled
taxi	540,000 km
busses	147,000 km
postal service	33,000 km
sum transport services	**720,000 km**
council services	24,000 km
civil waste disposal office	29,000 km
civil engineering office	13,500 km
civil garden offices	3,500 km
sum civil services	**70,000 km**
police	48,000 km
fire brigade	5,000 km
emergency services	11,000 km
sum rescue services	**64,000 km**
total sum	**854,000 km**

Part 3: Questioning of drivers on the roads

In order to check and calibrate the traffic flow from the commercial transport model, information on the actual structure of the traffic flow, i.e. the share of commercial traffic, was surveyed by means of driver interviews. Drivers were interviewed at five selected locations in the Munich network of arterial roads in the morning (8:00-11:00) and the afternoon (14:00-17:00). The survey showed a share of 36 % for commercial traffic during peak hour. The share of vehicles with commercial transport purposes is surprisingly high. However the values were confirmed by the projection of the business survey and further model calculations (trip generation and assignment). The latter also provide detailed information on the individual causes of transport (described in [12]) and the vehicle kilometre travelled by vehicle class (Table 1).

Table 1: Share of the workday kilometres by vehicle class for commercial transport in the Munich region



A total of 50 Million vehicle kilometres are travelled in the arterial road network of the Munich region. Out of this about 15 Million vehicle kilometres relate to the City of Munich (Table 2). Due to the longer trip distances of commercial transport the share of vehicles kilometres travelled is higher than the shares of trips. Within the inner ring road and in the city centre of Munich the share of commercial transport rises to 40 % and 55 %. This illustrates the significant impacts of commercial transport in urban transport.

Table 2: Kilometres travelled by commercial and private transport on a workday on arterial roads

vehicle kilometres travelled	**Munich region**		**within the City of Munich**	
	Mio. km	**Share**	**Mio. km**	**Share**
all types of road transport	50 Mio. km	100 %	15 Mio. km	100%
• private car transport	36 Mio. km	72 %	10 Mio. km	66%
• commercial transport	14 Mio. km	28 %	5 Mio. km	33%

2.2 National survey: freight vehicle statistic

Surveys on haulage are continuously being performed in Germany by the Kraftfahrtbundesamt (KBA) in Flensburg. This survey is based on the EU by-law from May 1998 (No. 1172/98) on statistical surveying of the motor freight industry and the EU by-law No. 2163/2001 on data transfer for statistics. The aim is to provide comparable information about the carriage of goods by road by means of goods road transport vehicles that are registered in the country. Each country is collecting the data for the registered HGVs in its territory. According to EU legislation and the German transport statistics law, this is real-time information, also on trip routes, the freight service performed there and data on the vehicles used which is integrated in freight transport statistics. The business contacted by the KBA are bound to participate (§ 23 Federal statistics law) and must return the questionnaire within 10 days after the end of the report period. In total each year for around 220,000 vehicles from 3,5 tonnes, the transport data of half a week, Monday to Wednesday or Thursday to Sunday, is surveyed. This data forms the central basis for most European countries for creating statistics and a central basis for modelling. Both national combinations and their trailers are statistically included in the surveys. The transported goods are classified according to goods classes (on the basis of the NST/R classification; see http://europa.eu.int/comm/energy_transport/etif/other_pages/nomencl_nstr.html) Evaluations are normally performed for Germany on a NUTS1 (Federal State) or NUTS2 level, but can also be provided for the main goods classes on a NUTS3 level. On an EU level the data are consolidated by Eurostat and evaluated on the level of the 15 member states. An evaluation for the 15 EU membership countries is displayed as example in Table 3. The 10 new acceding countries have partly already performed surveys according to the same design for 2002.

Table 3: Tonne-kilometre of HGV transports in the EU memberstates member states (source [7])

Road : Haulage by Vehicles Registered in the Country

1000 mio tkm

	B	DK	D	EL	E	F	IRL	I	L	NL	A	P	FIN	S	UK	EU15
National haulage																
1995	18.6	9.3	201.3	12.4	78.7	135.3	4.7	150.3	0.5	26.7	11.1	11.1	21.8	28.4	146.7	856.9
1996	16.6	9.4	199.2	15.1	76.3	136.5	4.7	151.0	0.4	27.3	11.4	14.0	22.2	30.3	150.2	864.6
1997	18.4	9.7	203.1	16.4	80.6	139.0	4.7	153.6	0.4	27.4	11.6	14.4	23.5	32.2	152.5	887.5
1998	16.7	10.1	210.4	19.3	91.3	145.5	4.7	155.0	0.4	28.2	11.7	14.7	25.6	30.4	155.4	919.5
1999	13.2*	10.4	226.9	20.0	98.1	159.0	5.4	155.0	0.4	32.0	12.3	15.3	25.6	30.4	152.8	956.9
International haulage																
1995	22.8	12.4	33.7	0.9	22.5	40.0	0.9	12.5	1.2	33.9	12.5	n.a.	n.a.	3.1	14.4	n.a.
1996	21.1	11.3	33.9	0.8	25.3	40.3	0.9	23.9	1.2	35.1	13.1	8.8	2.6	2.8	15.5	236.8
1997	21.9	11.2	38.8	1.7	28.3	39.4	0.9	19.8	1.2	36.0	13.6	10.0	2.1	2.7	16.3	244.0
1998	19.9	10.8	42.2	1.3	32.8	40.3	0.9	19.9	1.2	36.8	14.6	10.0	2.4	2.9	16.1	252.1
1999	14.5*	12.3	45.7	1.4	35.0	42.0	1.1	21.0	1.5	41.0	15.7	11.0	3.7	2.6	16.0	264.5

Source : Eurostat

Note : * figure refers to year 2000

3. Modelling regional commercial traffic (WIVER and VISEVA)

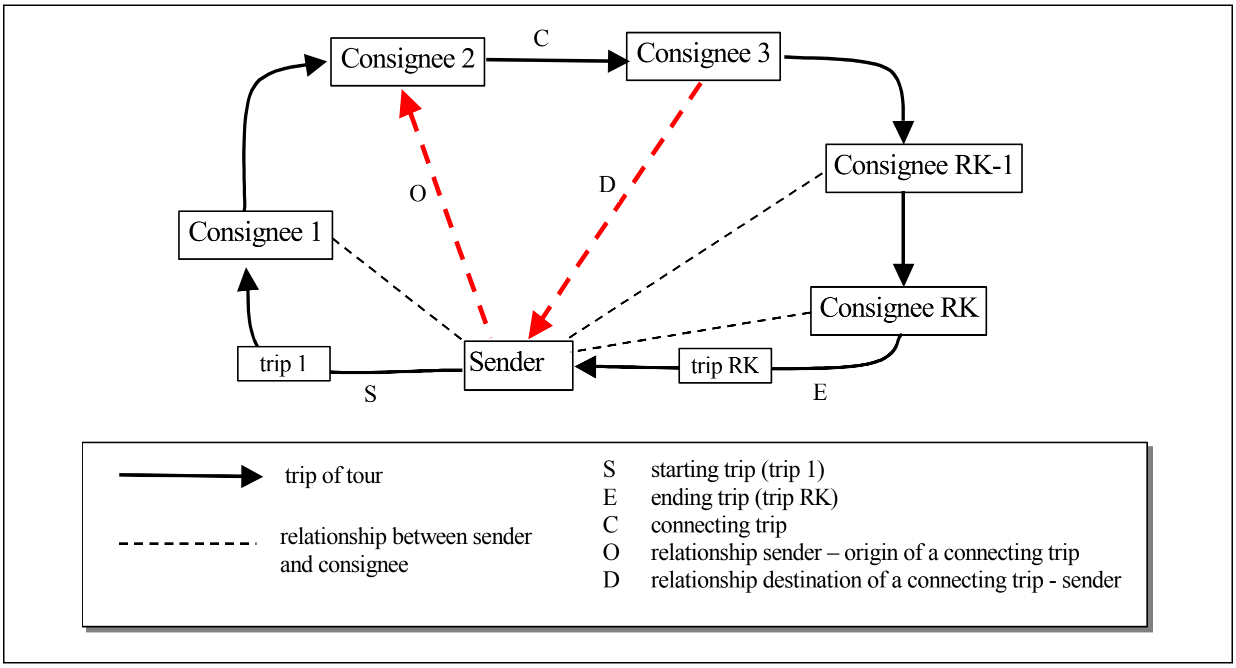
In Germany in the 1980s travel demand models for private transport were developed which are built on activities reported in trip diaries [8]. The trip generation was explained using the frequency of a certain type of activity chain (e.g. Home-Work-Shopping-Home). Choice of destination and mode of transport is performed in the trip chain context, i.e. the origin and destination of a trip chain is the person's own home. When choosing stop-off points the impedance for a (fictitious) trip home can be taken into account, as well as the difference between modes of transport which can or cannot be switched within a trip chain (reduced choice set for trips within a trip chain).

