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REGIONAL PUBLIC PASSENGER TRANSPORT SERVICE IN MACROSCOPIC TRANSPORT MODELS

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1. Introduction

The regional public passenger mass transport ensured in quality way is one of the basic preconditions for sustainable development. For illustration number of registered passenger cars in the Czech Republic was increased about 28.6 % between the years 2000 and 2008 [1]. The transportation performance realized by individual car transport is also increasing. The serious competition to public transport is created in this way.

On the other hand there are also able to be found some costs necessary for public mass transport operation. For that reason there is able to be found a relevant need of quality transport planning also in the field of public passenger mass transport. These all aspects have to be considered by planning of a public transport structure.

Quality input information is essential for effective operating of public passenger transport system. The transport models have got strong potential to discover some information about behaviour of examined transport system.

The overall consideration of public passenger transport systems is possible by macroscopic models. This paper is focused on some aspects of regional public passenger transport modelling with utilizing of macroscopic models. Macroscopic models are usually used for road traffic planning in large areas [2] and for that reason these models are able to create base for modelling of public passenger transport.

2. Main Features of Macroscopic Models

The main feature characterizing macroscopic models is the fact that only transport flows are considered by this type of models and the individual characteristics of single transport elements are neglect. The values of transport indices are mentioned as a number of transport elements passing the selected profile per selected time period (usually 2 hours for AM traffic peak). One passenger car or one passenger is often conceived as a transport element (unit of transport flow). For that reason this type of models is applied especially by solving of relative large areas (e.g. city, region, state).

The analogy between liquid or electric flow and transport flow is able to be observed by calculations designed for solution of macroscopic models. This access is essential for reducing of calculating demands, because it is almost impossible to process the model with some details like the dynamic characteristic of individual transport element from the global point of view of large area.

3. Regional Public Passenger Mass Transport

Operational extent of regional public passenger transport is depended on character of solved region, especially on the number of inhabitants. Number of passengers is also able to be influenced by some other socio-economic characteristics like structure of industry, unemployment rate or average income of inhabitants in the region. Relations between these values and number of trips are surveyed by transport surveys focused on a priori transport demand. The surveys are usually going ahead at households. The mathematical expression of this relation (in the form of functions) is able to be reached in the way of multiple linear regression based on results of the survey [3].

4. Averaging of Values from the Point of View of Calculating Period

Number of connections is depended on this value and this will be a potential problem, because the number of passengers is able to be low in comparison to individual road transport for calculating by macroscopic transport model.

The following example is able to be mentioned as an illustration case study. There are integrated 22 regional bus lines in the Integrated Transport System of Tábor agglomeration. The operation of these lines is consisted of 122 pairs of connections per working day in the time schedule 2009 [4]. It means 5.5 connection pairs on every line in average expression. The average interval between services is 262 min.

Average values mentioned in this case are illustrating disadvantage of macroscopic models application. These models are based on averaging of inputs thank to its principle.

Information capability of average values is limited. The transport irregularities are the first problem, because there is able to be found shorter interval (in traffic peaks), or longer interval (night operation). On the other hand all lines have not the same interval in the calculating time period. For instance in mentioned case the lowest number of connections on line per working day is 1 connection (interval 1440 min) and line with the most stretched operation has got 17 connections per day (approx. 90 min interval). The disproportions between the reality and model are clear visible on this case.

This type of problem is possible to be solved by disaggregating of the model from the time point of view. Utilized software tool OmniTRANS is able to support manual creation of a number of various time scenarios (for various time periods of a day) or automatic creation of a pseudo dynamic model. This model is based on automatic calculation of a sequence of static models divided according to flowing time. The dynamic modelling is continuously developed by updated versions of the OmniTRANS [5].

On the other side, the divided scenarios have to have same features. For instance the structure of main lines will be the same in all models. The differences are based in changing line intervals or in special cases in changing of type (capacity) of utilized vehicles. The orientation possibility of passengers is followed by this access. The general change of whole line structure is possible in some justified cases (e.g. night or weekend operation). In these cases for instance the operation of train will not be economically tenable and for that reason the service is able to be replaced by e.g. bus service. The savings of staff operating infrastructure are able to be followed in time period with reduced transport demand. The recommended structure of models in the point of view of time calculating periods is on the Fig. 1.

