Forecasting of travel demand in urban public transport

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Abstract—The key of the planning of public transport systems is the accurate prediction of the traffic load, or the correct execution of the planning stage assignment. This requires not only a well-functioning assignment method, but also reliable passenger data. Reliable passenger data means time-dependent origin-destination matrix. To solve the problem of lack of time-dependent passenger data we have developed a forecasting method. It consists of three stages. In the first stage we collect full scope cross-section data. This can be done either with personnel or an automatic counting system. If personnel are used it costs a lot and there are many possible errors. However the results in most cases are good enough. Automatic counting system can be either a counter machine or even a simple "Check in" E-ticketing system. In the second stage, we link boarding and alighting. As result we get the origin-destination matrix for each run. In the third stage, we combine origin-destination matrices of the runs through transfers. At this stage we assume that the probability of a transfer between two runs in a given stop is proportional to the travel possibilities in this relation. To view the entire method in the practice we proved it in a Hungarian cities. The results were reliable, so they could be use in the planning process.

I. INTRODUCTION

One of the possible solutions of handling the anomalies in city transport is the preference of public transport. Conversely, it is important to plan and operate high level public transport service. Bottleneck of the planning of such systems is the knowledge of user demand. Without this knowledge even the smallest change in the system is only a guess work, and the effect of it is unpredictable.

The cognition’s methods of travel demand have been known for a long time [1], but their use has limitation. Through our research we built up a model which is able to generate time dependent O-D matrix for public transport with the use of the present transport system’s characteristic.

II. DIFFICULTIES OF TRAVEL DEMAND’S DETERMINATION

There are several methods to discover travel demand. Such can be the use of questionnaires or the application of a “check in – check out” e-ticketing system.

The application of an e-ticketing system can perform very detailed and accurate time dependent data day by day. But the establishment of such a system is very expensive and for a small bus operator unrealistic.

Other way it is possible to organise questioners but it costs a lot and needs a number of employees. Furthermore the accuracy and reliability of the data are not always perfect, because reliable data need big sample at several times of the day.

As an example we can see a Hungarian city with 30,000 trips /day. It means about 7,000 trips in the morning peek period. The city can be divided into 25 zones it means 625 possible trip relations. Some of these possibilities are not realistic or used by few passengers, therefore the number of real transport connections are about 100. If it is needed to take a sample from the morning peek we have a basis of 7,000 persons. We can discover only the relations with at least 70 passengers, it means the incidence ratio is P=0,01. With the use of the common reliability of 95% and 10% relative error, the sample size is as follows (1).

\[ n = \frac{t^2 \cdot (1 - P)}{h^2 \cdot P} = \frac{1.96^2 \cdot (1 - 0.01)}{0.1^2 \cdot 0.01} = 38031.8 \]  

where \( t \) reliability level of 95% \( (t=1.96) \)  
\( P \) incidence ratio  
\( h \) relative error

This value should be corrected because of the finite number of the basis (2).

\[ n_0 = \frac{n}{N} = \frac{38031.8}{7000} \]  

where \( N \) number of the elements in the basis

It means a 85% sample to have accurate and reliable O-D data for the morning peek. Under the same conditions for the whole day (basis is 30,000 persons) it is needed to ask 16771 persons, it means 56% of the users should be questioned.

Literature recommends for such a network with home interviews a sample of 25% [2], [3]. This means 50% of users under a modal-split of 50% should be asked. It denotes that every 4. household has to be questioned.

It is easy to understand that this task (a sample of 50%) is hard or even impossible to perform. Therefore it is clear that there is a need for other methods to produce time dependent O-D matrix for public transport.
III. Calculation of O-D Matrix from a Cross-Section Counting

We are dealing with the evaluation and planning of public transport system long time age. We Almost in all cases we are facing the problem: How to produce reliable O-D matrix? Considering that at all of the analysis there were cross-section countings, it was obvious to start our method at these countings. On the basis of this revelation we built up a method to calculate the O-D matrix for public transport.

