Planning and Analyzing Transit Networks

an Integrated Approach Regarding Requirements of Passengers and Operators

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PTV AG
Stumpfstr. 1
D-76131 Karlsruhe
Tel.: +49-721-9651-0
Fax: +49-721-9651-299
Email: ptv@ptv.de

ptv solutions for traffic.

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Authors

Markus Friedrich (markus.friedrich@ptv.de) directs the unit Transport Planning Systems at PTV in Karlsruhe, Germany. He received his Ph.D in Transportation Engineering from Munich University in 1994.

Thomas Haupt (thomas.haupt@ptv.de) is Director of the business unit Transportation Modeling at PTV in Karlsruhe, Germany.

Klaus Noekel (klaus.noekel@ptv.de) is responsible for Research and Development at PTV in Karlsruhe, Germany. He received his Ph.D in Computer Science from the University of Kaiserslautern, Germany in 1990.

Abstract

Providing an equally sufficient and efficient transit service requires careful planning and permanent monitoring of service quality, operating costs and revenues. These requirements ask for a model which is capable of determining impacts on passengers as well as on operators. Additionally it is important to provide suitable and powerful methods to design and to modify the transit network. The transport planning software VISUM attempts to fulfil these requirements. In contrast to conventional GIS systems which are extended to provide specific functionality for transit planning, VISUM is a comprehensive transportation model with additional GIS functionality. It seeks to fill the gap between conventional GIS programs and vehicle scheduling programs.

1 INTRODUCTION

1.1 Requirements of passengers and operators

Demands for a competitive public transport which can offer alternatives to private transport and which requires minimum public subsidies calls for a planning process which equally considers the impacts on passengers and operators. Passengers ask for a good service quality which means

- a short travel time,
- a minimum number of transfers,
- a good service frequency and
- reasonable fares.

Operators and transit agencies need to provide this service in an economically efficient way. They need to monitor the performance of the existing service and forecast the impact of proposed measures. The operator for example needs to know

- the required fleet size,
- the operating costs,
- revenues from tickets and
- the cost coverage which indicates whether public subsidies are necessary.

These requirements of passengers and operators describe the fundamental conflict in transit planning. To solve this conflict the transport planner needs to find an acceptable balance by equally regarding two incompatible planning objectives, namely the maximization of service quality and the minimization of operational costs and public subsidies. For this complex planning task transport planners started to apply software approximately three decades ago. Meanwhile planners can select from a variety of software-tools. Most common for strategic planning are

- Comprehensive Transportation Models (CTM) and
- Geographical Information Systems (GIS).

1.2 CTMs versus GIS

CTMs (e.g. Emme/2, Trips, TRANPLAN) were developed exceptionally for transport planning purposes. They connect travel demand data and supply data in order to determine traffic flows through the network. Core of the model usually is an assignment procedure distributing travel demand onto the link network. In the beginning most models only focused on private transport. Extensions to cover public transport often adapted modeling techniques for private transport. As a result the models often tend to lack appropriate assignment procedures for public transport, i.e. timetable based assignment procedures, and hardly consider aspects of transit operation.

GIS (e.g. MapInfo, ArcInfo) are widely used for a broad range of purposes. Providing a user friendly environment they are applied to manage, analyze and display geographical information by connecting database tables with geographical objects. In the field of transportation GIS for example are used to build and maintain road databases or to determine the accessibility of transit stops. Since standard GIS functionality does not cover specific transport aspects GIS users all over the world are more or less successfully trying to adapt their GIS according to their planning requirement. The professional extension of GIS for transport brought up several systems. For transport planning purposes it is particularly the TransCAD system which may offer an alternative to CTMs by combining GIS and transportation modeling capabilities.

1.3 The VISUM approach

This paper will present particular aspects of the transport planning software VISUM (Friedrich 1998, 1999) which is part of the PTV-VISION transportation software suite (PTV 1999). VISUM is a software program for planning and analyzing transportation networks (Figure 1). It provides specific functionality for public transport which helps to analyze and evaluate an existing or a proposed public transport service from the perspective of operators as well as passengers. By providing additional GIS functionality it seeks to fill the gap between conventional GIS, CTM programs and vehicle & crew scheduling systems.

The development of VISUM was and continues to be strongly influenced by the needs of European transit authorities and transit operators. With the introduction of competition and the privatization of the state-owned railway companies (Meyer 1997) many European transport companies were reorganized. Simultaneously an increasing emphasis was laid on improving the attractiveness and efficiency of the service. Transportation planning software was consequently expected to meet the following requirements:

- *Multi-modal transport model:* Since the main challenger of transit operators is not the competing operator but private car transport a transport model is required which integrates private and public supply systems thus supporting exploration of passenger potentials.
- *Continuous control:* Transportation planning software is expected to assist not only during the planning process but also to constantly monitor the performance of a transit system. Results of line costing calculations serve as a continuous input for planning.
- *Modeling of fare systems:* Transparent and competitive fares are an essential prerequisite for success. This requires a model which allows to define fare-zones and different types of tickets in order to estimate and optimize revenues. Transit networks with an integrated fare system depend on methods for distributing revenues onto lines of individual operators.
- *Modeling of large networks:* Especially railway companies and national transport planning agencies are in the process of establishing network models which incorporate precise line and timetable information on a nation-wide or even European level.

