AN INTEGRATED PLANNING AND INFORMATION SYSTEM FOR TRANSIT NETWORK MANAGEMENT

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1 INTRODUCTION

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

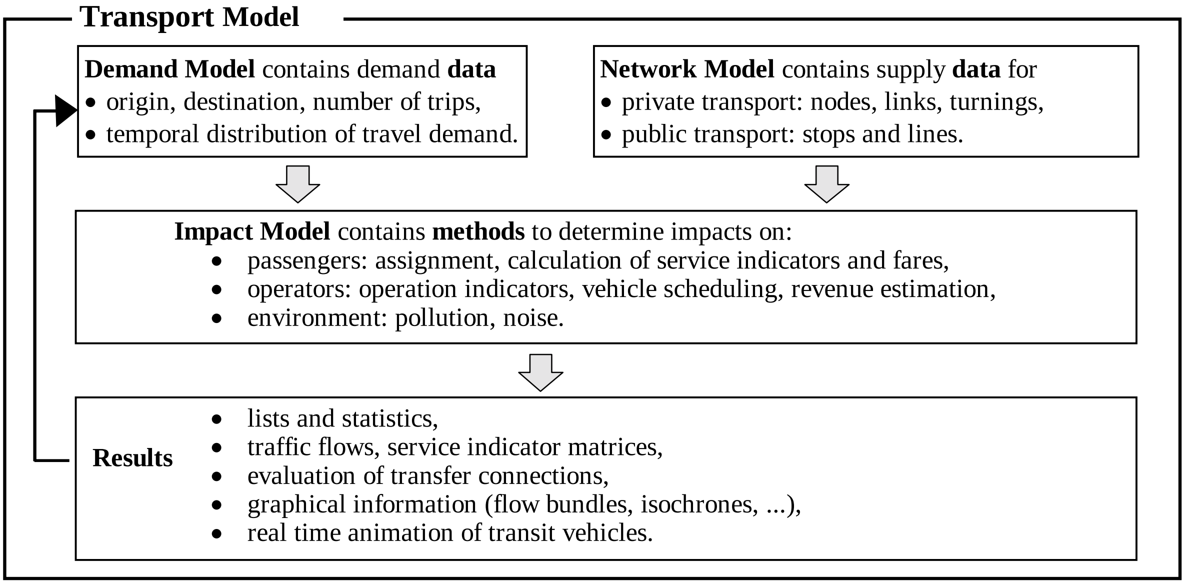
- a short travel time,
- a minimum number of transfers,
- a good service frequency and
- reasonable fares.

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 maximisation of service quality and the minimisation of operational costs and public subsidies. This paper will present the transport planning software VISUM (Fellendorf *et al*, 1997) which is designed to support the transport planner with his planning tasks. VISUM is a software program for planning and analyzing transportation networks (Figure 1). It provides specific functionality for public transport which helps to examine 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 GIS programs and vehicle & crew scheduling systems.

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



The remainder of this paper will present the network model and two parts of the impact model (user model and operator model) in greater detail. The demand and environmental models are outside the scope of this paper.

2 NETWORK MODEL

The network model describes the supply side of the transport system consisting of several supply systems. 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 public transport vehicles operate according to their timetable. The requirements of a 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 penalise 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 2 shows a simple network with one bus line “Bus1”. Figure 3 lists all relevant tables which are necessary to describe this network in a relational database.

Figure 2: Example network with link network and a bus line consisting of two sublines