At the end of the 1980s the model WIVER was developed by Sonntag [12] in connection with the survey data described in chapter 2.1. The VISEM / WIVER model calculates the demand of passenger transport and commercial road transport by vehicle type using structure data from a city / region and surveyed behaviour data from groups of persons and the transport activities of a company's employees.

Very recently (2002/2003) the WIVER model approach was transferred by Lohse ([11], [2]) to a general framework backed up by a system theory and included in the software program VISEVA at the Technical University of Dresden. VISEVA calculates the travel demand on the level of so-called origin-destination groups (examples in passenger transport are home-work or home-education) while considering the boundary conditions of the system (for example column and row sums from trip generation) and the transport participants' behaviour-related choices. For modelling commercial transport it is assumed that each sender generates one or several vehicle tours per day which start and end at the sender’s home zone. Figure 6 shows the different types of trips forming a tour: the starting trip S, the connecting trip C and the ending trip E. Each trip type belongs to one origin-destination group. The relationships O (sender – origin of the connecting trip) and D (destination of the connecting trip – sender) reflect the connection of the vehicle to the depot. For each trip an evaluation value EV is calculated from the impedance (time, costs) between the origin and the destination of this trip. For this an evaluation function (described in [11]) is applied which transforms the impedance value to an evaluation value EV between 0.0 and 1.0. The evaluation value for trips of type S, C and E is definded as follows:

$$\begin{array}{ll} \text{starting trip from i to j}: & \mathrm{EV}_{ij}^{S} = \mathrm{EV}_{ij} \\ \text{connecting trip from i to j with home zone e}: & \mathrm{EV}_{ije} = \mathrm{EV}_{ei}^{O} \times \mathrm{EV}_{ij}^{C} \times \mathrm{EV}_{je}^{D} \\ \text{ending trip from i to j}: & \mathrm{EV}_{ij}^{E} = \mathrm{EV}_{ij} \end{array}$$

Figure 6: Modelling of tours (= chain of trips) and definition of trip types within a tour



Trip production

Trip production of a sender in zone i can be calculated as follows:

1. The number of generated trips VV_i by the senders of zone i depends on the number of tours and the number of consignees visited per tour:

$$VV_i = \sum_p (RK_{pi} - 1) \cdot RA_{pi} \cdot BG_{pi} \cdot u_{pi}$$

with

BG_{pi}	Value of production unit p in zone i (e.g. workplaces by industry sector)
RA_{pi}	Tours per production unit p
RK_{pi}	Number of trips within one tour
u_{pi}	Share of trips within the modelling area

2. The number of trips SE_i starting at zone i is equal to the number of tours starting at this zone. It corresponds to the number of trips / tours ending at this zone:

$$SE_i = \sum_p RA_{pi} \cdot BG_{pi} \cdot u_{pi}$$

3. Number of connecting trips H_i related to home zone i :

$$H_i = \sum_p (RK_{pi} - 2) \cdot RA_{pi} \cdot BG_{pi} \cdot u_{pi}$$

Trip attraction

Trip attraction by consignees in zone j can be calculated as follows:

1. Potential of attracted trips PE_j by consignees in zone j

   $$PE_j = \sum_s SG_{sj} \cdot ER_{sj} \cdot v_{sj}$$

   with

SG_{sj}	Value of attraction unit s in zone j
ER_{sj}	Trip attraction rate of s in zone j
v_{sj}	Share of trips within the modelled area

2. Number of attracted trips VE_j by consignees in zone j results from balancing the attraction potential with the number of generated trips

   $$VE_j = fk \cdot PE_j \qquad fk = \sum_i VV_i \Big/ \sum_j PE_j$$

After balancing production and attraction the sum of generated trips is equal the sum of attracted trips:

$$\sum_i SE_i + \sum_i H_i = \sum_i VE_i$$

Trip distribution

The sum of all trips v_{ij} between zone i and zone j is the sum of all starting (^{S}), connecting (^{C}) and ending (^{E}) trips:

$$v_{ij} = v_{ij}^S + \sum_{e=1}^{m} v_{ije}^C + v_{ij}^E \qquad (i, j = 1,...,m)$$

For trip distribution the following conditions must hold over all zones 1 to m:

$$\sum_{j=1}^{m} v_{ij}^S = SE_i\ , \qquad \sum_{j=1}^{m} v_{ij} = SE_i + VE_i \qquad (i = 1,...,m)$$

$$\sum_{i=1}^{m} v_{ij}^E = SE_j\ , \qquad \sum_{i=1}^{m} v_{ij} = SE_j + VE_j \qquad (j = 1,...,m)$$