VISUM attempts to cover these requirements. The objective of this paper is to describe specific transit features implemented in VISUM:

- *Network model:* VISUM offers a network model which is compatible to GIS as well as passenger information systems or vehicle & crew scheduling systems. As a result it can combine geographical link network data and timetable data in an integrated network model.
- *Fare model:* VISUM provides a fare model to estimate revenues from ticket fares. The model supports distance based fare as well as zone based fare.
- *Design process:* VISUM provides functionality supporting the design process and assisting the planner in finding new solutions, for example by "drawing" the line-route onto the screen.
- *Service quality:* VISUM includes specific assignment procedures for public transport which apply search algorithms similar to passenger information systems. This allows to examine the impacts on passengers by calculating essential service indicators and travel cost for each o-d pair (journey time, waiting time, number of transfers, service frequency, fare).
- *Line costing:* VISUM supports line costing calculations which state the profit or loss on individual transit lines regarding costs and revenues.
- *Routes:* As a unique feature VISUM can store the routes of all passenger trips during assignment. Routes are most useful for post-assignment analysis of traffic flows and the calculation of fares.
- *Areas:* VISUM can aggregate performance indicators as well as cost and revenue indicators for user defined areas, e.g. traffic zones.

VISUM includes a demand model named VISEM. It 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. For a more detailed description see Fellendorf, Haupt *et al* (1997).

2 NETWORK MODEL

The network model describes the supply side of the transport system consisting of several supply systems (Figure 2). Each supply system belongs to either the mode "private transport" (PrT) or "public transport" (PuT) and uses one specific means of transport (car, heavy goods vehicle, bike, bus, train, etc.). The combination of mode and means defines the system's characteristics determining 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 transit vehicles operate according to their timetable. The requirements of an integrated network model for private and public transport 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 penalize turning movements for private transport during assignment and define junctions for the construction of transit lines.
- Transit lines may only use links which are suitable for vehicles of the particular system.

2.1 Transit lines

A transit 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. A set of vehicle trips (“service”) define the timetable which can be calculated from the departure time of any vehicle trip at the origin stop and the running times between stops. A line belongs to one supply system and can therefore use only links which are permitted for this supply system, e.g. a bus may only use certain links of the road network whilst a train may only use the rail network. Each vehicle trip uses a defined type of vehicle which can carry information on vehicle-specific costs. Figure 3 shows a simple network with one bus line “Bus1”. Figure 4 lists all relevant tables which are necessary to describe this network in a relational database.

- Table *Supply System* defines name and mode of each supply system.
- Table *Node* contains the attributes of nodes which can represent intersections or stops.
- Table *Link* describes the link network. Each link is defined by two nodes and several input attributes like link length, permitted supply systems, free-flow speed and capacity for private transport. The default running time for public transport systems is used during the interactive construction of a transit line in order to create a default timetable.
- Table *Vehicle* defines types of transit vehicles. The capacity attributes allow the calculation of a line’s saturation, the cost attributes are necessary to determine operating costs.
- Table *Operator* lists transit operators.
- Table *Subline* defines lines and line variants.

- Table *Line-Route* specifies for each subline a sequence of nodes and stops with running time between stops.
- Table *Timetable* lists vehicle trips which are described by a departure time at the origin stop, a vehicle type and an operator.

2.2 Creating a network model

Creating network models used to be a time consuming task. The possibility to obtain or purchase digital data opened new ways to build comprehensive and accurate network models. Main source for a multi-modal network model are digital link network data (e.g. NavTech) which need to be connected with transit data containing information on transit stops, line-routes and timetables. This requires three steps:

1. Import link network data using interface to GIS or relational database.
2. Import transit stops and match transit stops with nodes of link network. The matching process geocodes the transit stops. Where transit stops do not find corresponding nodes it is necessary to split links.
3. Import line-routes and timetables from transit source which can be passenger information systems (e.g. Hafas, EFA), transit databases (e.g. Transmodel [3]) or vehicle scheduling systems (e.g. HASTUS, MICROBUS, INTERPLAN). Since these sources generally store only served stops with the line-route the import process automatically inserts nodes into the line-route, which represent either intersections or through stops.

For importing and exporting network data VISUM provides integrated interfaces to ASCII files (comma separated values), relational databases (Microsoft Access, Oracle) and spreadsheets. Transit data may be accessed by product-specific interfaces or standardized transit databases.

2.3 Interactive construction of transit lines

Central task of the planning process is the development of new solutions. Although new solutions may be generated through optimization algorithms, most solutions are still developed using the planner's creativity and experience, since the complex interdependencies within a transport system cannot be described appropriately through an objective function. Therefore many practitioners spend a remarkable amount of their time modifying network data. 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 modeling software needs to be improved.

Designing a transit line a planner ideally wants to "draw" the line-route onto the screen. Operation 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 service 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 transit 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 5). Using a standardized 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:

- line length and running time,
- round trip time and number of required vehicles,
- origin and destination traffic, which starts or ends within walking distance from the line’s stops.

