EVALUATION CRITERIA FOR QUALITY OF TRANSIT LINES PLAN

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Abstract

The plan of mass transport or transit lines is a vital part of an organisation of public transportation services. An optimisation of the plan can improve the service either by reducing the operational costs or by improving of service quality. Three subjects interact in the problem namely state or local administration, transport companies and citizens. The plan optimisation should find the best compromise to satisfy interests of all actors. A relevant criterion must be defined to find the best solution.

Keywords**:** *mass transport, line plan, criteria, optimization*

1 TRANSIT LINES OPTIMISATION

Mass transportation or transit services carry passengers to a desired destination. An offer of transit services helps to reduce individual use of private cars and thus improve traffic in towns and their environments. The services must be offered for a reasonable price frequently under real operational costs of service providers and thus they must be subsidised to be attractive for passengers.

Basic criteria for evaluating quality of public transportation services are defined in European standard EN 13816 or Slovak standard STN EN 13816. Basic 7 criteria-principles mentioned in the standards are: Accessibility, Information, Time, Customer care, Comfort, Security, Environmental impact. Most of them can not be directly respected in the line plan optimisation as they can be hardly quantified to fit into an optimization model. So only time factors seem to be suitable for use in an optimization process as discussed in the following text.

An optimisation of transit services should find the best equilibrium among the interests of all participating parties, namely:

- governmental or local administration which subsidises transit services,
- service providers who run the services and try to gain some profits,

- passengers who desire to have affordable and quality services.

The administration bodies try to minimise their involvement and to pay as little as possible to subsidise the transit system. The optimisation model of transit services can suppose that a fixed contribution is agreed on and available from administration bodies.

Under such an assumption only two parties remain and an optimal solution should respect relevant interests of passengers and service providers. Passengers demand quality service, which can be measured by a total travel time and a service comfort. The travel time (which includes waiting for a vehicle, ride in a vehicle and changing vehicles) should be preferably short and comfort of the offered services should be as good as possible (comfort of the ride in a vehicle, walking to the next bus stop or railway station, changing vehicles or transportation modes etc.)

The better a service quality is the higher costs will arise to providers ensuring the services. So there is a contradiction between interests of passengers and service providers. The passengers are interested especially in:

- travel costs which is pre-eminently given by pricing policy and by real operation costs of providers;
- travel time;
- comfort

Service providers try to gain some profits which they can achieve by reducing their operational and fixed costs or in other words by minimisation of a total distance driven by vehicles and their crews (what reduces fixed costs as well - less distance driven equals less busses or trains needed at a time, less staff, etc…).

The discussed interests of service providers and passengers can be formulated in a simple model shown in the next paragraph. A relevant criterion for an optimisation of a transit system is then a total distance covered by vehicle rides or a travelled distance and time spent by passengers.

In principle, we have to determine the overall market size, based on characteristics of the population and the service. We then assume a launch date and model the diffusion of the service to determine the shape of logistic curve by which saturation level is reached. The diffusion model begins by identifying the total potential market for a service - those users that could potentially be interested in the service, if conditions (prices, network size, etc.) were suitable. From there, we implement a two-stage model showing how members of the potential market becoming aware of the new product, and then how those who are aware decide whether or not to subscribe. The decision to become a subscriber is a result of comparing the benefits and costs of the service.

2 OPTIMISATION MODEL

The optimisation of transit lines is an NP hard optimisation problem. There are many known approaches and optimisation models such as models presented in [1], [2], [3], [4]. Many of them are based on a network design model defined as follows.

Transportation infrastructure is represented as a graph G consisting of a set of nodes $\boldsymbol{V}$, a set of edges $\boldsymbol{H}$ and edge costs c

$G = (\boldsymbol{V}, \boldsymbol{H}, \boldsymbol{c})$

Nodes describe stops in a transit system (bus stops, railway stations etc.) and edges stand for a transport service between origin and destination nodes.