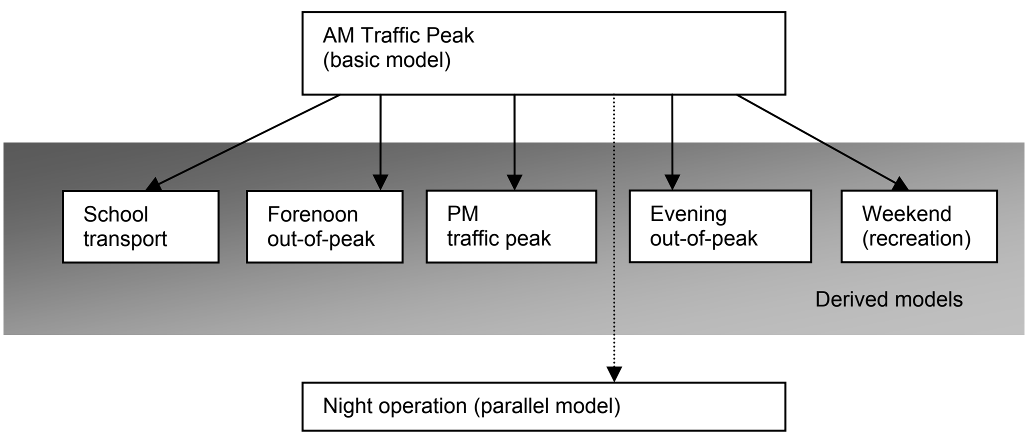

***Fig. 1** Implementing of Time Irregularities into Model. Source: Author.*

5. Trip Generation, Gravity Model

A problem is also able to be caused in the way of calculation of trip distribution by the synthetic gravity method. The method is defined by the formula (1) in general way [2]. This model has to be related to defined time period in all cases.

$$D_{ij} = k_{ij} \cdot \frac{P_i \cdot A_j}{f(w_{ij})} \quad [\text{trips}], \qquad (1)$$

where is:

D_{ij} .... number of trips between selected transport zones i and j [trips],

k_{ij} .... factor [-],

P_i .... production of source zone i [trips],

A_j.. attraction of destination zone j [trips],

$f(w_{ij})$ .... value of traffic resistance between zones i and j calculated in accordance with traffic resistance function (e.g. log-normal) with defined parameters.

The results of calculations based on the formula (1) are not integer. This fact may cause the problems by calculating with lower values of transport flow, what are occurring especially in the field of regional public passenger transport. There are able to be found some villages with the attraction or production in units (individual passengers only) especially in the rural areas.

The values calculated by the gravity model are often decimal values. From the technological point of view it is able to be expressed as a changeability of traffic flow depended on time. For instance the value 0.5 is able to be represented as a one trip in two days. From the point of view of reality it is able to be seen as an approximation, because reached values are often lower then 0.5 and the periodicity like one trip in a week is almost not in consonance with reality. One of exceptions is if these trips are made in the frame of recreational transport (periodically travelling to weekend relaxation). On the other hand, this type of transport is not so suitable for estimating by overall macroscopic transport model. Creation of special disaggregate modes for the days typical for recreational transport are recommended to the intent of the fig. 1. This fact is also corresponding with the need to make disaggregate models divided in consonance with different time periods.

There were examined on the two independent examples that by almost every element of the OD matrix calculated by gravity model is occurred this problem. About 8 % of trips are split into non-integer values of OD matrix elements what is in contradiction with the regional public passenger mass transport character.

6. OD Matrix Transformation for Integer Values

Linear programming model is proposed for transformation of OD matrices to integer values with preserving of all proportions calculated by gravity model. This procedure leads to better reflection of reality (discrete character of transport) in the macroscopic model. The OD matrix is also related to concrete time period.