$$\sum_{i=1}^{m} \sum_{j=1}^{m} v_{ije}^C = H_e \qquad (e = 1,...,m)$$

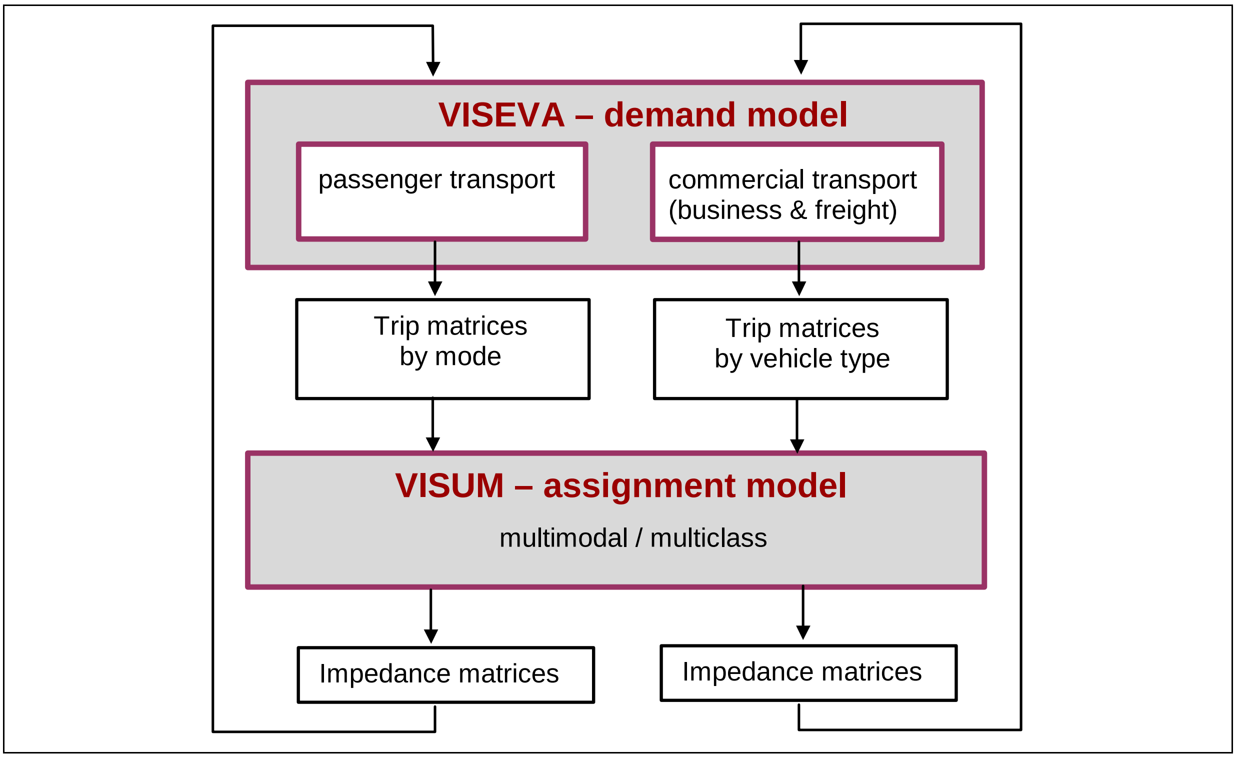
The number of trips v_{ij} between zone i and zone j are verified by projecting the evaluation matrix containing the evaluation values EV for starting, connecting and ending trips. For this the factors fo_i^S, fh_e^C, fd_j^E, fo_i *and* fd_j are to be determined in an iterative process such that the following condition holds:

$$v_{ij} = \left[EV_{ij}^S \cdot fo_i^S + \sum_{e=1}^{m} \left(EV_{ije} \cdot fh_e^C \right) + EV_{ij}^E \cdot fd_j^E \right] \cdot fo_i \cdot fd_j$$

Demand calculation and assignment

The flow chart (Figure 7) illustrates the feedback loop between demand model VISEVA (commercial and passenger transport) and the assignment model VISUM. The work flow in the model consists of two main processes: calculation of the travel demand matrices by use of VISEVA and assignment of the O-D-matrices by use of VISUM. The calculation of the travel demand is split up into two separate “VISEVA-projects” – one for passenger traffic and one for commercial transport. For commercial transport only road traffic is regarded whereas for passenger transport also the modes walking, cycling and public transport are considered. The result of the demand calculation are trip matrices for passenger transport by mode (passenger car, walk, bike, public transport) and for commercial transport by vehicle type (passenger car, vans, different types of trucks) which can be assigned simultaneously onto the road network. If available also other trip matrices which were calculated externally (e.g. matrices with long distance freight trips from the German federal plan for transport) can be integrated. The assignment produces link volumes and impedence matrices (e.g. travel times, costs, distances) which are the basic input for the next iteration step. The iteration the model stops, if an equilibrium between demand (trips) and supply (network) is reached.

Figure 7: Modelling of the total travel demand including commercial and freight transport as well as passenger transport



For the first time the model was applied by PTV for the region of Chemnitz, Germany in 2002. With this model it was possible to determine an equilibrium between demand and supply over all modes of transport including tour-based commercial transport.

4. The SPIN intermodal network model for Europe

SPIN (**S**canning the Potential for **IN**termodal **T**ransport, [16]) is a research and development project supported by DG TREN of the European Commission within the 5th framework programme. SPIN aims at providing initial information to support a modal shift for freight transport from pure road transport to more sustainable means of transport. To achieve this aim the SPIN project develops an internet based information service called *Advanced Scan*. This service allows to examine the potential for a modal shift towards intermodal transport. *Advanced Scan* is built on a multimodal network model containing road, rail and inland waterways infrastructure networks, short-sea-shipping routes and freight terminals. It also consists of available intermodal services based on timetables of major intermodal operators. The features of *Advanced Scan* include

- proposal of alternative modal choices,
- cost estimates for each individual part of the transport chain,
- proposal for alternative routings,
- time indications for a transport chain.

This chapter intends to give a brief outline of the structure of the multimodal network model. The network model is implemented in the transportation planning software VISUM [14]. For the *Advanced Scan* application VISUM is used as part of a client server system. VISUM with the multimodal network runs on a server and is accessed from clients via the internet using the COM interface of VISUM. The client selects an origin and destination point in the network using a web page (prototype web page of May 2003: http://62.225.145.29/SPIN/ advanced-scan.asp). VISUM calculates the optimal route for one or several modes and returns the results to the clients as a map or as a table.

4.1 Transport systems and modes

For the SPIN network model existing unimodal network models are merged into one multimodal transport network. The network model contains the following means of transport (transport systems):

- heavy goods vehicles using the road network,
- direct trains using the rail network with a fixed timetable,
- standard trains using the rail network without a fixed timetable,
- small inland watercrafts operating on inland waterways,

- large inland watercrafts operating on inland waterways permitted for this type of craft,
- large inland watercraft: inland waterways,
- sea ships operating on sea-shipping routes.

Modes combine one or several transport systems. Unimodal transport modes use only one means of transport for a shipment while intermodal transport modes employ more than one means of transport. Table 4 lists the modes of the SPIN network and the associated set of transport systems.

Table 4: SPIN network model: modes and their transport systems

mode	mode type	transport system / means of transport
road	unimodal	• heavy goods vehicle
standard rail	unimodal	• standard train
direct rail	unimodal	• direct train
inland waterway	unimodal	• small inland watercraft
wide inland waterway	unimodal	• large inland watercraft
road & standard rail	intermodal	• heavy goods vehicle • standard train
road & inland waterway	intermodal	• heavy goods vehicle • small inland watercraft
road & sea	intermodal	• heavy goods vehicle • sea ship
road & standard rail & inland waterway	intermodal	• heavy goods vehicle • standard train • small inland watercraft
road & direct rail & inland waterway	intermodal	• heavy goods vehicle • direct train • small inland watercraft
combined transport	intermodal	• heavy goods vehicle • direct train • standard train • small inland watercraft • large inland watercraft • sea ship

4.2 Link network

The SPIN link network combines several sources into one integrated network. Table 5 shows the different link types. Each link type is open for one or more transport system and has a system specific speed. The spatial course of the road links, railway links and inland waterway links is described by a polyline. Sea route links and direct train links exist only as direct line between to nodes. A direct train with a timetable operates on each direct train link.