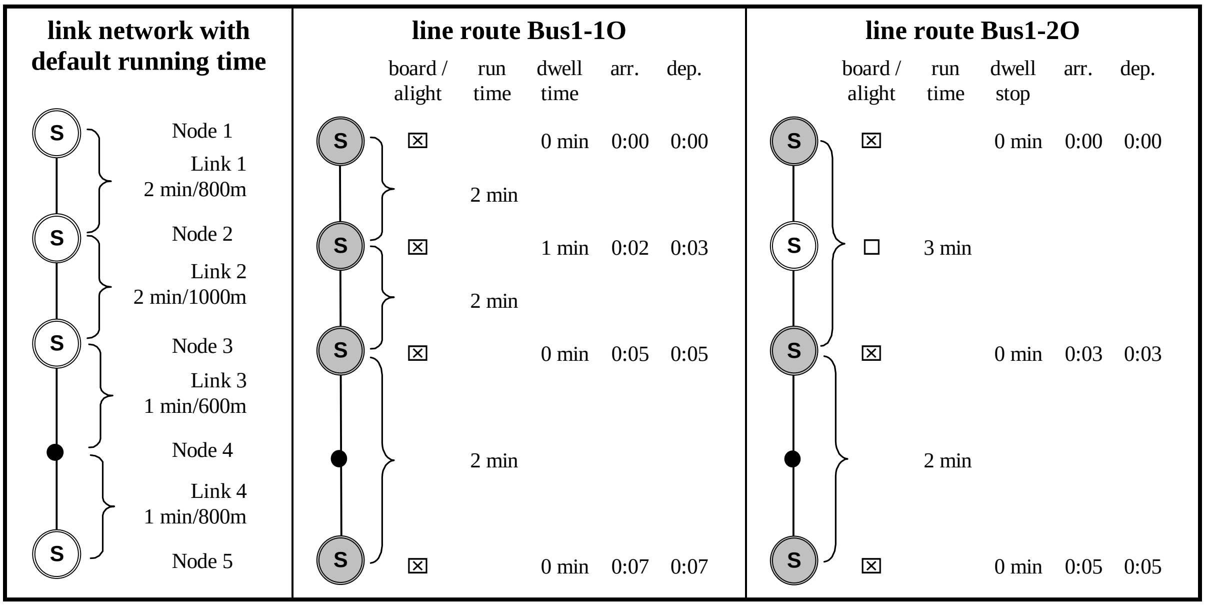


Figure 3: Description of example network in a relational database

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	SupplySys	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
BUS1	1	I (inbound)
BUS1	1	O (outbound)
BUS1	2	I (inbound)
BUS1	2	O (outbound)

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

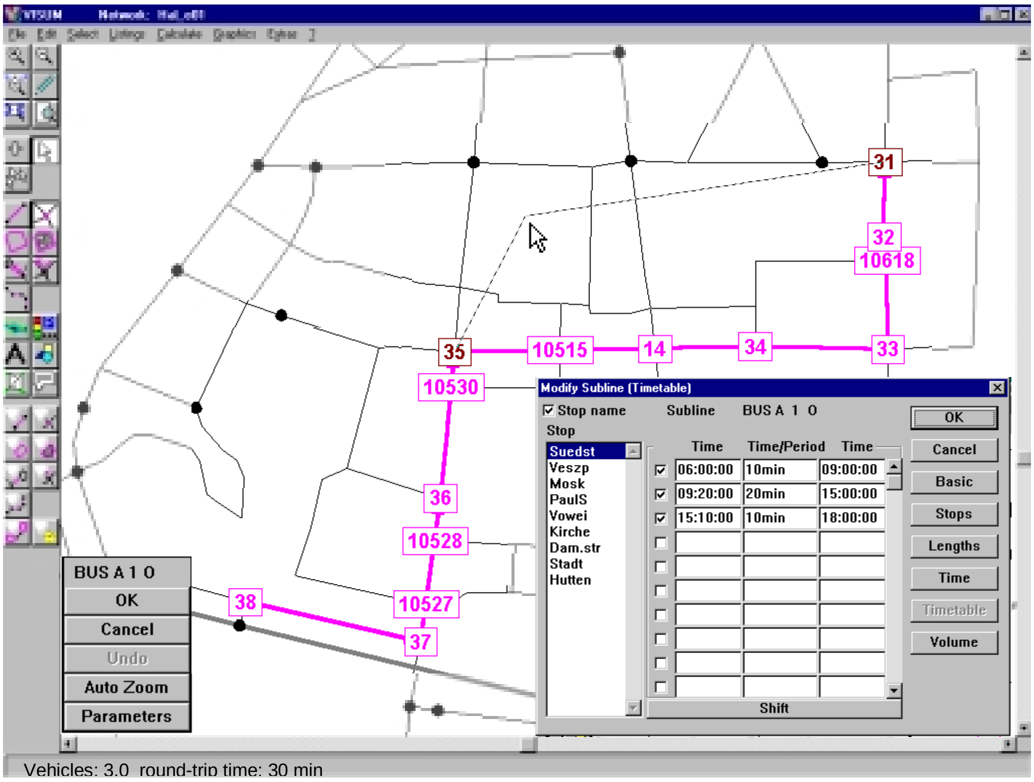
Name	Variant	Direction	Departure	VehTypeNr	OperatorNr
BUS1	1	O	6:00:00	2	1
BUS1	1	O	6:20:00	2	1
BUS1	1	O	6:40:00	2	1
BUS1	2	O	6:10:00	2	1
BUS1	2	O	6:30:00	2	1
BUS1	2	O	6:50:00	2	1