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

- Line-route generation: This method (Sahling 1981) incorporates an objective function which minimizes the number of transfers. Using a set of predefined terminals it generates and evaluates a set of possible line-routes to the planner. 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 transport system (e.g. bus) whilst other transport systems (e.g. train) are considered as fixed input.
- Timetable optimization: This method (Guenther 1985, Maziejewski 1992) minimizes 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.

3 USER MODEL

The objective of the user model is to determine the impacts of a transport supply system on travelers. Important indicators for evaluating the transport supply are journey time and travel expenses between two zones. To evaluate a public transport supply, additional indicators such as number of transfers, transfer wait time and service frequency must be considered (Friedrich 1994).

To determine these service indicators, the journeys of travelers are modeled. A private transport user chooses a route for his journey which appears convenient to him. In addition to choosing a route, a public transport user also selects a departure time from the timetable, that is, he searches for a connection. While a route only describes the spatial course of a trip within a network, a connection additionally encompasses temporal constraints such as departure and arrival times at the origin stop, transfer stops, and at the destination stop.

Methods to model the travel behaviour are based upon search algorithms which determine routes or connections between an origin and a destination. So-called shortest path algorithms are used as search algorithms which determine the "best", that is, the route with the lowest impedance. Impedance can consist of times, distances, comfort restraints and costs. Depending on the search algorithm used, this shortest path represents a route or a connection. Based on the service indicators of each route/connection the assignment then distributes the trips of an o-d pair onto the found routes or connections. As the characteristics of urban public transport and regional or interregional public transport differ, VISUM provides two special assignment procedures (Figure 6).

3.1 Assignment based on lines

The assignment procedure *based on lines* (assignment based on average headway) models each line through a sequence of stops, through the running times between the stops and through the headway of the line. Lines with no fixed-rhythm headway are described by their mean headway. This procedure does not explicitly calculate a transfer time but assumes that the transfer time depends on the headway. This means, the co-ordination of the timetable is not considered. Usually one assumes that the wait times at the boarding stop or at transfer stops is equal to half of the line's headway. Assignment based on lines guarantees good assignment results for urban areas with a dense network and short headways.

3.2 Assignment based on timetable

The assignment procedure *based on timetable* (real-time assignment) considers the timetable of each transit line with its exact departure and arrival times (Friedrich 1994). A shortest path algorithm based on these data calculates the “best“ connection between two traffic zones for a particular departure time. For different times of departure different “best“

connections may be calculated which can differ by the used transit lines and/or transfer stops. To determine all "best" connections the shortest path algorithm is performed several times for each possible departure time within the assignment time interval. Passengers select from this set of possible connections. Their choice is influenced by the service indicators of each connection and by the utility of the departure time. The individual components of disutility (e.g. access time, transfer time, in-vehicle time, fare) are weighted with user-definable perceived unit costs. Assignment based on timetable is the appropriate method for rural areas or rail 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 than the assignment based on lines.

3.3 Assignment results

The assignment produces three types of results (Figure 7). *Traffic volumes* on links, lines and stops, *service indictors* for all o-d pairs and *routes*. VISUM's capability to store all routes during assignment is a unique feature which allows extensive post-assignment analysis of traffic flows. It can also be used to calculate revenues from passenger fares without performing a new assignment. Thus it is possible to easily evaluate the impacts of new fare systems or higher fares concerning the revenue and cost coverage of lines.

4 OPERATOR MODEL

To estimate the impacts on transit operators, the operator model is applied to determine indicators which express the operational and financial requirements for providing a transit service. The operator model supports line costing calculations which are a most useful tool for those responsible for strategic, financial and operation planning. Line costing states the profit or loss on individual transit lines regarding costs and revenues.

In order to evaluate the performance of a transit line it is necessary to determine indicators on a line level. This is easy for indicators like vehicle kilometer which can be directly calculated from the line length and the timetable. Indicators like operating cost from vehicle depreciation or revenues from passenger fares, however, are more complicated, since a vehicle may be employed for several lines and a passenger may use more than one line for his journey. Operation indicators can be divided into the following categories:

- System performance indicators,
- Vehicle requirement indicators,
- Transport performance indicators,
- Cost indicators,
- Revenue indicators.

4.1 System performance indicators

System performance indicators express operation requirements in kilometers or time units. They are calculated automatically after every modification of line data and do not require demand data. Examples of performance indicators are:

- vehicle kilometer = vehicle trip length x no. of vehicle trips
- service time = time for passengers transport = line running time x no. of vehicle trips
- seat kilometer = vehicle kilometer x seats of vehicle

4.2 Vehicle requirement indicators

VISUM provides an algorithm with which planners can estimate the number of required vehicles for a specified transit supply. The main goal of this calculation is to assign the total number of vehicle trips of an operational day to vehicles in such way that a minimum number of vehicles is required. The basis for this calculation is the timetable. It consists of individual vehicle trips which are described by subline, direction, and departure time from the first stop of the line. Vehicle rotation result from the concatenation of individual vehicle trips to trip chains which can each be performed by one vehicle. In the simplest case a vehicle trip is concatenated at its last stop with a subsequent vehicle trip which starts at the same stop. If such a concatenation is not possible or not useful, the vehicle can be re-deployed to a different stop.

