THE CALIBRATION OF MACROSCOPIC TRANSPORT SUB-MODELS THROUGH TRAFFIC COUNTING

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Abstract: The estimation of transport demand at a future time moment represents a complex process in which are integrated data and information from multiple and diverse sources, as demography, economics, industry, land use, taking into consideration their implications on transport activity. One of the key elements that contribute to obtain a high degree of prediction confidence, besides the quality of data previously mentioned and the skill of expert that harmonizes these, is the knowledge of current situation of transport demand and behavior of transport systems users. Knowing the current situation of transport demand can be achieved by traffic surveys, but when we are dealing with a transportation network, metering traffic flows on each sector requires significant resources, both for collecting and for processing and interpretation of results. Thus, the best method for highlighting the transport demand on each network element is transport modeling. The classic model used in this respect is called "the four-step model" and contains inter-related mathematical models concerning trip generation, their distribution on destinations, mode choice and trip assignment. Representation with a fidelity as high as possible of the modeled reality requires calibration and validation of each sub-model of the transport model. In this paper is highlighted the way in which the traffic data, collected with the help of a pneumatic tubes system, are used to calibrate the inter-related mathematical models. The case study is applied for the transport model of Pitesti City, Romania.

Keywords: traffic survey, pneumatic tubes, transport model calibration, transport sub-models.

1. Introduction

Knowing the transport demand and traffic flows for the base year are essential elements which significantly influences the operation of transport systems, both at the time of analysis, and in future time moments. The results of traffic forecast process are inputs for transport planning and related sectors (air quality management, land planning). The values of predicted traffic flows are directly dependent on a range of socio-economic, demographic and land use factors forecasted for the study area, having as calculation basis the values of traffic flows specific for base year (Yao and Sun, 2013; Lippi et al., 2010). The current situation of the transport demand can be assessed through traffic surveys (Potocnik and Govekar, 2011), but when we are dealing with a transportation network, metering of traffic flows on each sector requires significant resources, both for the collection and for the processing and interpretation of results. Thus, the best method for highlighting the transport demand on each network element is transport modeling. The classical model used in this respect is called "four-step model" and contains inter-related mathematical models regarding trip generation, their distribution on destinations, modal choice and trip assignment on itineraries (Mitsakis et al., 2014; Ortuzar and Willumsen, 2011; Henser and Button, 2007). The representation with as higher fidelity of the modeled reality requires the calibration and validation of each sub-model within the transport model (Federal Highway Administration, 2010). In this paper is highlighted the way in which the traffic data, collected using a system with pneumatic tubes, are used to calibrate the inter-related mathematical models. The case study is applied for the transport model of the city of Pitesti, Romania.

2. Methodology

As a basis in various applications in transport domain and in the fields interacting with it, the result of transport models shows a major importance, therefore it requires a very high accuracy. In this respect, in the frame of modeling process, should not miss calibration and validation components. The implications of these phases can be observed in Figure 1.

Fig. 1. The elaboration process of transport model
Source: adaptation from: Federal Highway Administration, 2010

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Mathematical models applied for estimating the transport demand and traffic flows are working interdependently. Thus, in order to reduce the phenomenon of errors propagation from one stage to another, it is necessary the calibration at the level of each modeling step. This leads to a calibrated final model, but requires additional resources to carry out surveys specific for the calibration of each individual stage (Azad and Boushehri, 2014). Figure 2 presents the scheme of transport model in which is proposed the calibration of each constituent sub-model.

![Fig. 2. The scheme of the macroscopic transport model](image)

Creating a transport model based on the scheme in Figure 2 leads to increased accuracy of the model, but involves costs associated to activities of collecting and processing data needed for the calibration of inter-related models. The categories of surveys through which are collected the data used to calibrate every sub-model are specified in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Macroscopic sub-model</th>
<th>Survey type</th>
</tr>
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<tbody>
<tr>
<td>Trip generation</td>
<td>Household survey</td>
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<tr>
<td>Trip distribution</td>
<td>Origin - Destination survey</td>
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<tr>
<td>Mode choice</td>
<td>Stated preference travel surveys / Household survey / On-board transit survey</td>
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<tr>
<td>Trip assignment</td>
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</table>

The surveys through which are collected specific data for calibrating each sub-model are different and expensive (especially Household and Origin-Destination surveys). Therefore, in developing a transport model, a balance must be ensured between the accuracy of the model, established according to the project objectives, and the resources allocated for collecting and processing the data needed for calibration and validation. In this respect, in this paper is proposed the calibration of each sub-model integrated in frame of the transport model, based on data collected within traffic surveys.