Table 5: SPIN link types

link type	permitted transport system	no. of directed links	source
road motorway	heavy goods vehicle	25,100	PTV
road primary	heavy goods vehicle	75,300	PTV
road secondary	heavy goods vehicle	75,500	PTV
car ferry	heavy goods vehicle	1,100	PTV
non electrified railway	standard train	1,400	NESTE
electrified railway	standard train	3,200	NESTE
rail ferry	standard train	20	NESTE
direct trains	direct train	1,500	NESTE
inland waterways small	small inland watercraft	5,000	NEA
inland waterways large	small and large inland watercraft	1,200	NEA
sea routes	sea ship	11,100	NEA
total		200,400	

4.3 Nodes and terminals

Nodes describe unimodal points (road intersections, railway junctions and stations, locks and ports) as well as intermodal transfer points. The SPIN network distinguishes seven categories of intermodal terminals:

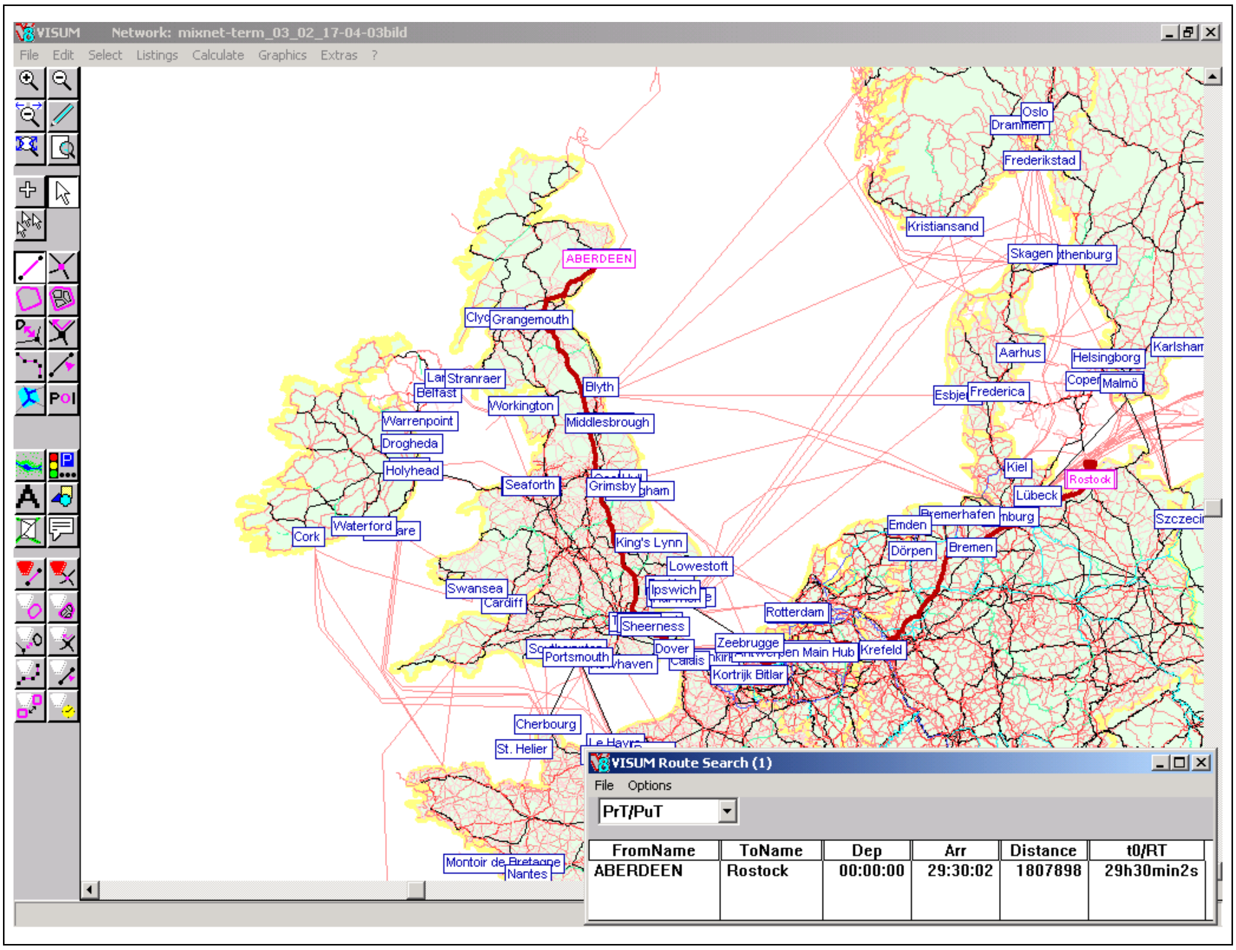
1. terminal road & rail,
2. terminal road & rail & inland waterways (e.g. Amsterdam, Duisburg),
3. terminal road & rail & inland waterways & sea (e.g. Rotterdam, Le Havre),
4. terminal road & inland waterways (e.g. Groningen, Regensburg),
5. terminal road & inland waterways & sea (e.g. Rotterdam, Le Havre, Bremerhafen),
6. terminal road & sea (e.g. Calais, Portsmouth),
7. terminal road & rail & sea (e.g. Barcelona, Naples, Rostock).

Delay times and transfer costs at terminals are modelled by extra links. These are specific terminal links connecting the nodes of the road-, rail- or water-network to a terminal.

4.4 Results

The multimodal SPIN network is the basis for calculating optimal routes for each mode based on time and cost parameters. This is used for developing mode specific time and cost matrices which then allow to compare the service quality of the different modes.

Figure 8: Screenshot of the SPIN network showing the link network, sea ports and a route between two locations with some route indicators.



5. VISUM Cargo: a tool for optimising rail freight transport

Rail freight operators face a two-fold planning task in order to offer good performance: On the one hand the quality offered has to meet the market requirements especially concerning transport times, on the other hand the services have to be performed economically, in order to improve the economic result of the operator. In rail freight transport this dual objective presents a special challenge, because the usual production structure today – particularly in wagon-load transport - is closely linked to the available infrastructure, e.g. the marshalling yards. Generally, rail infrastructure cannot be changed at short notice. This characteristic sets rail freight apart from long-distance road haulage, where carriers may use operational planning tools for flexible day-to-day route planning.

But even in the rail business, scope exists to increase flexibility and efficiency within the constraints of the existing infrastructure. The traditional production pattern of wagon-load transport, with a hierarchy of access points (sidings, freight stations) - subyards (syd) - marshalling yards (yd) and pre-determined yard sequences was developed in order to achieve an even capacity utilization in the days of predominantly manual planning of the workflow. Today it appears that a more flexible handling of routes and a less rigid allocation of access points to subyards can considerably improve the economy of the train formation process. In order to be able to quantify the advantage of such alternative production patterns, strategic planning models are necessary.

VISUM Cargo is a modelling tool especially developed for this type of rail freight modelling. On the basis of a network model with capacity restrictions for tracks, a train formation method and given goods volumes VISUM Cargo suggests an economical timetable for the transport of the goods volumes. Ideally, the suggested timetable respects both the capacity restrictions and the transport time requirements. For maximum flexibility, the user of the model can either choose a complete, automated timetable calculation, or preset certain factors like guaranteed trains or a given matrix of yard sequences. The timetable is generated simultaneously through an allocation of the goods volumes to individual trains. This corresponds roughly to the assignment procedure in passenger transport modelling. As in passenger transport models, numerous indicators can be derived from the results of the planning process permitting to measure effectiveness, productivity and economy on different aggregation levels; ranging from the individual wagons to the performance of operators as a whole.