4.3 Cost indicators

The costs of a line consist of the following cost segments:

- hourly costs: time-dependent costs for personnel
- kilometer costs: kilometer-dependent costs for fuel, repair, etc.
- vehicle costs: fixed costs for each required vehicles (depreciation, insurance)
- network infrastructure costs: costs from depreciation of new links or running costs for maintaining the network.
- operator costs: share of costs for overhead costs

Costs for vehicles, network infrastructure or overhead need to be distributed onto individual lines or vehicle trips. This requires a distribution key considering vehicle kilometer, seat kilometer and service time.

4.4 Transport performance indicators

Combining supply data with travel demand data allows to quantify the transport performance described by indictors like number of boarding passengers, saturation and passenger kilometer. These indicators are calculated automatically during assignment.

4.5 Revenue indicators

To estimate revenue from ticket fares, a revenue value per transported passenger is calculated considering the fare system (distance based fare, zone based fare). This revenue value is then distributed over the lines used by the passenger for one passenger trip. Revenue can be distributed onto the sections of a trip using the length of each trip section or the number of trip sections. Figure 8 shows an example with three different approaches to distribute a revenue of 3,00 monetary units onto two lines. Cost coverage of a line is calculated by comparing revenues and costs.

4.6 Selected Analysis

All performance indicators as well as cost and revenue indicators may be aggregated and displayed on the level of individual lines, supply systems or areas, e.g. districts. In order to determine indicators for an area it is necessary to define a specific calculation routine for each indictor (Figure 9). Vehicle kilometers of a line can be distributed onto areas proportional with the line length inside the area. This is not possible for the revenues of a line, since a line might earn different revenues in each area. Therefore the procedure for distributing revenues onto areas must process each single passenger route with its individual revenues.

5 CONCLUSION

Demands for an efficient public transport which can also offer alternatives to private transport and which requires minimum public subsidies call for a planning process, where the impacts on passengers and operators are considered simultaneously. This requires a planning system which integrates

- a disaggregated version of the four step procedure (CTM),
- detailed transit data and specific methods to analyze the impacts of transit supply systems,
- GIS capabilities for editing networks and analyzing spatial impacts.

VISUM combines these requirements thus stimulating the planner within the planning process to experiment with alternative solutions. Various performance indicators are calculated concurrently with the modification of network data, so that the impacts of measures can be assessed easily. Since modifications of the transit supply directly influence operating costs and revenues it is recommended to include a line costing calculation. Combining assignment results with a fare model allows to evaluate measures like new fare systems and higher fares.

VISUM currently has almost 400 installations, mainly in continental Europe. VISUM is used for transit planning by cities (e.g. Berlin, Vienna), transit agencies (e.g. Dresden, VSN Group) and railway companies (e.g. DB AG, SNCF). Compared to other CTMs and GIS it is especially the broad and detailed transit functionality which characterizes VISUM (for a comparison of Emme/2 and VISUM see SAMPLAN 1999). Embedded in an multi-modal model this transit functionality can serve as a powerful tool for planners involved in transit planning as well as integrated planning.

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Figures

Figure 1: VISUM - comprehensive transport model and its sub-models

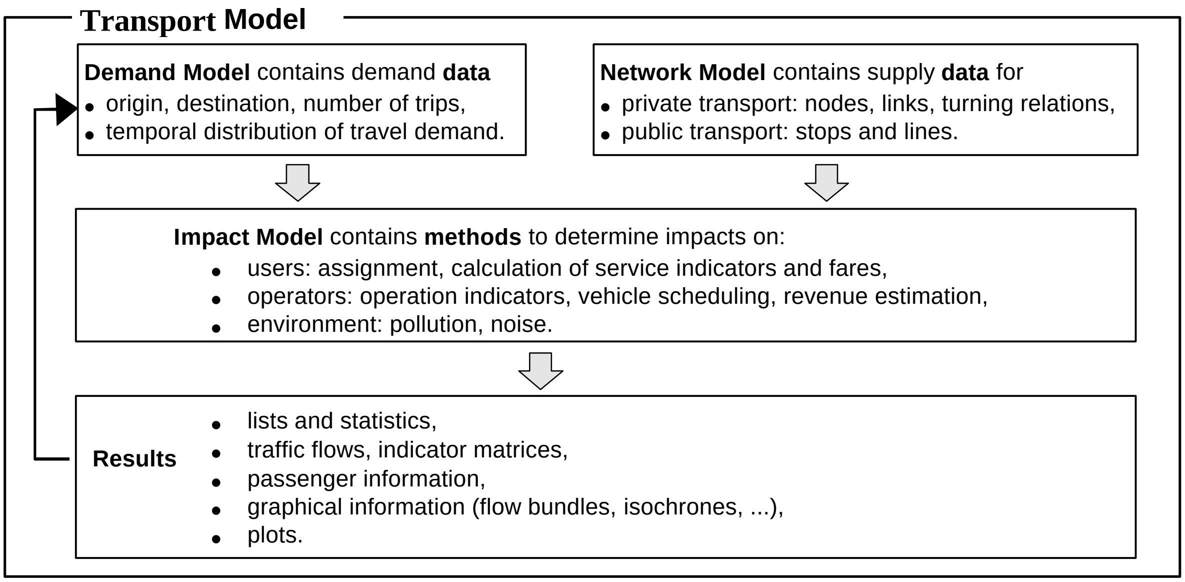


Figure 2: Definition of supply systems (Source: all screen-shots in this paper are taken from the software program VISUM 6)