#### 2.1. Traffic counting methods

There is a wide range of methods for collecting traffic data in order to estimate the ex-post transport demand. Depending on the observer's placement related to road surface, these can be divided into two main categories:

- **intrusive methods** – involve the placement of sensing device in contact with road surface;
- **non-intrusive methods** – entail the use of observation techniques from distance.

The most commonly applied intrusive methods consist in using the following means (Rodrigue et al., 2009):

- **inductive loop**: a wire incorporated into road surface as a rectangle and which creates a magnetic field through which relates information with a counting device located outside the roadway. The device shows a low viability, because it may be damaged by heavy vehicles and is predisposed to installation errors;
- **Piezo-electric transducer**: a device located in a slot formed in the roadbed of the lane to be counted. This electronic counter is used for measuring the mass and speed of the vehicles on the monitored lane. The mounting operations can affect the integrity of the embankment and reduce the pavement lifetime;

- **Pneumatic tubes**: a set of tubes made of rubber, which is placed perpendicular on the road axis, and uses the pressure variations to record the crossing of each axle, through a counting device located on the side of the road;

- **Bending plate**: a weight pad attached to a steel plate which is incorporated into the road surface in order measure the mass and the speed of each axle of the vehicle. The use of this device is costly and requires interventions at the level of wearing layer of the road.

Among non-intrusive methods and means, the most used are:

- **Manual counting**: traditional method that involves the placement of human observers in certain recording points to count the number of vehicles transiting in front of the observer. In classical manner the observers use registration forms in which they note the number and type of vehicles. There are also electronic devices that are operated by observers by pressing a button corresponding to category of which it belongs the vehicle that passed through the front of registration point. Through this method there can be achieved a detailed traffic monitoring by type of vehicles and travel directions. As downside, manual counting generates traffic safety issues;

- **Video recording**: video cameras are used to record vehicles by category and their instantaneous speed. With the help of various software systems are analyzed the video files. Adverse weather conditions may affect the accuracy of counting;

- **Doppler/Radar microwave sensing**: a device that counts the vehicles and records their travelling speed. Except for Radar equipment, they have difficulty in detecting vehicles closely spaced and cannot detect stationary vehicles. The counting devices with microwaves are not affected by meteorological conditions;

- **Passive magnetic sensing**: a magnetic sensor that counts the vehicles, recording the speed and type of thereof. In the operation of these counting devices occur difficulties in classifying the vehicles circulating at small distances one from each other;

- **Passive and active infrared sensing**: a sensor that detects the presence, speed and type of vehicle by measuring the infrared energy radiating in the detection zone. The device is mounted above the flow of vehicles, on top of a pole or on a bridge. This method shows a reduction in performance during unfavorable weather conditions and a limited coverage of the road lane;

- **Ultrasonic and passive acoustic sensing**: devices that use sound waves or energy for detecting vehicles. The ones based on ultrasounds are located above the road infrastructure to record the presence of the vehicle. Their operation can be affected by temperature and turbulences. The acoustic devices are located along the road infrastructure and can detect vehicles by categories.

### 3. Case study

#### 3.1. Study area

The study area is represented by the administrative territory of the city of Pitesti, Romania. Pitesti Municipality has a population of 164,664 inhabitants and an area of 40.7 km², being the administrative center of Arges County. The transport network of the city has a longitudinal shape, along the Arges River (Figure 3).

![The map of the city of Pitesti](http://www.openstreetmap.org)

*Fig. 3. The map of the city of Pitesti
Source: http://www.openstreetmap.org*
During authors’ studies regarding the planning of transport network, was developed a transport model for the mentioned study area for the base year 2012. The influence territory was divided into 92 traffic zones, to which were added another nine, representing external areas with which take place traffic exchange through national and county roads that are in the extension of the street network. The transport network was formalized through a graph with arcs and nodes (Elefteriadou, 2014) (229 nodes and 594 arcs).