The model is defined by the following formulas (2) – (7). The sum of differences between old (real numbers) and new (integer) values are minimized by the objective function (2).

$$\min. \sum_i \sum_j \left| d_{ij} - x_{ij} \right| \tag{2}$$

binding conditions:

$$x_{ij} \geq d_{ij} - 1 \tag{3}$$

$$x_{ij} \leq d_{ij} + 1 \tag{4}$$

$$\sum_i x_{ij} = \sum_i d_{ij} \tag{5}$$

$$\sum_j x_{ij} = \sum_j d_{ij} \tag{6}$$

$$d_{ij} \in N + \{0\} \tag{7}$$

where is:

d_{ij} .... original number of trips between transport zones i and j [trips],

x_{ij} .... integer number of trips (variables) between transport zones i and j [trips],

N .... range of natural numbers.

The proposed model is able to involve redundant 8 % of trips into consideration in real way, because here is possible to suppose, that this relative high variability in trip distribution is not so typical feature of commuting transport (regional public passenger transport). It is essential to verify these modified results in relation to reality for acceptability of model in every concrete case. This is standard procedure by all models and modelling activities as well.

Calculating demands are able to be a problem in the case of more extended tasks. The solution is seen in utilizing of specialized software tools designed for integer linear programming tasks often called as IP-solvers. These software products are based on heuristic algorithms like e.g. branch and bound methods. The result is sub-optimal in spite of the fact that linear programming (solved by e.g. simplex method) is created for reaching of optimal results, but the reason are growing calculating demands. Quality of reached results is also seen as sufficient for character of these tasks.

7. Factory Shifting – an Exception

Specific exception what are able to be found is shifting in factories in the case of disaggregate model from the time or purpose point of view. This fact is also possible to be implemented in the model.

This task is able to be solved in two ways. The first is to split the model after weeks (if one week is a common period of shifting). This access has got one disadvantage – the shifting periods are not the same in all companies serviced by modelled public passenger transport system. For that reason it is necessary to create a number of modelling variants reflecting all possible situations.

The second way is better, because there is modification incorporated in the procedure for departure time choice. This procedure is based on dividing of the total OD matrix into a number of sub-matrices in accordance to time division. Limitation is only in technical conditions of utilized software. The modifications of procedure are allowed e.g. in the OmniTRANS software, because the calculations are based on subprogrammes using modified Ruby programming language [5].

The production and attraction of zones connected to factories or industrial zones are able to be automatically divided in two or three parts and able to be implemented in three different time periods of disaggregate model after the shifting schedule of the factory. This procedure is in spite of the fact that it is calculated in automatic way different from the common calculation of the gravity model, because of additional commands input into the calculation programme for departure time choice step. The value of number of passengers on estimated relation e.g. 0.33 is relevant in this proved case, because of 1 person is travelling from the selected zone to the company after shifting schedule. Naturally this is also depended on the structure of input data (attraction and production of zones), if the shifting is incorporated or not.

8. Target Structure of the Model

As follows from above mentioned facts the target macroscopic model for regional public passenger mass transport planning will be constructed in disaggregate way.

It is essential to split the time of a day (week, year) into some time periods with approximately the same conditions for traffic operation during all period and also with the same characteristics of provided public passenger mass transport service. This structure of model is able to reflect all of possible transport irregularities (day-, week- or year-based).

Input data about number of passengers are reached from transport surveys or from transport statistics. The OD matrix is calculated in the way of gravity model. Calculations based on analogical methods (e.g. Detroit model) are also able to be used in the case that older OD matrix is at disposal and no serious changes in transport demand were occurred. These methods are based on growth factors.

The main aspect essential for estimation of the regional public passenger mass transport is the correction of OD matrix values to integer values, because of better reflecting of reality.

Departure time choice is the term for fourth step of extended (five-step) transport model. This step is also essential for modelling of regional public passenger transport service, because the discrete character of regional public mass transport is solved in the way of creation of a number of divided time periods.

These periods are able to be relatively short (e.g. 60 min) for modelling of concrete transport situation, e.g. AM peak, morning school transport, forenoon transport etc. It is possible to reflect discrete character of transport in the frame of these relatively short time periods in better way than e.g. by summarized macroscopic model for 1440 min of a day.

The last step of model is traffic assignment where the transport flows are assigned to concrete segments (public transport lines) of transport network. This step essential for reaching of results of modelling is able to be done in one of common ways, described e.g. in [2] or [3].