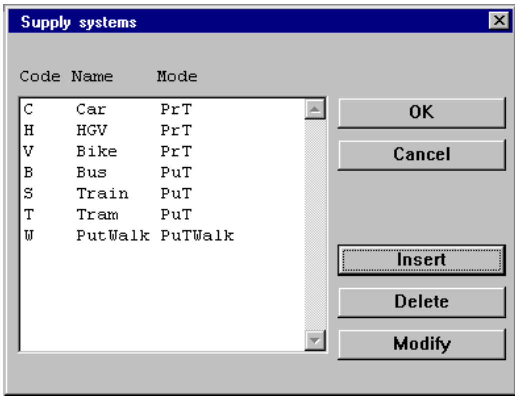


Figure 3: Example network with link network and a bus line consisting of two sublines

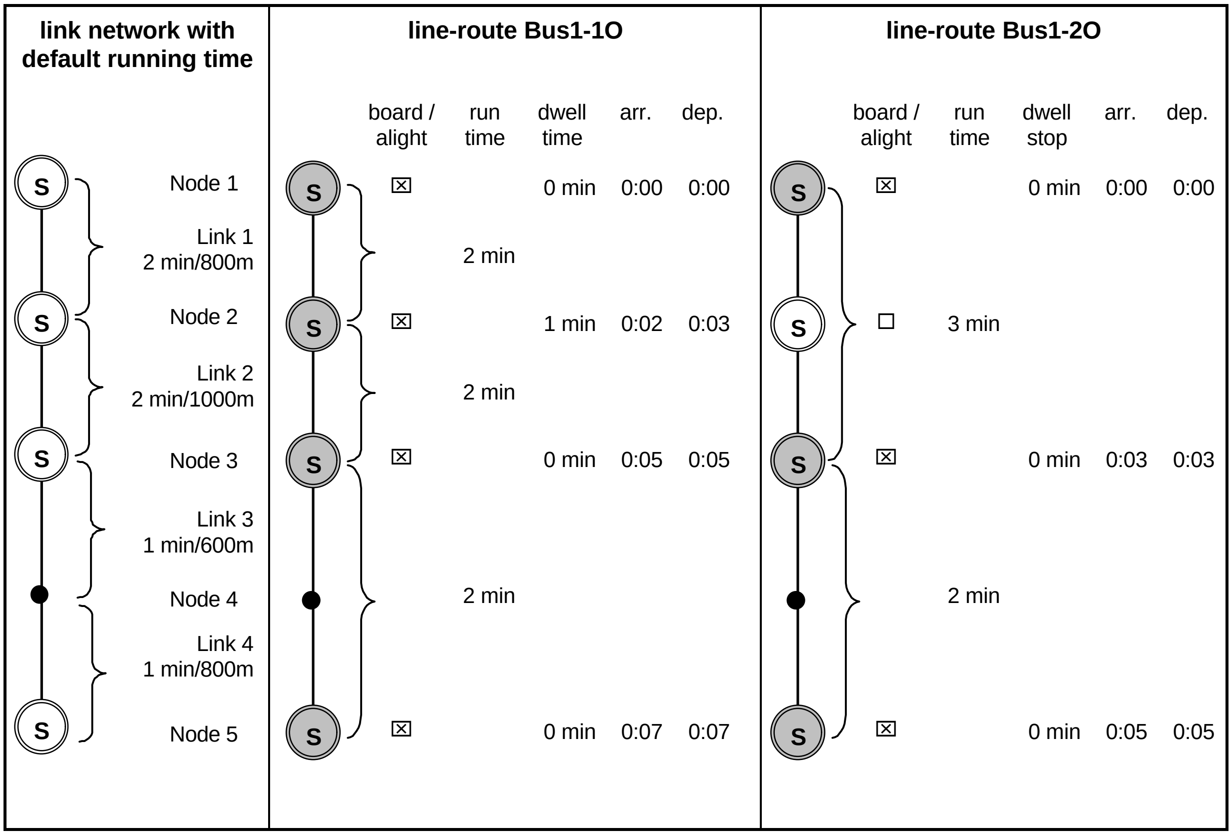


Figure 4: Description of example network in a relational database

Table SUPPLY SYSTEM

Code	Name	Mode
B	Bus	PuT
T	Train	PuT
C	Car	PrT
H	HevVeh	PrT

Table NODE

NodeNo	Name	X-Coord	Y-Coord	Stop
1	Node1	...		☒
2	Node2			☒
3	Node3			☒
4	Node4			☐
5	Node5			☒

Table LINK

LinkNo	FromNode	ToNode	Length	SupplySystem	PrT-Capacity	RunTime(Bus)
1	1	2	800	B,C,H	...	120s
2	2	3	1000	B,C,H		120s
3	3	4	600	B,C,H		60s
4	4	5	8000	B,C,H		60s

Table VEHICLE

VehTypeNr	Name	TotalCapacity	SeatCapacity	Cost/Hour	Cost/Km	Cost/Veh
1	Midibus	40	20	42,00	1,00	100
2	Standardbus	90	35	42,00	1,50	150

