

A MULTI-MODAL TRANSPORT MODEL FOR INTEGRATED PLANNING

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Abstract

Transport models are applied to support the planner in the process of planning and decision making. Models attempt to replicate the system of interest and the system's behaviour. The presented model considers the transportation system with its interactions between the several supply systems and the demand system. The transport model, implemented in a software product called VISUM, consists of

- a network model describing the structure of the supply systems,
- a demand model simulating activities and generating trip chains,
- multi-modal assignment models to determine service quality and route choice.

INTRODUCTION

Understanding and solving transport problems is a process which generally starts with an analysis of the current state (Figure 1) in order to deduct deficiencies. The analysis of the current state is followed by a design process which can be partitioned into four steps (Figure 2):

- development of a solution,
- determination of impacts,
- evaluation of impacts,
- analysis of deficiencies.

These four steps constitute a cyclic process which continues until a satisfactory solution meeting the planning objectives is achieved.

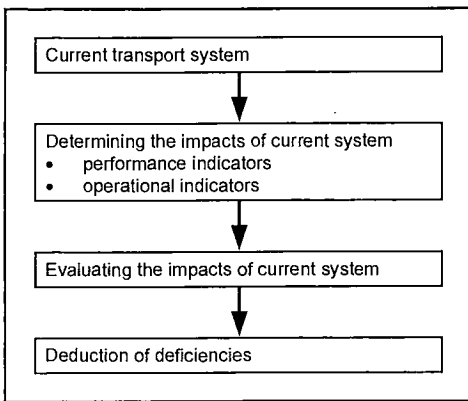


Figure 1 - Analysis of the current state

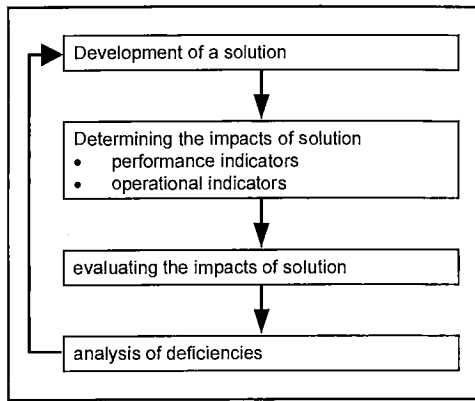


Figure 2 - Design process

Transport models are applied to support the planner in this process of planning and decision making. These models attempt to replicate the system of interest and the system's behaviour. The presented model considers the transportation system with its interactions between the several supply systems and the demand system. The transport model, implemented in a software product called VISUM, consists of a demand model, a network model and a set of impact models (Figure 3):

- The *demand model* contains the travel demand data. It simulates activities and generates trip chains to estimate and forecast mode-specific origin-destination matrices for behaviourally homogeneous population groups. Travel demand estimates are derived from structural land use data and service indicators determined by the impact model. Because the demand model describes the traveller's choice between various modes of transport it may be labelled "multi-modal".
- The *network model* contains the relevant data of the supply systems describing their spatial and temporal structure. It consists of traffic zones, nodes and public transport stops, links and public transport lines. Since the network model integrates private and public transport modes it may be labelled "pluri-modal".
- The *impact models* take their input data from the demand model and the network model. VISUM integrates different impact models to analyse and evaluate a transport system. A user model simulates the travel behaviour of public transport passengers and car drivers. Based on routing

and assignment models it calculates traffic volumes and service indicators, e.g. travel time, number of transfers or service frequency. Routing and assignment procedures are called "inter-modal" if they combine different modes for one journey or a trip chain. An operator model determines operational indicators of a public transport service, like vehicle kilometres, number of vehicles or operating cost. In combination with the demand data it allows to estimate line revenues. An environmental impact model provides several methods to assess the impacts of motorised transport on the environment.