9. Characteristics Estimated by AON Assignment Method

All or Nothing method (AON) is the basic method for assignment of transport flows in the transport network [3]. AON is based on shortest paths finding. Every passenger is assigned on his shortest path. The parameters (e.g. distance, travelling time, waiting time, number of transfers etc.) and its relevance for shortest paths finding are able to be specified. The impact of congestions (extending of travel times) is not able to be estimated in this way, but various important characteristics useful for public passenger planning are able to be reached just thank the application of AON method.

On the other hand the AON method is more suitable for public passenger transport modelling than for modelling of the road transport. This is caused by the fact that passengers are travelling in the scheme defined by lines and time schedule and the impacts of congestions are not so significant than by individual car transport from the point of view of transport route choice.

The network segments suitable for operation of public passenger mass transport are able to be also estimated from the point of view of operational reliability by the multimodal four (or five) step transport model created for overall estimation of transport situation in selected area. The concrete model of public passenger mass transport is able to be a part of this model or to be an independent model. It is also influenced by type of utilized software support and by model architecture.

Thank to application of the AON method following characteristics are able to be reached. Every calculated value has to be related to actually solved time period.

Total transportation performance – is reachable as a scalar product of OD and skim (distance) matrices by formula (8).

$$L_{total} = \sum_i \sum_j \left(d_{ij} \cdot l_{ij}\right) \qquad [\text{passengers} \cdot \text{km}], \qquad (8)$$

where is:

L_{total} .... total transportation performance [passengers.km],

d_{ij} .... number of passengers (trips) between transport zones *i* and *j* in direction *ij* [passengers],

l_{ij} .... distance between transport zones *i* and *j* [km].

Total spent time by all passengers in public transport system – is reachable as a scalar product of OD and skim (time-distance) matrices by formula (9).

$$T_{total} = \sum_i \sum_j \left(d_{ij} \cdot t_{ij}\right) \qquad [\text{passengers} \cdot \text{h}], \qquad (9)$$

where is:

T_{total} .... total time spent by all passengers in public passenger transport system [passengers.h],

d_{ij} .... number of passengers (trips) between transport zones *i* and *j* in direction *ij* [passengers],

t_{ij} .... time distance between transport zones *i* and *j* [h].

The formula (9) is representing the technical way, how this value is able to be reached with utilizing of outputs of transport modelling. It is necessary to mention also the technological point of view. The principle of time estimation is essential. The total time consumption of all passengers is able to be also expressed by the formula (10).

$$T_{total} = \sum_{i=1}^{n} \left(\frac{L_{1i}}{V_{wi}} + t^{b}_{add\ i} + \frac{l_{1i}}{f^{w}_{1i}} + t^{ride}_{1i} \right) + \sum_{i=1}^{n} \sum_{j=0}^{m_i} \left(t^{t}_{add\ ji} + \frac{l_{2ji}}{f^{w}_{2ji}} + t^{ride}_{2ji} \right) + \sum_{i=1}^{n} \frac{L_{2i}}{V_{wi}} \quad [\text{h}] \qquad (10)$$

where is:

T_{total} .... total time spent by all passengers in public passenger transport system [h],

L_{1i} .... access distance to first stop of *i*-passenger [km],

V_{wi} .... walking speed for *i*-passenger [km/h],

$t^{b}_{add\ i}$ .... additional time for check-in [h],

I_{1i} .... average interval of services on the first line [h],

f_{1i}^{w} .... factor for calculation of waiting time for the first line [-],

t_{1i}^{ride} .... time of ride of *i*-passenger in first vehicle [h],

$t^{t}_{add\ ji}$ .... additional time for *j*-transfer of *i*-passenger [h],

I_{2ji} .... average interval of services on *j* connective line for *i*-passenger [h],

f_{2ji}^{w} .... factor for transfer waiting time calculation [-],

t_{2ji}^{ride} .... time of ride of *i*-passenger in vehicle of *j*-connective line [h],

L_{2i} .... egress distance from last stop to final destination of *i*-passenger [km].

These two characteristics are able to be used as one of criterions or in special cases as an objective function by transport planning of public passenger mass transport systems. These characteristics are also able to integrate quality point of view into consideration or are able to create a base for other more detail considerations.