5.1 Data model

Demand

According to the usual production structure in goods transport, VISUM Cargo develops a weekly timetable. Accordingly, the demand is given for one week. The model uses seven supply matrices – one for each weekday. Thus the distribution of volumes over the days of the week (depending e.g. on the production processes of large shippers) can be considered realistically during train formation and empty wagon balancing. Loads are allocated to days of the week according to their departure time. Within one day, the transport demand is differentiated by three dimensions:

- geographically (origin/destination region),
- by content (goods class),
- according to form of conveyance.

Geographic differentiation works exactly as in passenger transport planning. Traffic zones are defined as origins and destinations of transport processes. Zones are connected to network nodes. For the cost calculation, each connector carries separate unit costs for customers and operator. The customer unit cost expresses which amount per ton arises for the shipper for access/egress. In combination with the rate for the rail transport, the total cost of the transport from the customer view is calculated. The operator unit cost expresses, which amount per ton the operators themselves must apply for supply/distribution outside of the rail network. These costs have to be added to the cost of the rail transport itself.

Demand differentiation by content is done using goods classes. Goods classes are freely definable and are aggregated for purposes of analysis. A goods class groups of goods of similar condition together (example: anthracite, coal, gravel, milk or „grain"). The first two goods classes could e.g. belong to the goods group "dry bulk goods", the latter two to the goods group "agricultural products".

Transport systems and transport modes

In VISUM Cargo each freight train belongs to a transport systems with a system-specific standard speed and, optionally further characteristics (e.g. max. axle load), which influence possible routings. For example a train system for fast overnight connections with a system speed of 120 km/h could be defined as one transport system. Track access fees are transport system dependent, so that e.g. differentiated track access charges can be modelled in this way.

Transport modes specify the form of conveyance. The following types of cargo transport modes are predefined:

- single wagon load,
- contracted train load,
- intermodal transport.

These three transport modes are differently treated during the train formation:

- Single wagons are usually carried in several trains with shunting operations at yards between origin and destination. Only if the shipping volume exceeds a minimum quantity determined by the user, a direct train is formed. For the distinction from services explicitly ordered as train loads such transports are called operational direct trains.
- Contracted full trains are generally carried as direct trains without shunting in transit.
- In intermodal transport, the goods are shipped in a container, swap body or on a lorry, which is in turn carried on a rail wagon during part of the total haul. Accordingly the standard vehicle is a container carrying wagon or a wagon for lorries or swap bodies. Also for the access and egress to and from the terminals this mode of conveyance is treated differently: volumes arising between the zones O (origin) and D (destination) is assigned to the combination of terminals TO-TD, which minimises the total cost = CustomerAccessCosts(O, TO) + freight rate (TO, TD) + CustomerEgressCosts(TD, D). Thus intermodal transport flows are modelled to be relatively price-sensitive, due to the flexibility concerning the selection of the terminals. This compares to wagon loads which can only originate or terminate at specific sidings.

Each goods class corresponds to a standard wagon type, whose carrying capacity is relevant for transforming shipping volumes into an appropriate number of wagons. Standard wagon types possess their own unit costs for the calculation of the train haulage costs.

Infrastructure and production facilities

Within VISUM Cargo, the underlying rail network is described by a graph consisting of nodes and links. Links possess a capacity for freight transport, which is defined as "number of train paths per hour" for 24 hourly time slices. Link capacities apply to the sum of all goods train paths of all transport systems. In addition, all links carry the travel time and the track access fee per transport system.

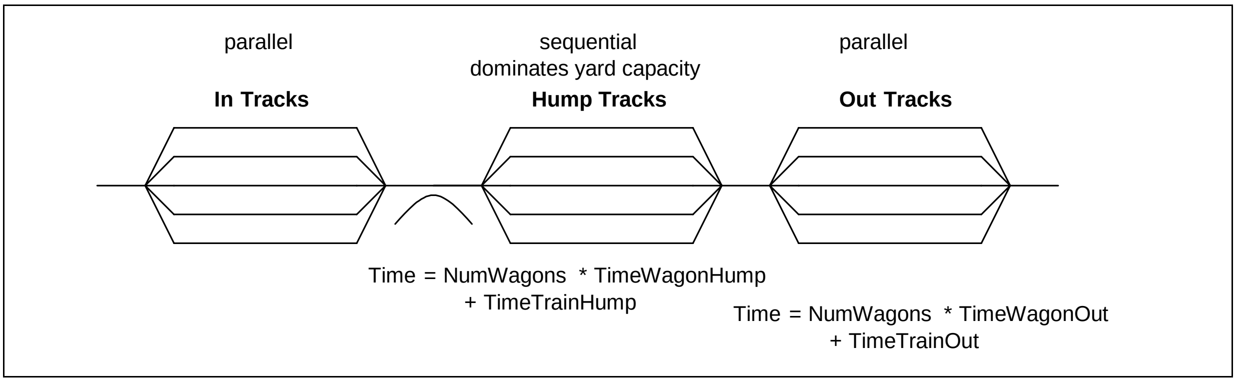
Nodes represent cargo stops - access points (ap), subyards (syd) and marshalling yards (yd) - as well as turnout points and junctions which have a purely operational meaning. The three predefined types of cargo stops correspond to a three-layer hierarchy for use in the yard sequence formation process. They are attributed with capacity restrictions, costs and time requirement values for the different elements of the train formation process. Additionally, a node carries information about the type of modes which can be handled and of the transport systems whose trains may be formed or resolved there.

The capacity modelling of a train formation facility is derived from the wagon flow through a conventional marshalling yard. In conventional gravity marshalling yards wagons pass successively through

- the in tracks, in which among other things the technical investigation takes place and the couplings between wagons are opened,
- the hump and the sorting tracks where in each track wagons with same target are collected,
- the out tracks, where on every track a train is formed from a group of wagons. Here the train receives its main-line loco and the necessary documentation, and the compulsory brake tests are performed.

In VISUM Cargo, each of the three phases carries attributes determining the time needed per wagon and per train. Thus the handling times result as shown in Figure 9. The total of the times determines whether a wagon transition from an incoming train to an outgoing train is possible.

Figure 9: Calculation of time elements during train formation at a marshalling yard



For the capacity calculation of the marshalling yard it is assumed that the hump saturation is the dominant factor. Therefore it is assumed that all work at in tracks and out tracks may be performed in parallel, at least in principle. In contrast to this processing at the hump can only take place strictly sequentially. Therefore the load of a marshalling yard is defined by the time during which the hump is occupied. Accordingly, the capacity is the period of operation of the marshalling yard. The degree of utilization is described by the quotient from both:

$$Capacity = Capacity_{Hump} = NumHumps \cdot OperatingHours$$

$$Load = Load_{Hump} = \sum_{sortedtrains z} Time_{Hump}(z)$$

$$Saturation = Load / Capacity$$

Production structure: partial routes and yard sequences

With the exception of direct freight trains all other wagons reach their destination through one or several shunting operations at intermediate subyards and marshalling yards. Therefore trains other than direct trains operate only between the following node types:

- Access point (Ap) – neighbouring subyard (syd) and v.v.
- Subyard – marshalling yard (syd - yd) and v.v.
- Between marshalling yards (yd - yd).