Let us name

$(i, j) \in \boldsymbol{H}$ – an edge from node i to node j, $\boldsymbol{H}$ is a set of all feasible edges,

$(r, s) \in \boldsymbol{Q}$ – passenger flow from node r to node s and $\boldsymbol{Q}$ is a set of all passenger flows,

q^{rs} – intensity of flow (r, s) characterised by a number of passengers travelling during a time period,

f_{ij} – fixed costs of creating an edge (i,j) which means costs of vehicle operations on line (i,j),

c_{ij}^{rs} – passenger costs for travelling along an edge (i, j), frequently can be substituted by cost c_{ij} independent origin and destination of passenger's travel,

y_{ij} – binary decision variable for creating an edge, which means edge (i,j) is created ($y_{ij}=1$) or is not ($y_{ij}=0$),

$x_{ij}^{rs} \in \{0,1\}$ for all edges $(i,j) \in \boldsymbol{H}$ and flows $(r, s) \in \boldsymbol{Q}$ are binary decision variables signifying that the edge (i,j) (in other words transport service between nodes i and j) is (for $x_{ij}^{rs} = 1$) or is not (for $x_{ij}^{rs} = 0$) used for transportation of a passenger flow (r, s),

The optimisation model for the network design problem can be formulated as follows:

Costs function

$$\min \sum_{(i,j)\in H} f_{ij}.y_{ij} + \sum_{(r,s)\in Q} q^{rs}. \sum_{(i,j)\in \boldsymbol{H}} x_{ij}^{rs}.c_{ij}^{rs} \qquad (1)$$

subject to constraints:

$$x_{ij}^{rs} \le y_{ij} \qquad \text{for } (i, j) \in \boldsymbol{H}, \ (r, s) \in \boldsymbol{Q} \qquad (2)$$

$$\sum_{(i,k)\in H} x_{ik}^{rs} - \sum_{(k,j)\in \boldsymbol{H}} x_{kj}^{rs} = \begin{cases} -1 & \text{for } k = r \\ 1 & \text{for } k = s \\ 0 & \text{for } k \ne r \text{ a } k \ne s \end{cases}$$

for $(r, s) \in \boldsymbol{Q}$ and $k \in \boldsymbol{V}$ (3)

$x_{ij}^{rs} \in \{0,1\}$ for $(i, j) \in \boldsymbol{H}, (r, s) \in \boldsymbol{Q}$ (4)

$y_{ij} \in \{0,1\}$ for $(i, j) \in \boldsymbol{H}$ (5)

The costs function consists of two parts where the first term stands for operating costs of service providers and the second one for passenger costs. If passenger interests are neglected the first term only is significant and corresponding optimisation model is known as travelling salesman problem. If only passenger costs are respected the optimisation will find shortest paths in a complete set of feasible edges (in the graph G) for every passenger. A suitable compromise between interests of providers and passengers must be found in real life.

3 PROVIDER COSTS

The function of provider costs can be discussed in detail now. The first term of the costs function (1) stands for operational costs, which must be paid by a service provider. A more detailed expression can define the operational costs as

$f_{ij} =$ sum ($d_{ij} . p_{ij}$) for all $(i, j) \in \boldsymbol{H}$

d_{ij} –costs of one ride along line (i,j),

p_{ij} –number of line trips (i,j) .

Variable y_{ij} can be in fact omitted and replaced only by variable p_{ij} , which will be set to zero if the line is not chosen and so no vehicle run will serve it in a transit service plan.

Distances or costs d_{ij} depend mostly on the length of the line and are well known at the moment of a design of a set of feasible lines. The problem arises with number of rides p_{ij} . The service frequency on a line is determined by several factors as:

- expected (predicted) number of passengers known from an O-D matrix,
- minimum frequency of a service estimated by enforced standards,
- expected (desired) occupancy of vehicles.

A significant criterion is needed to evaluate a quality of a transit lines plan. For a comparison of a new plan quality against the old one currently in use the best way would be to suppose that the number of runs on a line ensures the same quality of service at all bus stops or railway stations as is currently offered. Further optimisation can estimate a proper number of line runs and their departure times so that the better efficiency of the system is attained and operational costs are lowered or service quality is improved.