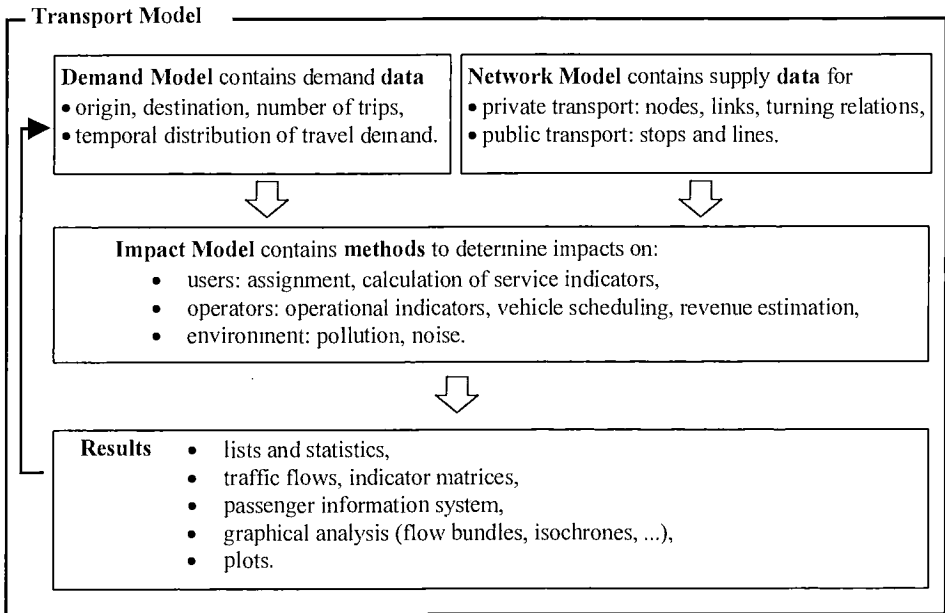


Figure 3 - VISUM: comprehensive transport model and its sub-models

This paper will focus on the requirements of a multi-modal transport model. It will

- give an overview of an activity-based demand model,
- present the structure of a network model which integrates various modes and supply systems,
- show methods which support the design process and assist the planner in finding new solutions,
- discuss multi-modal assignment procedures and approaches to combine modal split and assignment.

DEMAND MODEL

The demand model, which is named VISEM, estimates and forecasts mode-specific origin-destination matrices. The two basic ideas of VISEM are the classification of the population into behaviourally homogeneous population groups and the generation of trip chains derived from activity chains. This chapter only attempts to introduce the basic ideas of VISEM's activity-based approach to model travel demand. For a more detailed description see Fellendorf, Haupt *et al* (1997). As shown in Figure 4 VISEM consists of three sub-models:

1. An *activity model* which derives daily travel patterns from activity chains distinguished by residence zones and behaviourally homogeneous groups. A chain of activities describes the order of different activities during a person's course of the day, starting and ending at home. For example the chain *Home - Job - shopping - Home* represents three trips: *HJ, JO, OH*. In order to determine activity chains VISEM requires group-specific probabilities for each activity chain. This value states the probability that the activity chain is carried out by a group member on an average day.
2. A *destination choice model* which transfers activity chains into trip chains by allocating activities to specific destination zones. The choice of a destination zone depends on the separation (e.g. distance, travel time, public transport service quality class) between origin and destination zone and on the sensitivity to separation for each activity and each group. By choosing destinations the destination choice sub-model generates trips chains which can be aggregated to a complete trip matrix.

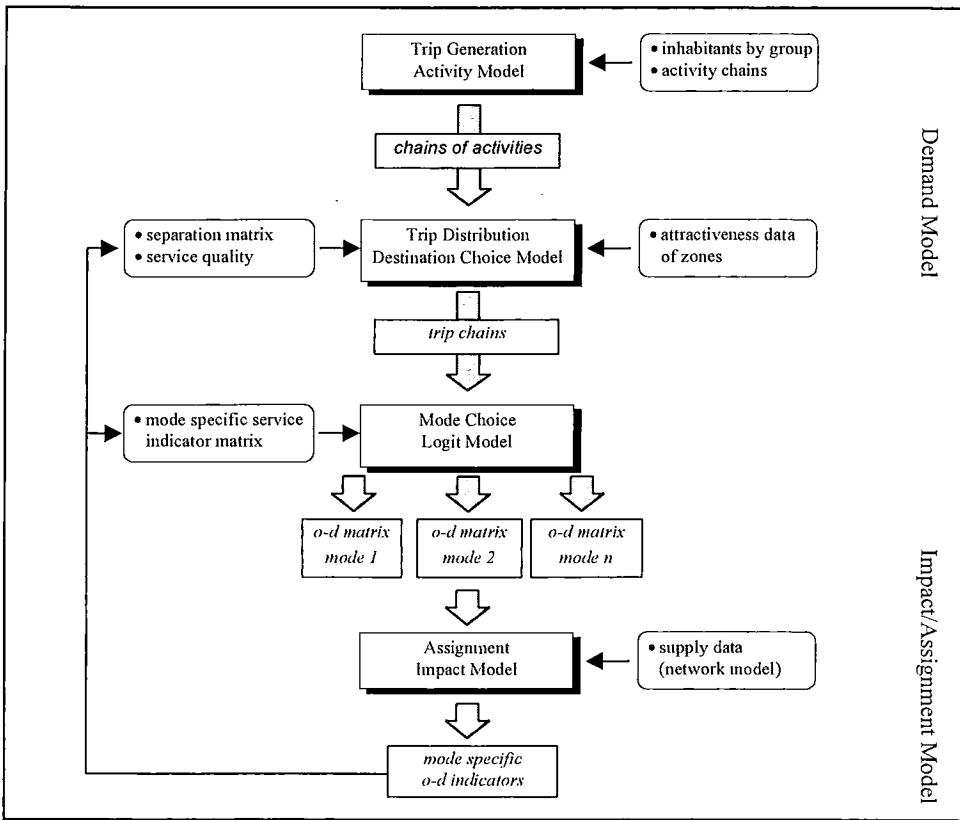


Figure 4 - The demand model and its interdependencies with the assignment model

3. A nested *logit mode choice* model which splits the trip chains to specific modes taking into account exchangeable and non-exchangeable modes. VISEM applies a behaviour-orientated approach which considers three aspects in mode choice:
 - the socio-economic situation, especially car availability of the deciding persons (by population group),