10. Accessing and Egressing of Public Passenger Mass Transport

Another important fact of public passenger mass transport modelling accented also in the formula (10) are access and egress phases of transportation. These phases are also essential to be taken into consideration. Accessibility of stops is also important qualitative feature of the public passenger transport system with real impact on transportation choices of passengers. In general not only walking is able to be used for access or egress of public passenger transport (Park and Ride system). It is not possible with exception of walking to set the same mode as access and egress mode, because in most of real cases the vehicle remains at the public transport stop with exception of bicycles able to be transported also by public passenger transport.

11. Time Coordination

Very important role is also played by the factors for waiting time calculation marked as f_{1i}^{w}, f_{2ji}^{w} in the formula (10), because these factors provide an information about time coordination based in time schedule. In the case of non-coordinated lines waiting time is correct to be mentioned as a one half of average interval of services. In the case of node of integrated improved frequency time schedule with coordinated arrivals and departures of all connections, waiting time calculated as a part of average interval of services is irrelevant, because the real waiting time is shorter. In this case it should be expressed as a part of constant additional time ($t^{t}_{add\ ji}$). Additional times ($t^{b}_{add\ i}$, $t^{t}_{add\ ji}$) are used for expression of walking time through large stations or terminals or for expression of time losts connected with check-in procedures.

12. Conclusion

Transport modelling is powerful tool creating support for transport planning. Regional public passenger mass transport is also able to be modelled for reaching of better information about operation of the public transport systems. Information about transport operation and possibility of proposed measurements proved in advance will create a better environment for complex optimizing of the public passenger transport, optimizing of costs etc.

Macroscopic models are seen as appropriate tool for public passenger mass transport modelling, because solved regions are able to cover a large area and the calculation demands are rising with the rising area extent.

On the other hand macroscopic models are not appropriate for modelling of public passenger transport with discrete character, but some aspects for implementation of regional public passenger transport with discrete character into macroscopic models are mentioned in the paper. There are able to be found some principles for solving of some problems connected with estimation of regional public passenger transport in the frame of macroscopic models.

13. Acknowledgement

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Resumé

REGIONÁLNÍ VEŘEJNÁ OSOBNÍ DOPRAVA
V MAKROSKOPICKÝCH DOPRAVNÍCH MODELECH

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Příspěvek je zaměřen na vybrané aspekty posuzování veřejné hromadné osobní dopravy v regionálních oblastech pomocí makroskopických dopravních modelů. Doprava je v tomto druhu modelů pojímána jako přepravní proudy cestujících, ale regionální dopravní obslužnost veřejnou hromadnou osobní dopravou má převážně dávkový charakter. V příspěvku jsou uvedeny základní předpoklady pro řešení této problematiky. Hlavní důraz je kladen na model lineárního programování pro získání celočíselných hodnot v OD maticích směřování přepravních proudů cestujících se zachováním proporcí v OD maticích vypočtených dopravním gravitačním modelem.

Summary

REGIONAL PUBLIC PASSENGER TRANSPORT SERVICE
IN MACROSCOPIC TRANSPORT MODELS

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The paper is focused on selected aspects of estimating of public passenger transport service in regional areas by macroscopic transport models. The transport is envisaged as transport flows in this kind of models, but the regional public passenger transport service mainly has got discrete character. The basic preconditions for solution of these questions are characterized in the paper. The main accent is put on the linear programming model for acquirement of integer values for OD matrices with preservation of proportions in OD matrices calculated by transport gravity model.

Zusammenfassung

REGIONAL ÖFFENTLICHER NAHVERKEHR
IN DER MAKROSKOPISCHEN VERKEHRMODELLS

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Der Artikel ist auf die abgehobene Aspekte der Beurteilungs dem öffentlichen personen Nahverkehr in der Regionalgebiete mit makroskopischen Modellen gezielt. Der Verkehr ist als Verkehrsströme beurteils in disem Typ von Modellen, aber regional öffentlichen personen Nahverkehr hast stapelweiseren Charakter. Die Grunglagen für die Lösung dieser Problematik sind in dem Artikel beschrieben. Das Linearprogrammierung Modell für Erwerb von Ganzzahl OD Matrix mit der Erhaltung von allen Proportionen bezahlt mit Gravitationsmodel ist akzentiert in dem Artikel.