The method has two major parts:
- Calculation of O-D matrix for runs (services)
- Forecasting of the O-D matrix for the whole network considering transfers

A. Calculation of the O-D matrix for runs

After the performance of the full-scope cross-section counting we know the number of boarding and alighting passengers for each run in each stop (Fig. 1).

![Figure 1. Number of boarding and alighting through the route of a line in one run](image)

Assuming that the destinations (alighting) of the passengers boarding at a given stop are commensurate with the ratio of the alighting passengers of the remaining stops, we can forecast on likelihood basis the possible alighting stop of a passenger boarded at a given stop. The probability, that a passenger boarded in stop i will travel to stop j can be calculated (3).

\[
P_{i,j} = \frac{\text{out}_j}{\sum_{k=i+1}^{n} \text{out}_k}
\]  

where \(\text{out}_j\) number of passengers alighting at stop j  
\(n\) number of stops on the line route

With the help of this probability the estimated number of trip makers between stop i and j on a given run of a given line is as follows (4).

\[
f_{i,j} = \text{in}_i \cdot P_{i,j}
\]  

where \(\text{in}_i\) number of passengers boarding in stop i

The method can be refined if we take into account the average trip length on that given run. The average trip length can be calculated if we know the number of boarding and alighting and the stop distance (distance between stops) (5).

\[
l_{i,j} = \frac{\sum_{k=1}^{n-1} l_{k,k+1} \cdot p_k}{\sum_{r=1}^{n-1} \text{in}_r}
\]  

where \(l_{k,k+1}\) length of the \(k^{th}\) link (distance between stop \(k\) and \(k+1\))  
\(n\) number of stops on the line route  
\(p_k\) number of passengers on the \(k^{th}\) link

In this case the probability of someone’s travelling from stop i to stop j is as follows (6):

\[
P_{i,j} = \frac{1}{1 + \left| \frac{l_{i,j} - l_{i,j}}{l_{i,j}} \right|} \cdot \frac{\text{out}_j}{\sum_{k=i+1}^{n} \text{out}_k}
\]

where \(\left| l_{i,j} - l_{i,j} \right|\) absolute value of the difference between average trip length and length of the analysed trip

Before we start the calculation of the probabilities to estimate the O-D matrix of the run, we can isolate some of the trips. These are the so called definite trips. At these trips either before or after the vehicle is empty. It means really empty, or a full passenger change happened (after alighting the vehicle is empty, but there are also boarding). At these point the line route of the run can be divided into sub-runs or sub-line routes.

![Figure 2. Process of the O-D matrix calculation for one run](image)

Our task is to search the possible trip inside these sub-runs. This method gives much more accurate result than the calculation of the original one without any prudence. A special case is the first and the last link because before or after them the vehicle is empty, so the alighting after the first link, and the boarding before the last one are definite trips. Through these thoughts the process of the model is shown on the Fig. 2.
B. Transfers between runs

The O-D matrix of the runs should be corrected, because a trip from i to j with a transfer in k will be two trips after the first step. These two trips are: i-k and k-j. The connection between these two trips is the transfer. In this second step of the method we have to search this connection. To determine these trips with transfers, first we need to calculate the transfer ratio for stops and/or trips.

There are two different kinds of transfer ratio: transfer ratio for alighting passengers, transfer ratio for boarding passengers.

Transfer ratio for alighting passengers means the share between passengers who reached their destination at a stop and the passengers who alighted for transfer. Clearly it is the ratio of passengers how needs to transfer and sum of alighted passengers.

Other way round transfer ratio for boarding passengers means the share of passengers who boarding because of a transfer among all of the boarding passengers.

If a trip from i to j needs to transfer at stop k, then the passengers of relation i,j has to be chosen from the passengers of the trips i-k and k-j. If we know the share of transferring and reaching destination of the passengers travel from i to k, then we can give estimation on the number of passengers travelling from i to j. Similar to this there is a ratio for passengers travel from k to j. With this ratio we know the share of trip starters and transfer makers. On the basis of this there is another estimation on passenger number of i-j. We have to choose the right one from these two estimations. In general if a trip needs n transfers there are $2^n$ possible passenger numbers.