- service indicators for each of the transport mode alternatives (user-defined utility function considering indicators like travel time, access and egress time, fare, mode-specific "advantage distance" etc.),
- choice restraints within a trip chain as there are defined exchangeable modes (e.g. foot, car passenger, public transport) and non-exchangeable modes (e.g. car, bike).

This activity-based demand modelling approach is continuously applied in transportation planning studies (until today for more than 40 cities and regions, e.g. Hannover/Germany, Prague/Czech Republic, St. Gallen/Switzerland, Izmit/Turkey). This paper will describes two possible extensions to this demand model improving the linkage between demand and assignment model:

- Park&ride model: An explicit modelling of inter-modal trips (park&ride, bike&ride), where travellers use different modes for one trip, requires new routing and assignment routines. Using supply data stored in a pluri-modal network the routing process needs to find private and public transport route sections to and from park&ride terminals. Combining these uni-modal route sections to an inter-modal route allows the calculation of service indicators for evaluation purposes.
- Multi-modal assignment model: Assuming that the mode choice of travellers depends not only on the service quality of a single o-d pair but is influenced by the service quality of an entire trip chain it is sensible to consider a combination of mode choice and assignment model. This combined choice and assignment model uses the trip chains generated by the destination choice model as input values.

NETWORK MODEL

The network model describes the supply side of the transport system consisting of several supply systems. Each supply system is either of the mode-type "private transport" (PrT) or "public transport" (PuT) and uses one specific means of transport (car, heavy goods vehicle, bike, bus, train, light rail, etc.). The combination of mode-type and means defines the system's characteristics, which determine a set of rules for the operation of the vehicles. The actual speed of individual transport vehicles is influenced by the network's capacity whereas public transport vehicles operate according to their timetable. The requirements of a pluri-modal network model influence the design of the network objects:

- Nodes can represent intersections and/or public transport stops.
- Link attributes describe speed and capacity for private transport and carry default values for running time of public transport vehicles.
- Turning relations penalise turning movements for private transport during assignment and define junctions for the construction of public transport lines.
- Public transport lines may only use links which are suitable for vehicles of the particular system.

The definition of modes allows to link supply systems and travel demand (Figure 6). A mode may consist of one single supply system (e.g. car) or a set of supply systems (e.g. public transport).

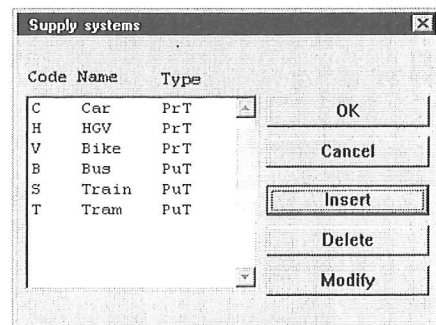


Figure 5 - Definition of supply systems

Source: all screen-shots in this paper are taken from the software program VISUM 6

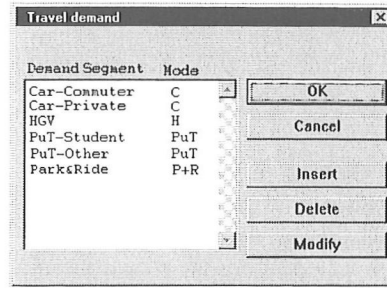
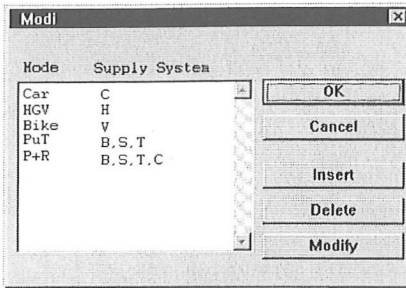


Figure 6 – Definition of modes and demand segments to link supply and demand

The following section gives an overview of essential network objects and their main input attributes. Depending on the planning objectives it is possible to store further input attributes. Especially environmental impact analyses and certain cost-benefit analyses require additional input attributes.

Nodes, Intersections and Stops

Nodes are objects which define the position of public transport stops and intersections in the network. Links start and end at nodes. Nodes are described by the attributes number, name, type and co-ordinate. A specific flag determines if the node is a stop, where public transport passengers can board and alight.