- 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 public transport vehicles. The capacity attributes allow the calculation of a line’s saturation, the cost attributes are the parameters for cost calculations.
- Table *Operator* lists public transport 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 Interactive construction of transit lines

Central task of the planning process is the development of new solutions. 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 transport system cannot be described appropriately through an objective function. Therefore many practitioners spend a remarkable amount of their time modifying network data. 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 4). 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 4: Modifying a line-route



Modify Subline (Timetable)

☑ Stop name   Subline   BUS A 1 0

Stop

Suedst
Veszp
Mosk
PaulS
Vowei
Kirche
Dam.str
Stadt
Hutten

	Time	Time/Period	Time
☑	06:00:00	10min	09:00:00
☑	09:20:00	20min	15:00:00
☑	15:10:00	10min	18:00:00
☐			
☐			
☐			
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Vehicles: 3.0 round-trip time: 30 min

3 USER MODEL

The objective of the user model is to determine the impacts of a transport supply system on travellers. 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. To determine these service indicators, the journeys of travellers are modelled. 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 5).

Figure 5: Characteristics of assignment based on lines and based on timetable

<table>
<tr><th>Assignment based on lines</th><th>Assignment based on timetables</th></tr>
<tr><td>**1. route search**</td><td>**1. connection search**</td></tr>
<tr><td>Search for best route:
impedance =
access time + egress time + in-vehicle time
+ transfer penalty P x no. of transfers
+ mean transfer time (= *w* x mean headway)
Repeat search with different penalties P and weights *w* to determine several routes</td><td>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</td></tr>
<tr><td>**2. route choice**</td><td>**2. connection choice**</td></tr>
<tr><td>Delete unattractive routes, where
journey time > min. journey time x factor
transfers > min. transfers + factor</td><td>Delete unattractive connections, where
journey time > min. journey time x factor
transfers > min. transfers + factor</td></tr>
<tr><td>**3. route split**</td><td>**3. connection split**</td></tr>
<tr><td>For each route calculate
• perceived journey time PJT which consists of weighted components of journey time
• fare
• Impedance Imp = f (PJT, Fare)</td><td>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)</td></tr>
<tr><td colspan="2">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</td></tr>
</table>