Generally several possible routings in the network exist for a journey between two nodes. These are called partial routes, because they represent a sub-section in the routing of a wagon. Partial routes are defined as a sequence of links, like public transport lines. Freight trains operate on a partial route from start to destination station without scheduled stops on the way and do not change their composition on the way. VISUM Cargo can both use externally given partial routes (for status quo evaluations), or compute routes automatically according to different optimisation criteria.

A wagon travels from origin to destination over a sequence of partial routes, with shunting operations at (sub)yards in between. For a given O-D relation, operators often permit only certain pre-determined yard sequences. Several yard sequences may exist for an origin-destination relation which are stored in a yard sequence matrix. This matrix indicates the set of permitted successor yards for each origin-destination pair. Again, VISUM Cargo can process pre-determined yard sequences or generate yard sequences.

For the transport of a wagon between origin and destination, first a yard sequence is selected to connect origin and destination. The yard sequence determines the yards where the wagon is marshalled, but not the detailed routes. Then for each successive pair of yards several partial routes may exist, one of which is chosen. After the step the sequence of links for the journey is completely determined, only the departure times remain to be fixed.

5.2 Balancing of empty wagons

The conversion of the demand, given in tons, into wagon loads, determines at the same time the number of incoming and outgoing wagons per wagon type and cargo stop. Since the directed transport flows in goods transport usually do not match, differences between inbound and outbound number of wagons occur. These have to be balanced by empty wagon runs. The empty wagon runs are to be handled at minimum cost, i.e. after unloading an idle wagon is conveyed to a nearby cargo stop, where it is provided for the next customer.

The situation corresponds to a classical transportation problem per wagon type:

$$\min! \sum_i \sum_j x_{ij} c_{ij}$$
$$s.t. \sum_j x_{ij} \geq a_i, \forall i$$
$$\sum_i x_{ij} \geq b_j, \forall j$$

where

- Sources a_i = cargo stop with wagon input > wagon output
- Drains b_j = cargo stop with wagon input < wagon output
- Costs c_{ij} = costs of the transfer of an empty wagon from i to j

VISUM Cargo plans with a temporal horizon of one week. Thus, the empty wagon balancing does not have to take place over night, but only in time for the next loading. This is reflected in the transportation problem algorithm by introducing a node for each pair (source/weekday) or (drain/weekday). If desired, it can be modelled that for a short term balancing higher costs apply than for a balancing over several days.

The transportation problem is solved with a standard technique and supplies cost-minimum empty wagon flows x_{ij}. These are added to the original demand matrix as demand with the fictitious goods classes "empty wagon of type X", for each wagon type X. The extended demand including the empty wagon flows enters the subsequent train formation procedure.

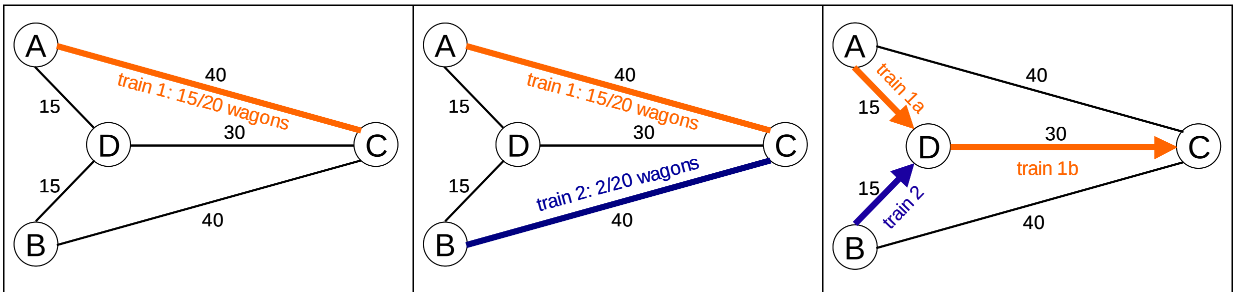
5.3 Train formation

During the train formation two conflicting objectives are to be brought into agreement. On the one hand the capacity of nodes and links is limited. Staff costs and track utilisation fees cause a jump in costs when inserting a further goods train. For these reasons timetables which handle given transport volumes with few well-loaded trains are favoured. On the other hand, strong bundling leads to extended standing times at yards. Furthermore, bundling potential often arises only when indirect routes are selected, so that flows can share a common partial yard sequence. Both factors extend the transport time – often beyond the transport time windows demanded by real market conditions and specified in the demand matrix.

The objective of an economic train formation is therefore maximal bundling of wagon loads to trains, without violating the acceptable transport time windows. Attempts to formulate the task with all restrictions in a closed model lead to extensive multi commodity flow approaches, for which no efficient procedure for finding a global optimum is known. Therefore

VISUM Cargo uses a sequential loading procedure, which combines greedy scheduling with a revision of previous decisions where a bundling to similar yard sequences with previously allocated volumes could save cost.

Figure 10: Example for the bundling of wagon resources during train formation



a) Situation before optimisation
b) Variant without bundling
c) Variant with bundling to D-C

A simplified example illustrates the effect of bundling: In Figure 10a a small network is shown, in which the link labels correspond to the distances. For the relation A-C, a train with capacity for 5 further wagons was scheduled previously. In the current step, on the relation B-C 2 cars are to be transported. Two alternative yard sequences (B-C or B-D-C) are available. First the algorithm checks whether on one of these routes trains are already scheduled, to which the two wagons might be added. In the example this is not the case. Without bundling a new train has to be created, using the more economical, direct route B-C (Figure 10b). However A-D-C is an admissible yard sequence from A to C, leading to an alternative solution where both groups of wagons are conveyed separately to D, and from there in one train to C (Figure 10c). The advantage is the saving of the fixed cost of running an extra train B-C. This is traded against the detours via D. If the savings exceed the costs of the detours, the train formation procedure suggests the variant with bundling along D-C.

An undirected revision of previous decisions would lead to unacceptable computing times for such a procedure. Therefore, a substantial part of the search procedure and the data organisation implemented in VISUM Cargo serves the purpose of estimating quickly whether a bundling attempt has a chance for success at all. From the set of all transport variants for a vehicle deployment, the algorithm finally selects one with minimum marginal costs. The procedure terminates, if either all vehicle deployments are processed, or if no more transport capacities exist for remaining vehicle deployments. In both cases, the resulting plan contains yard sequences with flow volumes and transport times. For each partial route, the trains operated are determined.