Links

Nodes of the network are connected through links, which describe the rail and road infrastructure. A link is defined by two nodes and characterised by the following input attributes:

- a link-type for network categorisation,
- the link's length,
- the supply systems, which may use the link,
- the free-flow speed and capacity for private transport,
- the running time for public transport systems.

Links which are permitted for a specific private transport system (e.g. car) are *considered during private transport assignment*. Links which are permitted for a specific public transport system (e.g. bus) are *considered during the construction of a public transport line*. Public transport assignment is not based on links but on line-routes and timetables. To model passenger transfers by foot between certain public transport stops a transfer walking link may be introduced to connect these stops. This link is part of a special public transport system "walking transfer".

Turning Relations

Turning relations record which turning movements are permitted at an intersection:

- For private transport systems time penalty and capacity can be specified thus describing the impact of the intersection on the network's performance.
- For public transport systems turning relations define junctions which are considered during the construction of a line-route.

Public Transport Lines

A public transport line has a particular line name and usually serves two directions. It may include one or several line variants (sublines) which show different line-routes or running times between stops. Each subline line is described by

- the line's name: e.g. *Bus1*,
- the number of the subline: e.g. *1*,
- a direction,
- a supply system,
- a line-route: sequence of nodes and stops with running time between stops,
- a timetable: list of departure times,
- operational data: name of operator and type of vehicle.

With these input attributes it is possible to determine operational and financial requirements for a public transport service. VISUM computes various operational indicators:

- Line indicators, like vehicle-kilometres, seat-kilometres or out-of-depot time are calculated from the line and timetable data.
- Operational costs result from vehicle specific costs and the required number of vehicles which can be determined by applying a vehicle scheduling procedure.
- The number of passengers using a particular line results from the assignment. Together with revenue parameters and a fare model they are used to estimate the revenue of a line.

Modify line variant (Basic data)

Subline: BUS1 1 H

TrSysName: Bus

OperatName: Operator A

VehTName: Standard Bus

Stops_total: 4

Stops: 4

Length: 27500

RunningT: 45min

Rides: 14

Veh-km: 305.0

Passenger-km: 50.5

Layover time: 5min

Modify line variant (Time table)

Stop name: Subline BUS1 1 H

Stop	Time	Time/Period	Time
WestSt	06:10:00	06:55:00	07:25:00
S Town	00:10:00	1h	18:10:00
Central			

Modify PuT vehicle types

No.: 1

Name: Standard Bus

Code: SBus

No. of vehicles: 10

Transport System: Bus

Capacities

Total capacity: 90

Seats: 35

Cost

per hour: 42.00

per km: 1.00

per vehicle/day: 100.00

Figure 7 - Selected attributes of public transport lines and vehicles

Traffic Zones and Connectors

Traffic zones define the origin and destination of trips. A traffic zone is described by the attributes name, type and co-ordinate. It may also contain information on zone boundaries. Each traffic zone needs to be connected with at least one public transport stop and one node of the private transport network to ensure that travellers from/to this particular traffic zone have access to the transport network. This connecting link is called connector.

DEVELOPMENT OF SOLUTIONS AND NETWORK ANALYSIS

Central task of the design process is the development of new solutions. Each new solution usually suggests various modifications to the network, e.g. an additional bypass, a modified line network or a new park&ride terminal. Although new solutions may be generated through optimisation algorithms, most solutions are still developed using the planner's creativity and experience, since the complex interdependencies within a transportation system cannot be described appropriately through an objective function. Therefore many practitioners spend a remarkable amount of their time modifying network data. The same applies to analysing and understanding results of impact calculations. Everybody working in the field of modelling will have experienced several situations when the modelling software failed to "answer" the most obvious questions or when network modifications required exhausting and error-prone search-and-replace routines in a text editor. Though every planner encounters these common experiences the planner's requirements in the process of developing solutions or understanding results are hardly discussed in research journals which seem to focus mainly on state-of-the-art algorithms. Most practitioners will agree that appropriate methods to create solutions and to conduct post-assignment analysis are equally important. On an extreme level one may argue that as long as a planner prefers to take a pen and a sheet of paper in order to develop a first draft of a public transport network the user interface of the modelling software needs to be improved. In an age where everybody got used to office software offering assistants, grammar checks or clip art it is increasingly difficult for transport modelling software to keep pace with the standards of modern software.

This following section will show selected examples of how modelling software can contribute to a creative design process and how it can support the planner in the post-assignment analysis.

Construction of Public Transport Lines

Designing a public transport line a planner ideally wants to "draw" the line-route onto the screen. Operational aspects favour a line length which produces effective round trip times and a stop sequence which ensures a sufficient catchment area. Passengers want fast, direct and frequent line services with timed transfers.