Table SUBLINE

Name	Variant	Direction	SupplySystem
BUS1	1	I (inbound)	B
BUS1	1	O (outbound)	B
BUS1	2	I (inbound)	B
BUS1	2	O (outbound)	B

Table OPERATOR

OperatorNr	Name
1	Urban Operator
2	Railway Company

Table LINE-ROUTE

Name	Variant	Direction	NodeNr	Board	Alight	Arrival	Departure	Length
BUS1	1	O	1	☒	☒	00:00:00	00:00:00	0
BUS1	1	O	2	☒	☒	00:02:00	00:03:00	800
BUS1	1	O	3	☒	☒	00:05:00	00:05:00	1000
BUS1	1	O	4	☐	☐	00:00:00	00:00:00	600
BUS1	1	O	5	☒	☒	00:07:00	00:07:00	800
BUS1	2	O	1	☒	☒	00:00:00	00:00:00	0
BUS1	2	O	2	☐	☐	00:00:00	00:00:00	800
BUS1	2	O	3	☒	☒	00:03:00	00:03:00	1000
BUS1	2	O	4	☐	☐	00:00:00	00:00:00	600
BUS1	2	O	5	☒	☒	00:05:00	00:05:00	800

Table TIMETABLE

Name	Variant	Direction	Departure	VehTypeNr	OperatorNr
BUS1	1	O	6:00:00	2	1
BUS1	1	O	6:20:00	2	1
BUS1	1	O	6:40:00	2	1
BUS1	2	O	6:10:00	2	1
BUS1	2	O	6:30:00	2	1
BUS1	2	O	6:50:00	2	1

Figure 5: Modifying a line-route

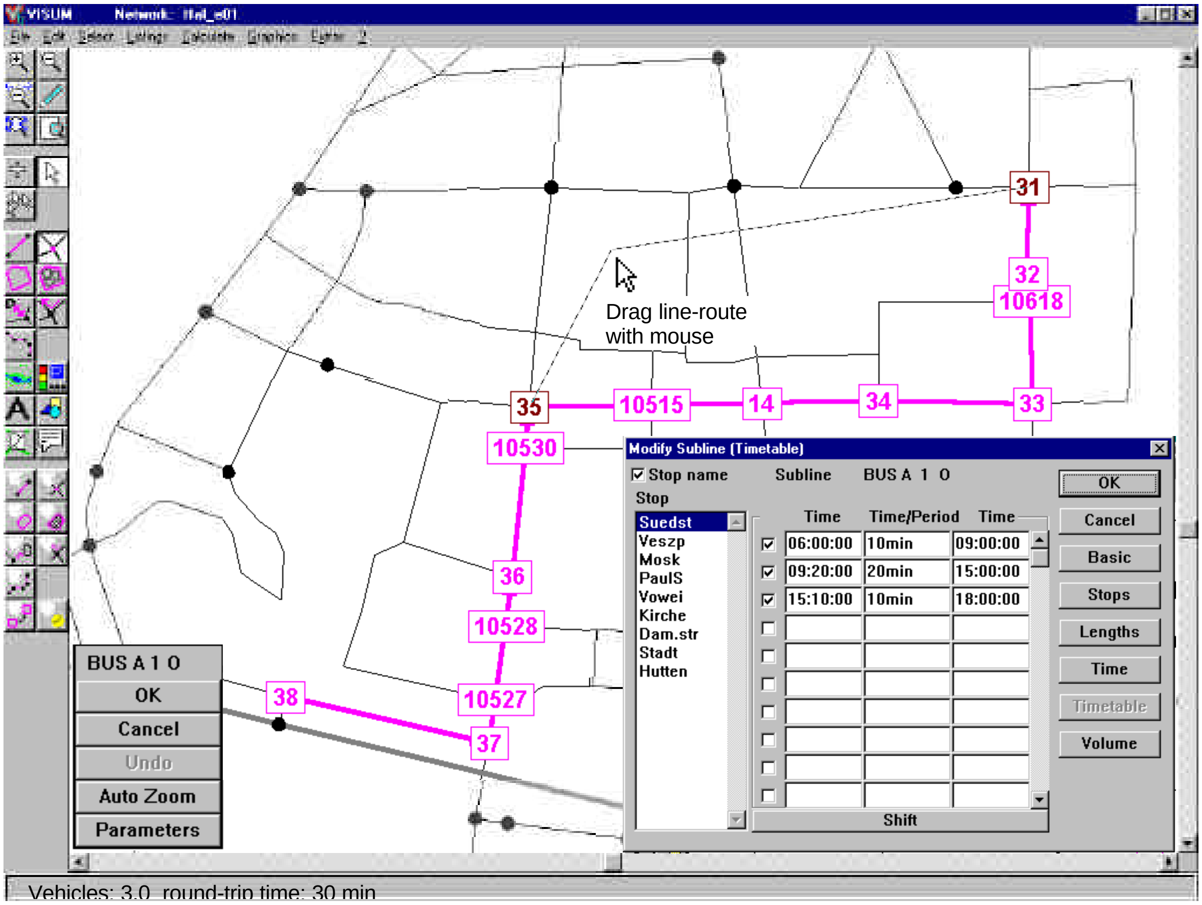


Figure 6: Characteristics of assignment based on lines and assignment based on timetable