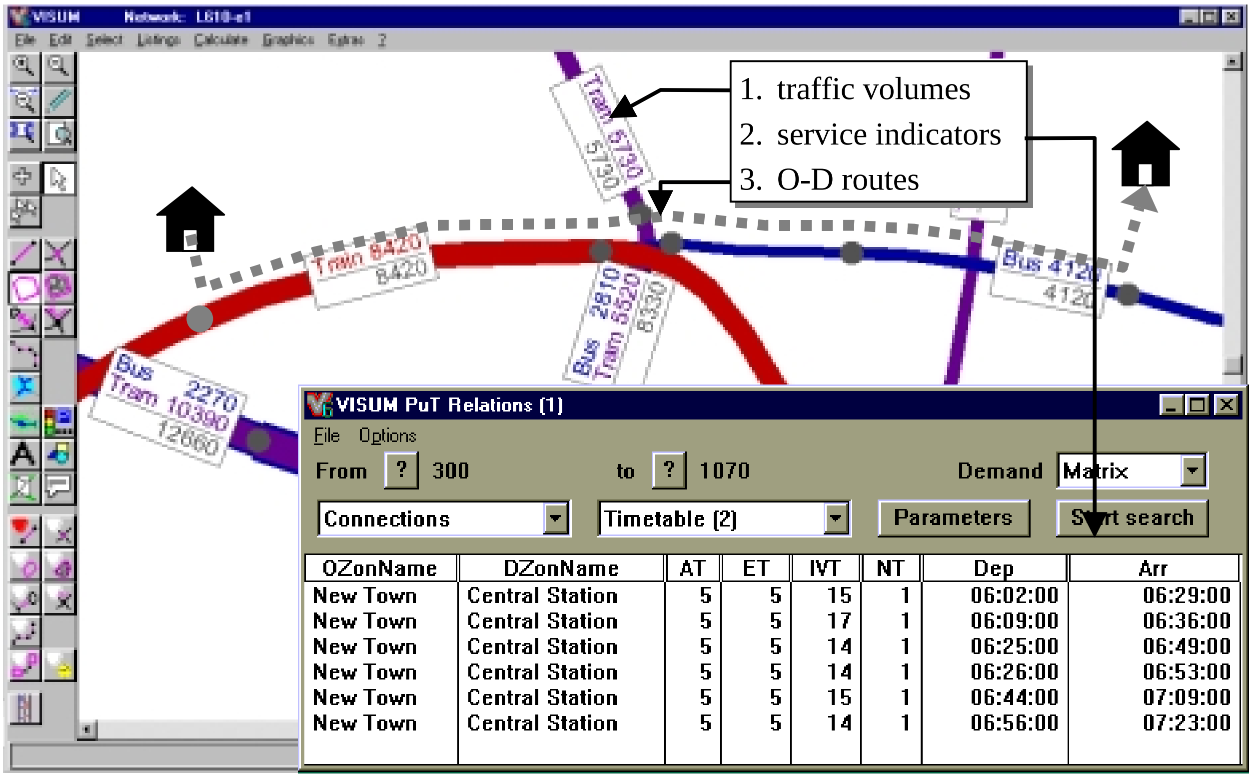
3.1 Assignment based on lines (assignment based on average headway)

The assignment procedure *based on lines* 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 (real-time assignment)

The assignment procedure *based on timetable* 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. 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.

Figure 6: Assignment results: traffic volumes, service indicators and routes



From ? 300 to ? 1070 Demand Matrix

Connections Timetable (2)

OZonName	DZonName	AT	ET	IVT	NT	Dep	Arr
New Town	Central Station	5	5	15	1	06:02:00	06:29:00
New Town	Central Station	5	5	17	1	06:09:00	06:36:00
New Town	Central Station	5	5	14	1	06:25:00	06:49:00
New Town	Central Station	5	5	14	1	06:26:00	06:53:00
New Town	Central Station	5	5	15	1	06:44:00	07:09:00
New Town	Central Station	5	5	14	1	06:56:00	07:23:00

3.3 Assignment results

The assignment produces three types of results (Figure 6). *Traffic volumes* on links, lines and stops, *service indictors* for all O-D pairs and *routes*. VISUM 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 PuT-operators, the operator model is applied to determine indicators which express the operational and financial requirements for providing a public transport 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 kilometre 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 kilometres 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 kilometre = vehicle trip length x no. of vehicle trips
- service time = time for passenger transport = line running time x no. of vehicle trips
- seat kilometre = vehicle kilometre 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 PuT-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
- kilometre costs: kilometre-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 to individual lines or vehicle trips. This requires a distribution key considering vehicle kilometre, seat kilometre 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 kilometre. 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.

4.6 Line costing

By balancing the cost and revenue indicators, it is possible to compute the cost coverage for each single line in the network. While it is important to take into account the network effect of individual lines, line costing can still reveal economic trouble-spots in the network that require optimisation.

5 PERSPECTIVE: BEYOND STRATEGIC PLANNING

It is obvious how the models described so far can be employed in a typical strategic planning setting where the consequences for passengers and operators of several alternative options are calculated and compared. But this is just one type of public transport planning task, others differ in time scale and / or the consideration of degraded modes of operation (Figure 7).