The VISUM network editor provides a method which attempts to meet these requirements. In order to define a line-route the user simply marks the two terminals of a line by a mouse click. Based on the link infrastructure VISUM proposes a complete line-route with running times and distances. The proposed line-route may be modified subsequently by merely dragging parts of the line onto other links (**Figure 8**). Using a standardised timetable (e.g. peak hours/off peak hours 10 min / 20 min headway) and an o-d matrix it is possible to continuously inform the planner on the line's performance by displaying essential indicators in a status window.

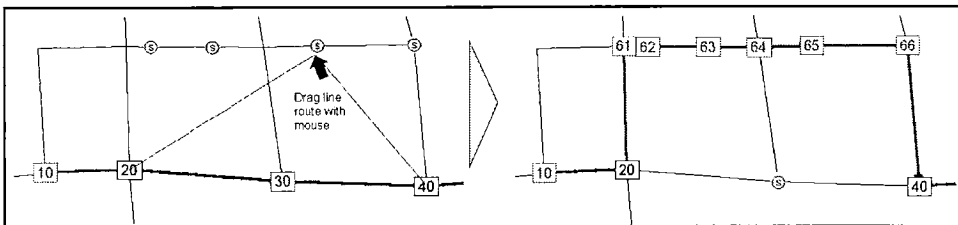


Figure 8 - Modifying a line-route: Fix stop 20 and 40, drag line-route with mouse from stop 30 to stop 65.

Advanced methods generate possible line-routes and optimise timetables with a fixed headway:

- Line-route generation: This method (Sahling, 1981) incorporates an objective function which minimises the number of transfers. Using a set of predefined terminals it generates and evaluates a set of possible line-routes. The algorithm is based on an o-d matrix and the link network which may be used by lines. It considers existing lines and therefore allows to focus on one supply system (e.g. bus) whilst other supply systems (e.g. train) are considered as fixed input.
- Timetable optimisation: This method (Maziejewski, 1992, Günther 1985) minimises the transfer waiting time of passengers in a line network with a fixed headway. Based on the results of a public transport assignment a genetic algorithm develops and evaluates "populations" of possible solutions by varying the departure time.

Graphical Network Analysis – Flow Bundles and Routing

Flow bundles (Figure 9): As a unique feature VISUM stores all routes during the assignment procedures. This feature allows extensive post-assignment analysis of traffic flows. With few mouse clicks the user can display flow bundles containing

- the different routes of private and public transport travellers between two zones,
- the routes of travellers passing a combination of nodes and links (selected link analysis),
- the through traffic of a certain area.

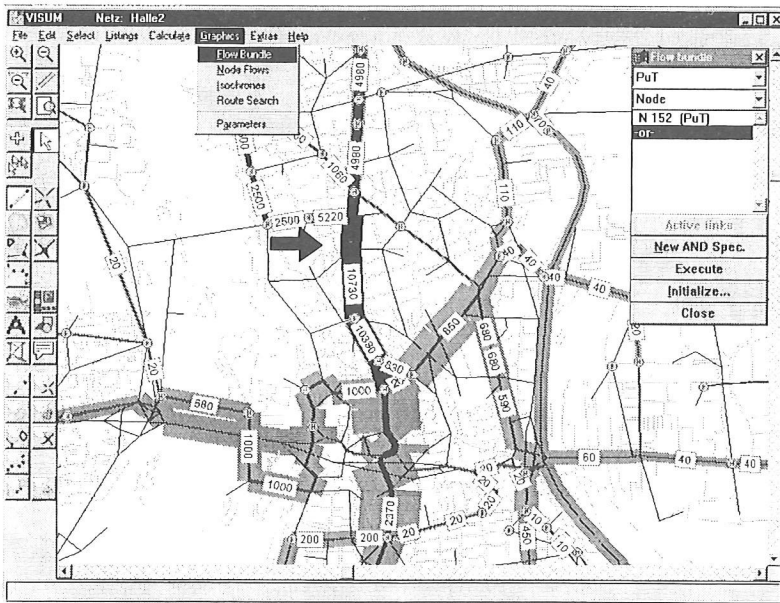


Figure 9 – VISUM environment showing a flow bundle for the marked stop

Routing information: This functionality simultaneously determines and displays private and public transport routes between two locations. The resulting routes are highlighted in the network, accompanying service indicators are shown in listing windows.

Passenger information system (Figure 10): This functionality allows in depth-analysis of public transport connections. Comparable to passenger information systems it calculates connections with

departure and arrival time. Additionally, it lists service indicators for each connection (journey time/length, in-vehicle time, transfer waiting time, number of transfers, fares, etc.) and shows the distribution of assigned trips. For o-d search and assignment the user can select the same assignment procedure/parameters he intends to apply in the public transport assignment. This helps to understand how trips are actually distributed over selected connections and thus assists in calibrating the parameters for public transport assignment. As the characteristics of urban public transport and regional or interregional public transport differ VISUM provides two special assignment procedures:

- *Assignment based on lines* guarantees good assignment results for urban areas with a dense network and short headways. This procedure ensures fast computing times by assuming that the time for transfer between lines depends on the headway of the following line.
- *Assignment based on timetable* is the appropriate method for rural areas or train networks, where headways are long and the co-ordination of the timetable is important for the service quality. The exact calculation of connections, however, requires more computing time.