Assignment based on lines	**Assignment based on timetables**
1. route search	**1. connection search**
Search for best route: impedance = access time + egress time + in-vehicle time + transfer penalty P x no. of transfers + mean transfer time (= Fac x mean headway) Repeat search with different penalties P and weightings of Fac to determine several routes	Search for best connection impedance = access time + egress time + in-vehicle time + transfer penalty P x no. of transfers + actual transfer time Repeat search for all possible departure times at origin stop
2. route choice	**2. connection choice**
Delete unattractive routes, where journey time > min. journey time x factor transfers > min. transfers + factor	Delete unattractive connections, where journey time > min. journey time x factor transfers > min. transfers + factor
3. route split	**3. connection split**
For each route calculate • perceived journey time PJT which consists of weighted components of journey time • fare • Impedance Imp = f (PJT, Fare)	For each connection calculate • perceived journey time PJT which consists of weighted components of journey time • fare • temporal utility U which results from comparing the desired departure time of passengers with the actual departure times of the connection • Impedance Imp = f (PJT, Fare, U)
Distribute trips with Kirchhoff Law	

$$P_i = \frac{Imp_i^{-\alpha}}{\sum_{j=1}^{n} Imp_j^{-\alpha}}$$

P_i	proportion of trips using route/connection i
n	number of routes/connections
Imp_i	impedance of route/connection i
α	impedance sensitivity factor

Figure 7: Assignment results: traffic volumes, service indicators and routes

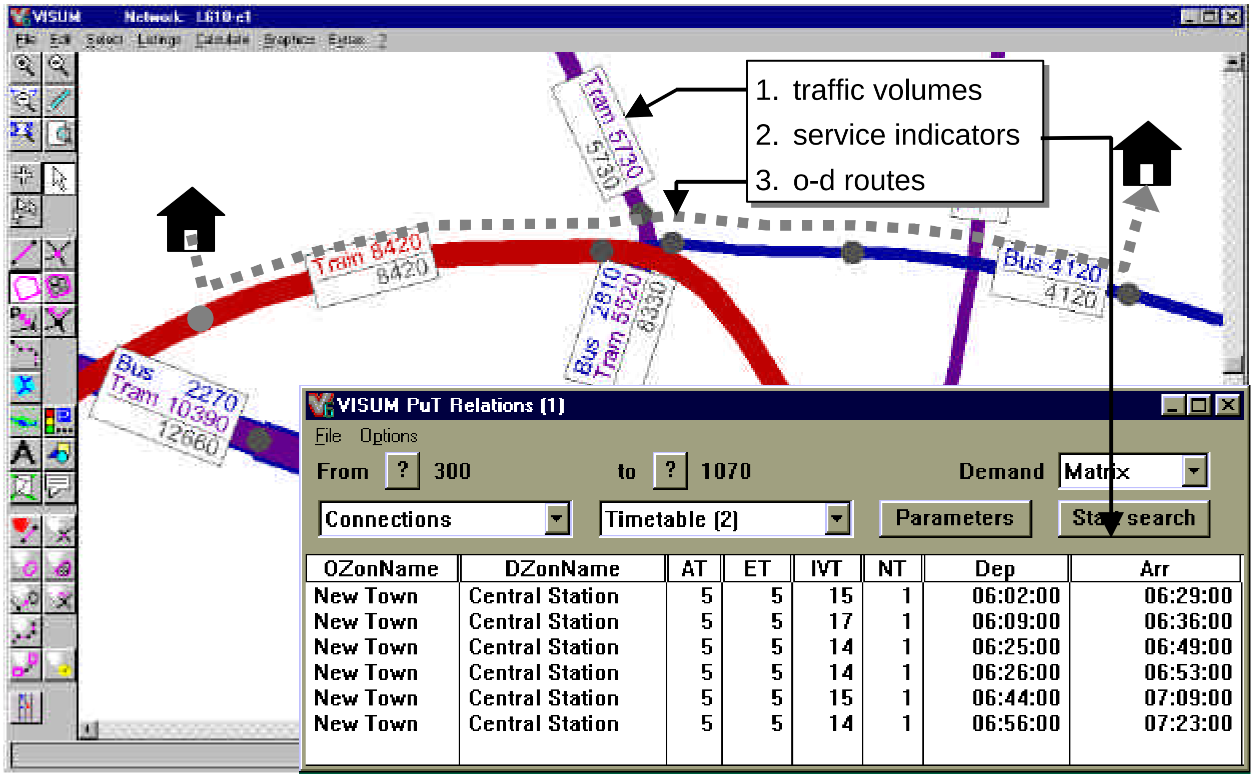
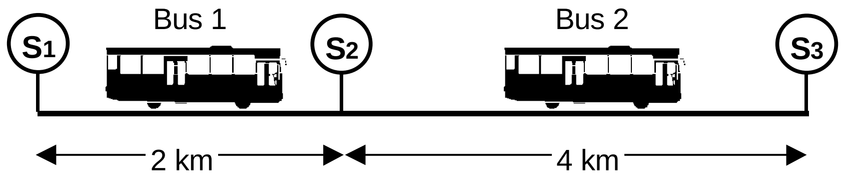