Figure 7: Types of planning tasks

	Short-term (Operations)	**Long-term (Strategic planning)**
Undisturbed operation	Monitoring of performance and demand, controlling	Decision support for investment and timetable design
Operation with stochastic disturbances	Dispatching, direct intervention in case of delays / breakdowns, degraded mode	Robustness of nominal timetable against stochastic deviations

5.1 Monitoring public transport

In this diagram, VISUM, like most planning tools, is used to address primarily the tasks shown in the top right quadrant. More recently, however, it has been recognised that the same models can be applied to more short-term tasks like monitoring operations (top left). Here the challenge is to provide operators with up-to-date performance indicators, ultimately on a day-by-day basis. Two recent developments have brought this goal within reach:

- Computerised command & control systems in public transport operations provide as a spin-off benefit an inexpensive source of up-to-date performance statistics on a by-vehicle basis. In conjunction with timetable and network information already present in the network model, the same set of indicators can be derived that would be estimated in a planning situation. Basically, the inputs to the operator model are not calculated as part of an assignment, but instead imported from the database of the command & control system. They are then broken down by line, time, area, etc. in identical fashion as described in section 4. Thus a direct comparison of current performance against targets is possible.
- For complete up-to-date line costing, not only the current performance must be known, but also the current demand. In strategic planning, demand is usually determined by a household survey or a traffic generation model. Both approaches are much too expensive for daily use, but simpler O-D estimation procedures, while inherently limited in their precision, have matured over the last years. VISUM offers a choice of three matrix estimation procedures, which all take a start solution (e.g. last year's O-D matrix) and current traffic counts at either stops or cross sections to produce a new matrix whose assignment result matches the observed counts and otherwise approximates the proportions between the O-D relations in the start solution. The main advantage of these procedures is their use of counts without additional O-D information. Therefore expensive on-board interviews are not needed, instead data obtained from automatic passenger counting units are sufficient.

5.2 Stability analysis

Another emerging direction for the use of transportation planning models is the stability, or robustness, analysis of proposed planning options. Traditionally, performance indicators (from both the users' and the operators' point of view) are computed on the basis of deterministic models, i.e. models of undisturbed operation according to the nominal timetable. But in reality a timetable with short transfer wait times may result in long expected travel times and / or an increased fleet size, because tight connections are frequently missed due to delays. One way of exposing these problems at the planning stage is to perform a sensitivity analysis by systematically applying stochastic disturbances to the timetable and recomputing the performance indicators. This is a typical example of a task where the planner will prefer an extensible planning model, i.e. one in which he himself can formulate the assumptions for varying the timetable, yet build on the existing analysis functions to reevaluate the indicators. VISUM offers the user a scripting interface where analysis functions can be called from an industry-standard scripting language which is also shared by many spread-sheets and word-processors and thus can be used to set up custom reporting and charting formats complementing those already built into VISUM.

5.3 On-line operation

Integration with problem solving in daily operations (bottom left) is not yet a reality, but it is conceivable that a transportation planning model such as VISUM could recompute on-line the impact of current delays both for users (in terms of changed routes and increased travel time) and for operators (in terms of invalidated runnings, additional work-hours and reserve vehicles needed).

The computation would make use of the existing best-path search algorithms for assignment, but would use actual departure times instead of nominal ones and model transfer coordination, i.e. waiting for delayed connections. A display of these indicators would direct the dispatcher's attention towards the trouble-spots with highest priority and assist in selecting correcting measures.

6 CONCLUSION

Demands for a competitive public transport which can 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 detailed network model containing the relevant information on all public transport supply systems. Since busses share the road network with private transport vehicles it is useful to develop an integrated network incorporating private and public transport modes. Such an integrated network also allows the calculation of inter-modal indicators which for example describe the journey time for a park&ride trip.

Many practitioners spend a remarkable amount of their time modifying network data. The same applies to analyzing and understanding results of impact calculations. Most practitioners will therefore agree that appropriate methods to create solutions and to conduct post-assignment analysis are equally important. In an age where everybody is getting used to office software offering assistants it is increasingly difficult for transport modelling software to keep pace with the standards of modern software. VISUM tries to provide an easy to use interface which stimulates the planner within the planning process to experiment with alternative solutions. Many indicators are calculated concurrently with the modification of the network data so that the impacts of a measure can be easily assessed.

Since modifications of the public transport supply directly influence operating costs and revenues it is recommendable to include a line costing calculation. Combining assignment results with a fare model allows to evaluate measures like new fare systems and higher fares.

7 REFERENCES

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