The screenshot shows the VISUM PuT-Relations (1) window. At the top, there are input fields for 'From' (set to '? 100'), 'to' (set to '? All'), and 'Demand' (set to 'Matrix'). Below these are buttons for 'Connections', 'Time table (2)', 'Parameters', and 'Start search'. The main part of the window is a table with the following data:

OZonName	SStpName	DZonName	TStpName	PassTrip	AT	ET	IVT	JT	Dep	Arr
NewTown	NewTown	EastTown	Central Station	135	3	5	45	53	06:52:00	07:45:00
NewTown	NewTown	EastTown	Central Station	135	3	5	45	53	07:22:00	08:15:00
NewTown	NewTown	EastTown	Central Station	135	3	5	45	53	08:07:00	09:00:00
NewTown	NewTown	EastTown	Central Station	134	3	5	45	53	09:07:00	10:00:00
NewTown	NewTown	EastTown	Central Station	134	3	5	45	53	10:07:00	11:00:00

Figure 10 – Passenger information system with assignment results

MULTI-MODAL ASSIGNMENT

Considering the journeys of a travelling person, the term "inter-modal" indicates

- the use of different modes for one trip (park&ride, bike&ride, kiss&ride) or
- the use of different modes within one trip chain during the course of the day (e.g. public transport to work, walk from work to shop, public transport back home).

This chapter intends to outline current developments and ideas for inter-modal route search and assigning trip chains by integrating mode choice and assignment. As a useful base these new methods can use VISUM's capability to store routes during private and public transport assignment. This capability which is currently required for fast post-assignment link flow analysis (flow bundles) can be applied to combine private and public transport routes after assignment to inter-modal routes.

- *Private transport routes:* Each route is stored as a sequence of nodes (origin zone - list of nodes - destination zone) and contains information on its traffic volume (distinguishing different supply systems, i.e. vehicle types) and its service indicators (length, free-flow journey time, journey time in loaded network, tolls).
- *Public transport routes:* Each route is stored as a sequence of nodes and lines/transfer links (origin zone - departure stop - line1 or transfer walking link - transfer stop1 - line2 or transfer walking link - destination stop - destination zone) with its traffic volume. Due to the large number of relevant connections in a public transport network the limitation of computer memory does not allow to save connections including their precise information on departure/arrival time and transfer waiting time. Aggregating connections to routes, however, means that attributes of a route can only hold average values for the transfer waiting time and the journey time.

Inter-Modal Route Search

A inter-modal route search seeks to determine routes between o-d pairs which utilise more than one mode. Requirements for such a inter-modal route search come from the request for detailed park&ride modelling. The example network displayed in Figure 11 is used to illustrate one potential approach for searching inter-modal routes which is currently implemented as prototype.

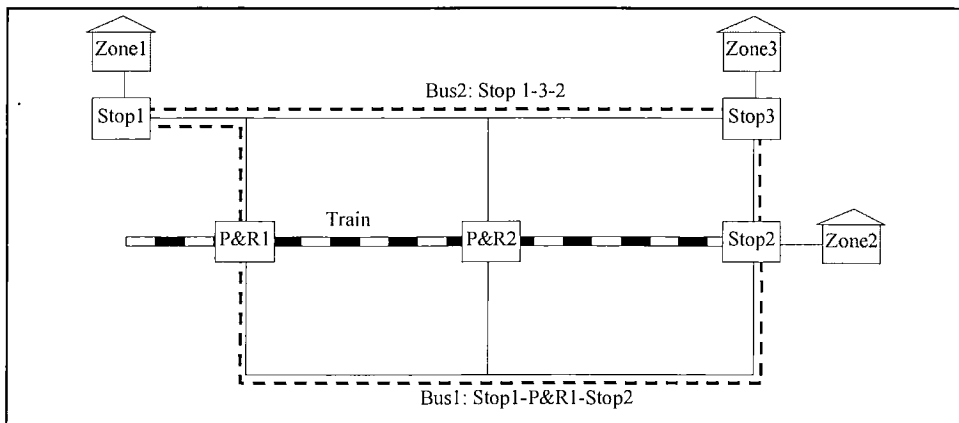


Figure 11 - Example network for inter-modal route search

A inter-modal route search which combines the results of existing assignment procedures for private and public transport and which uses VISUM's capability to store routes requires the following steps:

1. *Identify park&ride terminals*, i.e. stops where traveller can transfer between private and public transport modes are marked out by a special node type.
2. *Private transport assignment* assigns all private transport demand matrices (car, heavy goods vehicle) to determine travel time in loaded network.
3. *Private transport route search* between all zones and all park&ride nodes determines one shortest route for each relation and stores them as private transport routes in VISUM's route memory (see Table 1).
4. *Public transport route search* between all zones and all park&ride nodes (see Table 2). By conducting several route searches with varying transfer penalties (Fac-NT) and weighting factors for access/egress time (Fac-AT), transfer waiting time (Fac-TWT) and fare (Fac-Fare) this step determines and stores relevant public transport routes.

$$\begin{aligned}
 \text{Impedance of PuT-route} &= \text{in-vehicle time} \\
 &+ \text{access/egress time} \quad \times \quad \text{Fac-AT} \\
 &+ \text{transfer waiting time} \quad \times \quad \text{Fac-TWT} \\
 &+ \text{no. of transfers} \quad \times \quad \text{Fac-NT} \\
 &+ \text{fare} \quad \times \quad \text{Fac-Fare}
 \end{aligned}$$

5. *Generation of inter-modal routes* creates park&ride routes which result from a combination of private transport routes and public transport routes (see Table 3). This step needs to consider that park&ride travellers can use private transport vehicles only for the first or last section of a park&ride route. Since the private transport section usually originates from rural or suburban zones and the public transport section originates from urban zones, it is useful to identify zones:
 - zones which park&ride routes can access only with PrT-vehicles,
 - zones which park&ride routes can access only with PuT-vehicle,
 - zones which park&ride routes can access with PrT-vehicle or PuT-vehicle.

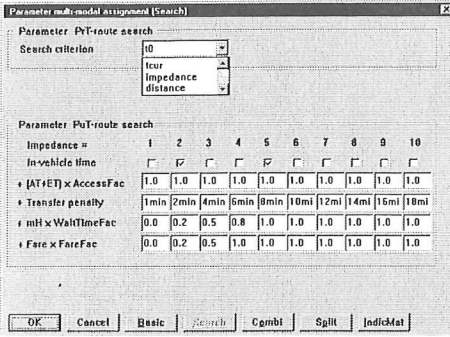


Figure 12 - Parameter for route search between zones and p&r nodes

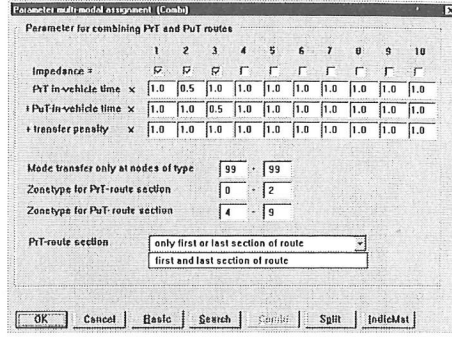


Figure 13 - Parameter for generating inter-modal routes

Varying weighting factors for private and public transport in-vehicle time and for node specific penalties (parking fees) allow to find several park&ride routes:

$$\begin{aligned} \text{Impedance of park\&ride-route} &= \text{PrT in-vehicle time} \times \text{Fac-PrT} \\ &+ \text{PuT in-vehicle time} \times \text{Fac-PuT} \\ &+ \text{node penalty} \times \text{Fac-Node} \end{aligned}$$

Weighting factors $\text{Fac-PrT} < \text{Fac-PuT}$ prefer park&ride routes with longer PrT-sections and shorter PuT-sections, i.e. urban park&ride terminals. Weighting factors $\text{Fac-PrT} > \text{Fac-PuT}$, however, favour outlying park&ride terminals. This step also includes an evaluation of the park&ride routes which eliminates routes where

- journey time of P&R route > journey time of shortest P&R route \times factor,
- journey time of P&R route > journey time of shortest car route \times factor.

6. *Connection search* superimposes the timetable to the public transport sections of the route in order to calculate connections with departure time, arrival time and accurate transfer waiting time.
7. *Park&ride assignment (connection split)* assigns the park&ride demand onto the park&ride connections. This requires an impedance function which evaluates the time and fare components of a park&ride connection. Park&ride trips can then be distributed using Kirchhoff's law.