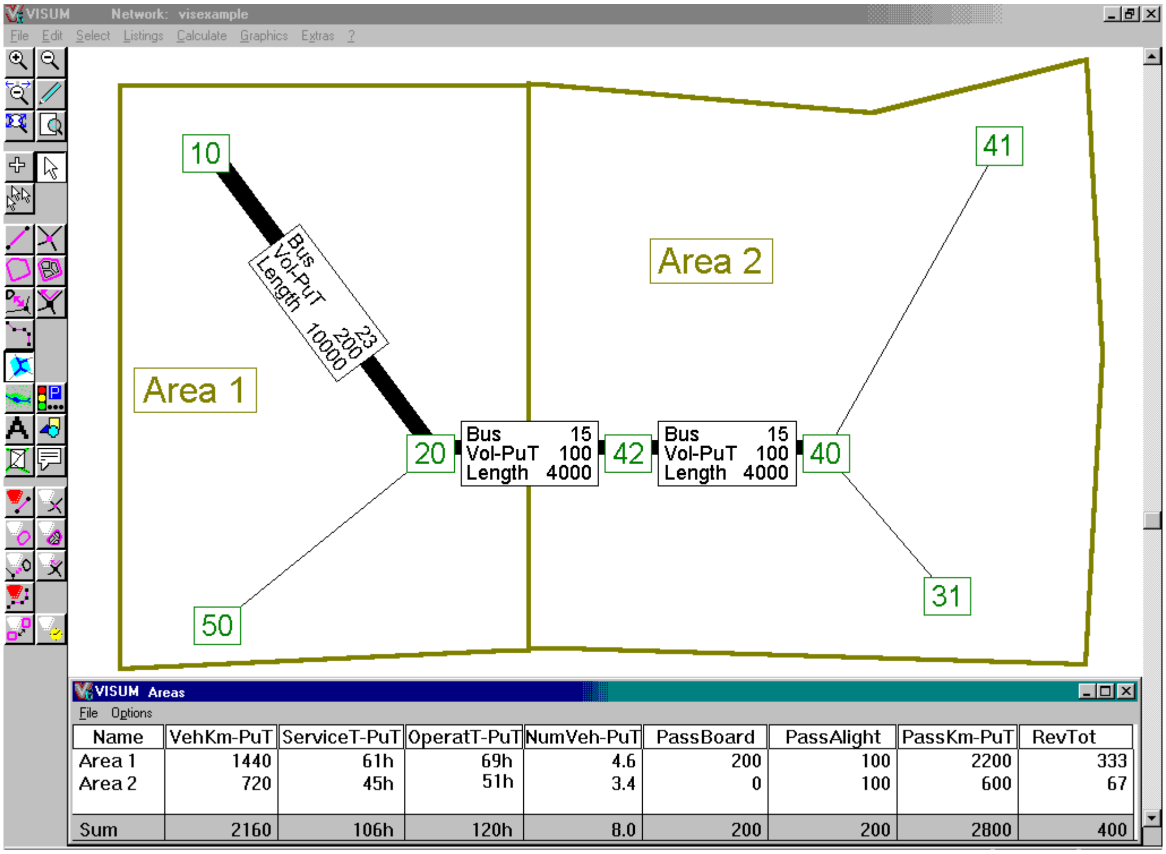
Figure 8: Example for revenue distribution



no. of trip sections: 2
no. of passenger trips: 1
no. of passenger line trips: 2 (= no. of trip sections x no. of pass. trips
revenue for trip S1 to S3: $3.00

	weighting		revenue	
	length of trip sections	no. of trip sections	Line Bus 1	Line Bus 2
1	100 %	0 %	$3.00 x 2/6 = $1.00	$3.00 x 4/6 = $2.00
2	0 %	100 %	$3.00 x 1/2 = $1.50	$3.00 x 1/2 = $1.50
3	50 %	50 %	50% x $3.00 x 2/6 + 50% x $3.00 x 1/2 = $1.25	50% x $3.00 x 4/6 + 50% x $3.00 x 1/2 = $1.75

Figure 9: Example for distributing line indicators onto areas



Bus line route 10 – 20 – 42 - 40

- Line length: 18.000 m
- Running time: 53 min
- Layover time: 7 min
- Cycle time: 120 min
- Services/direction: 60
- min. headway: 15 min
- Vehicles required: 120/15 = 8 veh
- Stop 10 to stop 20: 100 passengers
- Stop 10 to stop 40: 100 passengers
- Revenue/PassTrip: $2

	Area 1	Area 2
Line length	12,000 m	6,000 m
Vehicle-km	120 x 12 km =1,440 km	120 x 6 km =720 km
Running time	30.5 min	22.5 min
Layover time	7 min x 30.5/53 = 4.0 min	7 min x 22.5/53 = 3.0 min
Service time	120 x 30.5 min = 61 h	120 x 22.5 min = 45 h
Operating time	120 x 34.5 min = 69 h	120 x 25.5 min = 51 h
Required vehicles	8 veh x 61h / (61h + 45h) = 4.6	8 veh x 45h / (61h + 45h) = 3.4
Passenger boarding	200	0
Passenger alighting	100	100
Passenger-km	100 x 10 km + 100 x 12 km = 2,200 km	100 x 6 km = 600 km
Revenue	100 x $2 + 100 x $2 x 12/18 = $333	100 x $2 x 6/18 = $67