The process of this estimation can be done as follows: first all of the possible routes between i and j has to be calculated. Afterwards trips with transfers will be broken up into sub-trips (arms). For all of the arms the number of passengers will be calculated. For all of the transfer points the transfer ratio will be calculated. On the basis of these all of the trips will have several possible passenger numbers. Finally out of these possible numbers the right one will be chosen.

The calculation of this step starts with the calculation of the routes. Through this calculation it is important to write down all the stops which are reachable from a given origin point with a given run. If a stop can be reached with several runs the transfer possibilities will be noted, and new possible destinations will be recorded. In the practice in works like follows: first line’s first run starts from first stop. From this stop the second stop of this run can be reached. If there is a new line’s new run, the process starts again, if not, then the third stop can be reached etc.

This will resulted in the list of all transport connections. Some of them are wrong or unrealistic connections. They have to be deleted either through the generation or afterwards. A connection is unrealistic if:
- it starts earlier and finished together or later than another connection
- in a T time period the number of transfers of this connection is $n/a$
- in a T time period it is k times or at least with t minutes longer than the shortest path
- the trip time is longer than $T_{\text{max}}$

According to the literature [4] the parameters should be as follows:
- $T=10$ minutes
- $a=2$
- $k=1.5$
- $t=10$ minutes
- $T_{\text{max}}$ in Hungarian cities can be 50 minutes

In the previous step was calculated the number of passengers for the direct trips. In this step the task is to calculate the number of passengers for the trips with transfer.

The goal is to calculate the number of passengers in the relation i-j while the route lead through i-k1-k2-j with transfer in k1 and k2. On the basis of the first step number of passengers for i-k1, k1-k2 and k2-j are known. The transfer ratios (calculation will be shown later) are known for both transfer points for alighting and boarding. It means for n transfers $2^n$ transfer ratios. It is impossible to use all of them separately because relation i-j has only one number of passengers. There is a method to solve this problem:
- Trips with one transfer: the average of the two number of passengers has to be used
- Trips with more than one transfer: highest and lowest number of passengers will be deleted. The searched number is the average of the rest

The number of passengers calculated in this way is higher then one of the arms (e.g.: i-k1, k1-k2 or k2-j), then the smallest number of the arms has to be used.

C. Calculation of transfer ratios

Key of the transfer correction (shown previously) is the accurate calculation of the transfer ratio. There are two ways to calculate these:
- Questionnaires
- Estimation

At the use of a questionnaires the basic problem returns. In this case the situation is much better because smaller sample can give good results due to the limited number of possible answers at few transfer points.

It is enough to ask passengers at selected transfer points about their behaviour at that stop: are they start here or transfer, if transfer which line have they arrived from, which line they want travel further. Theoretically a small sample can give accurate results.

The other possibility to estimate the transfer ratio has a principle that the operated public transport system describes more or less the travel demand. Accepted this idea it is possible to build up a basis matrix with reciprocates of the journey times. This matrix has to be corrected with the known boarding and alighting numbers. On the basis of this matrix it is possible to determine the transfer ratio [5].

Following this the transfer ratio for relation i-j in transfer point k1 can be calculated:
\[
tr_{ijk[out]} = \sum_l f_{ik[l]}^n \cdot tp_{k[ij]} + f_{ik}^n
\]

where \(f_{ik}^n\) member of the basis matrix after correction (iteration in n step)

\(tp_{k[ij]}\) coefficient for transfer: 1 if trip from i to j has to transfer in k; 0 if not

Afterwards the first possible passenger number for relation i-j on run r can be:

\[
f_{ij,r}^1 = f_{ik,r} \cdot tr_{ijk[out]}
\]

It is possible to calculate all the potential numbers for relation i-j. With the application of the method written in the previous section the number of passengers can be calculated for relation i-j.

**D. Utility of the O-D matrix**

After the calculation of all the possible relations it resulted in a “travel diary”. This diary will contains all the passenger numbers of all connections. These connections are true only in the existing public transport system therefore the diary is useless for planning in this format.