Table 1 - Private transport journey time of car-routes

from Zone 1 to	from Zone 2 to	from Zone 3 to	from P&R 1 to	from P&R 2 to
Z2: 25'	Z1: 25'	Z1: 15'	Z1: 10'	Z1: 17'
Z3: 15'	Z3: 15'	Z2: 15'	Z2: 20'	Z2: 15'
PR1: 10'	PR1: 20'	PR1: 20'	Z3: 20'	Z3: 10'
PR2: 17'	PR2: 15'	PR2: 10'	PR2: -	PR1: -

Table 2 - Public transport routes with service indicators

from Zone 1 to	JT	NT	SF	from Zone 2 to	JT	NT	SF	from Zone 3 to	JT	NT	SF
Z2: Bus1	45'	0	3	Z1: Bus1	45'	0	3	Z1: Bus2	30'	0	1
Z2: Bus1/Train	30'	1	2	Z1: Train/Bus1	30'	1	2	Z2: Bus2	25'	0	1
Z3: Bus2	30'	0	1	Z3: Bus2	25'	0	1		45'	0	3
PR1: Bus1	15'	0	3	PR1: Train	10'	0	3	PR1: Bus2/Train	40'	1	1
PR2: -	-	-	-	PR2: Train	5'	0	3	PR2: Bus2/Train	35'	1	1

JT = journey time, NT = number of transfers, SF = service frequency
assumed transfer waiting time = 5 min

Table 3 - Park&ride routes with journey time

from Zone 1 to Zone 2			from Zone 3 to Zone 1		
Mode	Vehicle	JT	Mode	Vehicle	JT
PrT	Car	25'	PrT	Car	15'
PuT(1)	Bus1	45'	PuT	Bus2	25'
PuT(2)	Bus1/Train	30'			
P&R(1)	Car/Train via P&R1	25'			
P&R(2)	Car/Train via P&R2	27'	P&R(1)	Car/Train/Bus1 via P&R2	>> JT car
P&R(3)	Bus1/Car via P&R1	35'	P&R(2)	Bus2/Train/Car via P&R1	55'
assumed transfer waiting time = 5 min					

Multi-Modal Assignment of Trip Chains

To guarantee the consistency of a modal split model, travellers may only switch between certain modes. For example, a traveller using public transport for his trip to work cannot use his car for the return journey. Usually this restriction is achieved by determining a mode's proportion from *i* to *j* with the same indicators as for the relation from *j* to *i*. The presented approach, however, does not regard an o-d matrix but trip chains, assuming that the service quality of the entire trip chain determines the traveller's mode choice. According to this assumption, a traveller would not choose a good quality public transport service for his first trip if he required the car for a relation with poor service quality subsequently. Using VISUM's capability to store routes a multi-modal assignment process would consist of the following steps:

1. Determine activity chains and calculate trip chains.
2. Determine private transport, public transport and multi-modal routes.
3. For each trip chain calculate the service quality (utility) for all predefined combinations of modes (e.g. car-car, pt-pt, p&r-p&r, car-car-car, pt-pt-pt, p&r-pt-p&r, etc.).

Table 4 - Possible combinations for trip chain 1 → 2 → 3 → 1 (home-job-shop-home)

Trip1 Zone 1 → 2	Trip2 Zone 2 → 3	Trip3 Zone 3 → 1	JT	remarks
PrT	PrT	PrT	25'+15'+15' = 55'	
PuT	PuT	PuT	35'+25'+30' = 90'	35 min for trip 1 = 1/3 × 45' + 2/3 × 30'
P&R	PuT	P&R	25'+25'+55' = 105'	
P&R	PrT	P&R	25'+15'+40' = 80'	only possible for car passengers

4. Determine the proportion of each combination of modes (mode choice) using a multinomial LOGIT model (Fellendorf, Haupt *et al*, 1997):

$$P(m) = \frac{e^{U(m)}}{\sum_{k=1}^M e^{U(k)}} \tag{1}$$

with:
m, k index of mode combination (M= total number of mode combinations)
P(m) probability to choose mode combination *m* for the trip chain
U(m) utility of mode combination *m* for the trip chain

$$\begin{aligned}
 &\text{with utility function } U(m) = && (2) \\
 &- p_{1m} \times JT(m) && \text{marginal utility of 1 min journey time } JT \text{ for mode combination } m \\
 &- p_{2m} \times AT(m) && \text{marginal utility of 1 min access time } AT \text{ for mode combination } m \\
 &+ p_{3m} \times \log_e(D/p_{4m}) && \text{impact of trip chain distance } D \text{ on the utility of mode combination } m, \\
 & && \text{which has a positive value if } D > \text{"advantage distance"} \ p_{4m} \\
 &- p_{5m} \times C(m) && \text{marginal utility of 1 monetary unit } C \text{ (fares, toll)} \\
 &+ p_{6m} && \text{constant utility of mode combination } m \\
 &+ p_{7m} \times A(m) && \text{marginal utility of additional attribute } A \text{ of mode combination } m
 \end{aligned}$$

If there are different routes for one mode the trips need to be distributed onto these routes. In the example network, for instance, this is necessary for the public transport mode between zone 1 and zone 2. The proportion of different public transport routes is a result of the initial public transport assignment which is stored with the routes. For private transport a succeeding equilibrium assignment using the routes of step 2 as initial solution distributes the trips.

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