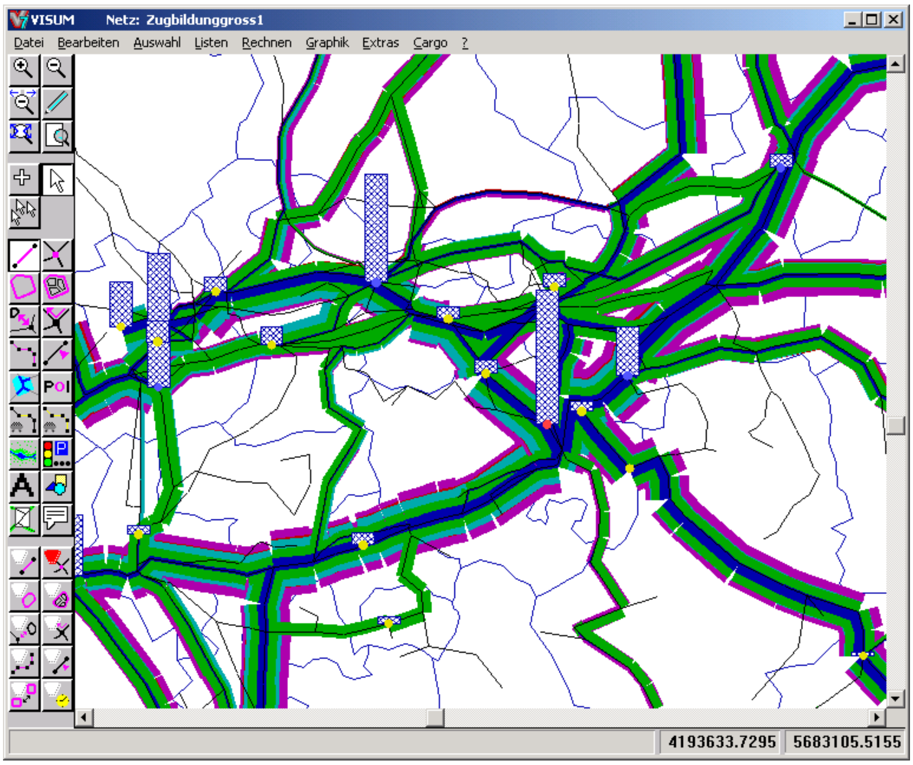
In the post-optimisation analysis, vehicle deployments which could not be transported because of capacity limitations can be regarded as lost demand. Likewise, transport volumes can be identified, which can be carried, on a part of its route, only with a train with utilisation below a given economic threshold.

5.4 Post-optimisation analysis and assessment functions

The result of a planning run consists of a network with timetable and an allocation of goods volumes to wagons and trains. In sum, this represents a large, complex body of data. Special tools are offered for analysis, consisting of graphic visualisation of loads and similar characteristics on the network, and user-definable tabular reports.

Figure 11 shows a typical example of a graphic analysis, in which the link loads in tons of transport quantity per transport system are represented in different colours. Simultaneously, the number of incoming wagons per cargo stop is shown as column diagram.

Figure 11: Graphical analysis of the result of the planning process



Tabular analyses cover a wide range from highly aggregated characteristics (e.g. total train kilometres) to drill-down investigations of problematic individual cases (e.g. uneconomic train runs, O-D relations with non-competitive transport times). In order to give to the users maximal flexibility with the definition of their analyses, the entire calculation result is stored in a relational data base. A special assistant supports the user in the composition of queries. The assistant uses the knowledge of the data base scheme, in order to avoid incorrectly formulated queries. In addition, experienced users can program their own evaluation programs and access the contents of the data base of results directly through an ODBC interface.

In the data base the results of planning are stored on the finest detailing level, related to individual wagon deployments and train runs. From these raw data, aggregations in spatial or temporal dimension, related to individual wagon types, transport systems, goods classification or any combinations can be formed.

6. Freight assignment

Assignment in general simulates the route choice of travellers or vehicles within a transport network thus allocating the demand to the network. Since each mode of transport has particular characteristics mode specific assignment procedures are necessary. A freight transport mode combines a set of transport means (i.e. vehicle types) which is used for shipping a consignment from origin to destination. A mode is unimodal, if only means of transport of the same type are used. The main unimodal freight modes are:

- road freight which uses road vehicles (lorries, vans, cars) operating on the road network,
- rail freight which uses rail vehicles operating on the rail network,
- water freight which uses ships operating on the inland waterway or seaway network,
- air freight which uses aircrafts operating on the air network.

A unimodal mode may require transfers between vehicles of the same mode, e.g. between heavy goods vehicles and smaller vans at some type of logistic point or between two trains at a marshalling yard. The equivalent for unimodal modes in passenger transport are cars or public transport. Passengers using public transport may require several transfers for one journey.

As discussed in Section 4, a mode is intermodal, if different types of transport means are used for a shipment, e.g. combined transport, where the major part of the journey is by rail, inland waterways or sea and the initial and final legs are carried out by road transport. Counterparts for intermodal modes in passenger transport are park & ride or rail & fly.

Assignment procedures more or less explicitly distinguish the steps route search and route choice. The search step tries to identify all possible routes between two points. The choice step then uses the collection of routes as choice set for modelling the decision process.

Road freight assignment

Road freight transport has almost identical characteristics as road passenger transport. Both modes use the similar types of vehicles and share the same road space. For this reason it is desirable to apply the same assignment algorithms. Using capacity restraint multi-class assignment procedures (see for example Cascetta [4]) allows to simultaneously assign different demand segments to the road network. Demand segments distinguish user classes with specific characteristics resulting either from the type of vehicle or from the type of driver. The vehicle type (car, lorry, etc.) determines the speed, the toll level, the impact on road capacity (passenger car equivalent) and the set of links which may be used (some links may be blocked for heavy vehicles). The driver type (private, business, etc) can influence the value of time. Multi-class assignment procedures for road transport are widely used in transport planning and are available in several commercial software packages.

Rail freight assignment

Rail transport differs from road transport as the vehicles operate according to a timetable. In passenger transport models the timetable may either be described by precise departure times or simply by headways. There are specific algorithms for timetable-based assignment (e.g. Friedrich et al. [9]) and headway-based passenger assignment (e.g. Spiess, Florian [15]). The main difference between the timetable- and headway-based assignment is that timetable-based assignment not only determines spatial routes through the network but also considers the temporal itinerary of a journey, i.e. it computes a connection.

These algorithms from passenger transport can also be applied to rail freight assignment, if the freight trains operate according to a schedule. This is the case for specific trains (rolling road, mail trains). The majority of freight trains, however, operate depending on demand. For these trains a ready timetable does not exist, not even a line network with headways or frequencies. Instead it would require a train formation algorithm to build the train journeys and their timetable. If it is not applicable to use such a detailed train formation model a shortest path or multi path search algorithm may be appropriate. Using a shortest path algorithm alternative routes can be generated in successive shortest path searches, where the links already used in the previous steps are penalised, in order to prefer routes using other links. For reasonable results the rail network should distinguish different train types (slow feeder trains, faster direct trains) and contain realistic penalties for shunting operations at transfers points. It may also be sensitive to apply a capacity restraint assignment as transfer points (marshalling yard) or the links only have capacity for a limited number of trains.