To use it in the planning it has to be aggregated in time (time periods for e.g. peak) and space (zones).

If there is detailed plan for the future it is possible to use it as 10-15 minutes matrices other way it can be also useful to have it in the format of hour matrices.

**IV. MATRIX ESTIMATION IN THE PRACTICE**

**Case “A” City of Dunaújváros.**

**A. Raw data for estimation**

In 2008 there were a full scope cross-section counting in the Hungarian city Dunaújváros [6]. Through this counting the whole public transport system was analysed. The numbers of the counting was processed with the shown estimation method.

To make plans, improvements in the public transport system we built up the model of the transport system in the software Visum. The model had two pieces of input data:

- Supply (transport service)
  - Transport network (routes, stops)
  - Public transport service (lines, timetable)
- Demand (travel demand)

While the supply side was clear, the demand side was only partly known.

**Application of the estimation method**

We estimated the O-D matrix for each run with the help of the above described method. To accelerate the process we divided the area into 24 zones and aggregate the data not after but before the process. In this way we search zone-zone connections instead of stop-stop ones.

In this city there are few transfers. The transfer correction was needed only in limited number of cases.

Therefore the errors caused by this correction (if) was not significant.

As a result of the process there were a matrix with 8819 rows and 24 columns. All of the rows symbolised passenger movement in stops on the basis of runs. After aggregation of these 8819 rows there were 19 O-D matrices each for one hour through the day.

It was possible to divide them into smaller parts but it was enough for the planning.

These 19 O-D matrix was implemented into the transport model created by the software Visum (Fig. 3).

![Figure 3. Travel demand in the transport model](image)

**Figure 3.** Travel demand in the transport model

After implementation of this demand into the model the next step was to calibrate the assignment method. To calibrate it some assignment was done on the present network.

In the calibration we used the timetable-based assignment method since the timetable was known for the present system.

The result of the assignment was checked on the basis of the links of the network. Theoretically the measured (counted) and calculated values should be equal. It means a graph of \(y=x\), where \(y\) is the calculated and \(x\) is the measured (observed) value. In this study we get a graph of \(y=0.98x+100.18\) which is really good. The indicator of the accuracy, the correlation coefficient was \(R^2=0.94\) (Fig. 4.).

![Figure 4. Calculated values in the function of measured values](image)

**Figure 4.** Calculated values in the function of measured values
After these the estimation can be declared as good enough for planning purposes.

The values can be compared also on graphical way, with the help of a link-bar graph.

![Diagram](image)

**Figure 5.** Measured and calculated values on the link-bar graph

Further modification of the assignment model it was possible to reach a correlation coefficient of 0.9991 although the graph was worse in this case ($y=0.9245x$). Important to note that both situations give good results for network planning purposes.

Case “B” City of Eger

**B. Raw data for estimation**

Similar to the previous case our research group lead a project in 2011 in the Hungarian city Eger [7]. Through this counting the whole public transport system was analysed. The numbers of the counting was processed with the shown estimation method.

The structure of the transport model was the same, it had two main parts: supply and demand.

**C. Application of the estimation method**

In this case the city was divided into 30 zones, although the public transport net was more clear than in the previous case. The demand side was grouped also into 19 OD matrices.

As a result of the simpler network but more zones the coefficients and $R^2$ also better now. The result of the assignment analysis can be seen on Fig. 6.

![Diagram](image)

**Figure 6.** Calculated values in the function of measured values

It is clear that this picture shown a much better situation than the other case. The same can be read numerically: $y=0.999x+56.07$. Even $R^2$ has a better value with 0.99.

**V. CONCLUSIONS**

The bottleneck of the planning of public transport systems is the knowledge of user demand. This knowledge is usually missing or only partly known. To solve this problem we built up a method to estimate the travel demand in time and space with high reliability. It means the estimation of a time-dependent O-D matrix for public transport systems.

The method was checked in the practice. Firstly it proved that the method is good enough to use it in the all day work for planning public transport systems. Secondly both cases show that number of zones and complexity of the network have strong effect on the accuracy of the results.

**REFERENCES**