4 PASSENGER COSTS

Passenger's costs are formulated in the second term of the costs function (1). A more detailed expression can define the passenger's costs as

$c_{ij} = X*(t_{ij} + tp_i) + Y*l + cp_{ij}$ for all $(i, j) \in \boldsymbol{H}$

t_{ij} –in vehicle time (i,j),

tp_i – access time (i,j),

cp_{ij}– price of a ride along line (i,j),

l – quantification of comfort

X – weight of time parameters in the formula

Y – weight of comfort parameter in formula

Passenger costs are rather difficult to evaluate relevantly, because of many factors included. This part of costs function is actually determining, whether a passenger will choose to ride public transportation or not. All of above mentioned parameters are relevant in deciding whether to ride public transportation or not, but there are many parameters that can be hardly included in a costs function formula such as:

- current weather condition,
- outside temperature,
- what time of year it is (summer holiday, winter, spring, autumn….),
- quality of actual ride (comfort of seats, comfort of vehicle and driving),
- distance from home to bus stop or station,
- distance from destination to bus stop or station,
- how long is whole trip,
- social and economical status of a passenger,
- local customs of passengers,
- etc….

Relevancy of mentioned factors is indisputable, however determining weights of time and comfort parameters along with weights of all other mentioned factors not included in formula would demand a serious analysis by itself. Despite of all the efforts the analysis may bring no valuable results while the final decision on choice of a transportation mode is still taken by a human being. Passenger decisions which depend on actual plan of transit line and other factors should also affect provider costs in costs formula, because it determines number of passengers actually riding a vehicle.

5 RELEVANT CRITERIA

Evaluating quality of line plan is the same problem as a value estimation of costs function (1), however passenger flows as input data to the above mentioned optimisation model depend on many parameters mentioned in chapter 4. In other words passenger flows depend on a designed plan of transit lines and transit line design is done using data on passenger flows what is a circular dependency which leads to a completely different view on a problem. Costs function value of a solution (designed plan) represents costs assuming that all passengers actually use the public transportation for their whole trip from origin to destination. In reality a lot of potential passengers may switch to another type of transport if the offered services do not comply with their needs. In this point provider income and costs may differ from model results. The correct way to design a line plan would be to design a line plan based on input data from current system, then to implement the designed plan in real traffic, and after stabilisation of passenger flows to collect data on passenger flows and make a new design based on these new data. Designed plan must be evaluated using criteria from both passenger and provider's point of view:

From passenger's point of view:

- total ride time,
- total distance,
- total count of transfers.

From provider's point of view:

- total number of runs,
- total distance driven.

Total ride time is a sum of time that passengers spend in a mean of mass transportation or waiting for a mean of mass transportation what reflects a speed of transportation. The only problematic point in evaluation of the criteria is a determination of waiting times for transfers. Number of line trips for every line can be estimated but also departure times of individual trips and intensities of passenger flows during the hours of a day are necessary for a precise calculation of waiting times at transfers. Waiting time can be substituted by a constant value that will not suppress relevance of actual travelling time and also will not become irrelevantly small.

Total distance is a sum of all distances that all passengers travelled in means of transport. This value can be calculated by choosing certain decision strategy for transportation route for every passenger and calculating route's distance. This parameter is equivalent with previous one excluding waiting time.

Total count of transfers is sum of all transfers of all passengers as getting to their destination using designed plan and certain decision strategy. This parameter describes comfort factor of the designed line plan.

Total number of runs is determined by count of runs per day of every designed line. This number can be set only by statistical research, but it cannot be precisely determined while its count is being influenced by many factors where some are not even quantifiable.

Total distance driven is a parameter derived from **total number of runs** and there are same problems determining the exact value.

6 CONCLUSIONS

As discussed in previous text, decision of potential passengers whether or not to ride public transportation depends on many factors, where some of them are hard to be included into costs function. Designing a transit line plan should be periodically repeated continuous process of analysing currently operated mass transport system and taking steps for its improvement. Every change of the system invocates response of the passengers what needs some time to stabilize whole system to a new status to be analyzed. Passenger decisions must be evaluated after every iteration, while total ride time comes out as the only relevant criteria correctly representing quality of the designed route plan.

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