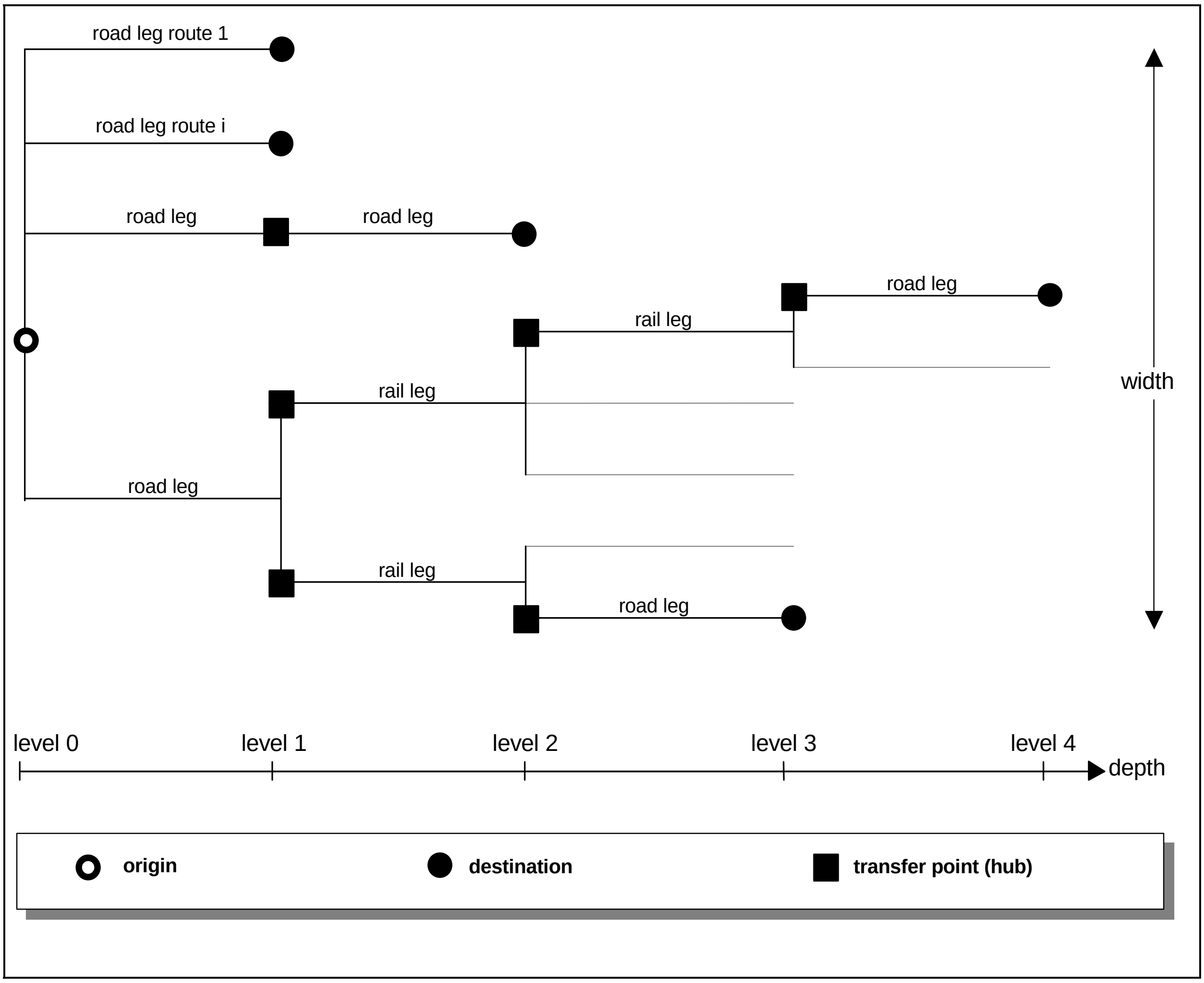
Intermodal freight assignment

Intermodal assignment requires a multimodal network model like the SPIN network model described above. In such a network many routes may be generated for a specific origin-destination pair. Routes can be generated by building a multimodal route tree. The route tree concatenates unimodal route legs to intermodal routes. A route leg describes the part of a journey between two transfer points which does not require a transfer between vehicles. An intermodal freight assignment based on a route tree would consist of the following steps:

1. Generation of direct route legs between all origins and destinations using a unimodal search.
2. Generation of route legs between transfer points using a unimodal search.
3. Construction of route tree.
4. Calculation of generalised costs for all routes including transfer costs.
5. Distribution of demand onto routes.

Figure 12 shows an example of a route tree. This route tree may contain several routes from the origin to every destination. It may also hold alternative route legs for one mode between two points, e.g. if there is more than one route in the road network between the origin and the rail access point. Since the tree's width largely depends on the number of transfer points and route legs, it may be much wider than a usual shortest-path tree. On the other hand, the use of entire route legs as tree edges simplifies the tree's structure to a great extent and limits its depth by the maximum number of transfers. The construction of the route tree may use a branch & bound method similar to the method described in Friedrich et al. [9]. This method inserts a route leg from node i to node j only if the total cost for the new route from the origin to node j does not exceed the minimum cost to node j by a user-defined factor.

Figure 12: Structure of a multimodal route tree



The route tree holds the routes for all destination of one origin. The route choice process extracts all the routes of one origin-destination pair and evaluates each route using a generalised cost function. This function can include cost and time components for links and transfer points, but also other attributes like capacity impacts. As the choice set of routes contains routes of different modes the route choice simultaneously integrates the mode choice. For the distribution of demand onto the routes one can apply a multinominal choice model of type Logit, Box-Cox or Kirchhoff.

Since some of the routes may overlap, i.e. they share several links, the assumption of independent alternatives required by multinominal choice models is unrealistic. This problem can be overcome by introducing a commonality factor (C-Logit) as described by Cascetta [4]. The commonality factor expresses the level of overlapping with alternative paths and reduces the utility of this path.

This, however, only works, when the routes describe only spatial characteristics, like length, time or costs. If some of the route legs hold information on service frequency - for example trains per day – or if the route legs represent connections with precise departure and arrival time, then it is no longer appropriate to integrate mode choice and route choice. Such a case requires a hierarchical choice model which firstly splits the demand between modes and then between routes. The mode split could for example cover the following three modes :

- road transport: only routes with times
- rail transport: routes with times and frequencies or connections (= route with a set of departure times)
- combined transport: rail routes or rail connections with feeder route legs from the road network

7. Outlook

This paper summarises a variety of specific approaches for demand and supply modelling of freight transport which have been developed and applied over the last 10 years. Employment of these models has shown, that strategic planning models can make an important contribution towards the analysis and optimisation of freight transport. Despite the associated large quantities of data, the quantitative comparison of alternative scenarios becomes possible with manageable effort. Thus models provide valuable decision support for investment and organisational measures. The practice-proven software packages for passenger transport planning lend themselves as a stable implementation base for such models, because they already come with a large part of base functionality for comfortable data entry and for the analysis of the results. Even the implementation of new freight-specific computation methods benefits from a common stock of basic algorithms and data structures which are tuned for optimum efficiency in extensive networks.

But the integration into a more general planning tool offers advantages, which go far beyond the pure technical implementation. Collecting and maintaining consistent planning data cause significant, recurring effort, which can be reduced, if e.g. a single common network is used for both passenger and freight transport planning.

Furthermore, modern transport planning tools offer simultaneous planning capabilities for road and rail transport within a common network model. This opens the possibility of examining complete logistics chains in intermodal transport within a single planning model. Discussions with courier and express parcel companies (parcel services) indicate the potential for a fully integrated intermodal model.

The authors believe that future development of freight models should consider the following points:

- Freight and passenger models should be integrated into the same software tools. This is equally desirable for the supply data described in a network model and the methods for demand calculation and assignment.
- Network models need to include hub locations. The software tools ought to provide specific network objects suitable for describing the transfer process at hub locations. This concern time and cost aspects as well as capacity restraints.
- Since commercial road traffic is responsible for a growing share of the road volumes and the road delays current developments of dynamic, i.e. time-depended methods for demand and supply modelling should equally comprise passenger and freight transport.
- Demand models should attempt to develop methods for modelling the medium- to long-term decisions about investment in or leasing of particular types of equipment, infrastructure and freight handling methods.

8. Acknowledgement

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