3.2. Transport model calibration

The calibration of transport model was performed at all stages of modeling. The transport network was calibrated in terms of length and average speed on road sections. In framework of model, the transport demand was calibrated at each of the four steps. The option was for calibration based on traffic data recorded at the level of street network. This was possible through the procedures available within VISUM software (updating demand matrix with TFlowFuzzy procedure, projecting path volumes, calibrating a matrix), with the help of it was implemented the transport model. In total were used the data from 20 survey posts (Figure 4).

3.2.1. Traffic count system

The method for automatic collection of traffic data which has been applied in this case study is the intrusive one which consists in counting and classifying the vehicles with the help of two devices with pneumatic tubes – MetroCount 5600 Vehicle Classifier System (Figure 5). One such device has two main components (MetroCount, 2008; MetroCount, 2007);

- **hardware component** – an assembly consisting of a central unit and two axial sensors (pneumatic tubes) installed parallel to a predetermined distance (1 meter) across the roadway; these emit a signal (impulse given by increasing the pressure in tubes) when a vehicle cross over that tube. Signals are sent to the central unit (which can retrieve them with a frequency of less than 1 ms⁻¹), where are recorded, processed and saved. By using this assembly, it is possible to get traffic information, such as vehicle speed and vehicle type (by deducting the number of axles, the distance between them and measuring the time elapsed between the events of crossing the axles over tubes).

- **software component** – installed on a portable computer, working together with hardware component, allows the setting of system parameters, retrieving basic information from central unit, their processing and delivering them in the form of reports, such as:
  - the number of vehicles in each category within the range of specified time;
  - the effective speeds of each of them;
  - grouping counted vehicles in classes depending on speed;
  - tracking interval of vehicles;
  - real-time monitoring of recorded vehicles flows;
  - the direction of travel.
Automated counting and classifying of vehicles with MetroCount 5600 Vehicle Classifier System

The use of this automated system for traffic data collection has the advantage of continuously monitoring traffic flows, can be revealed the travel behavior in terms of time moment at which the movement is performed, the category of vehicle used, the average moving speed, the routes chosen by users to perform travels. These aspects are easily obtained, being output elements of the data processing software.

Further are presented data collected in the survey post number 1 in the way that has been processed with this tool.

3.2.2. Obtained results

To exemplify, there have been considered the most important reports generated from data recorded in Post 1 on the direction of traffic North - South. The software of the system allows displaying the results in several ways: as tables or graphs, in raw or processed form, etc. at different time intervals and on different vehicle considered classes. Also, hereinafter is briefly described the way these data are used to calibrate the transport sub-models.

![Vehicle Flow Chart](image)

**Vehicle Flow Chart**

In Figure 6 is presented the vehicle flow chart, showing the total vehicles volume (of all 12 classes specific to ARX classification scheme (MetroCount, 2008)) in a time-based graph. The vehicle flow report is a measure of vehicles per time period. With an integration time of one hour, each point on the graph represents total vehicles per hour. The hourly distribution of total traffic volume emphasizes the travel behavior of users in the study area, based on it being possible to identify the peak traffic periods. Knowing the total number of vehicles transiting the key points of transport network is very important for calibration and validation of overall traffic model.
Moreover, the system software allows to generate the flow stacked by class report (Figure 7), which is similar to flow report, but with either vehicle class bin differentiation. Total flow per integration period is represented by a stack of bars for each included class bin. Fewer classes bins may be required to give sufficient detail. Aggregating a class scheme (usually light, medium and heavy vehicles) often gives extremely useful results, which can be used for calibrating the sub-model for trip assignment; these correct O-D matrices, calibrating the trip distribution sub-model and consequently the trip generation one.

**Flow Stacked by Class**

**ClassStack-59**

**Site:** Str. Gh. Sincai.1.0N

**Description:** Pitesti

**Filter time:** 20:37 Wednesday, November 14, 2012 => 23:00 Friday, November 16, 2012

**Filter:** Cls(1 2 3 4 5 6 7 8 9 10 11 12) Dir(NESW) Sp(10,160) Headway(>0)

**Scheme:** Vehicle classification (ARX)

**Fig. 7.**

**Flow stacked by class**

In calibration and validation of transport models, besides traffic flows, a very important role has the knowing the moving speed of vehicles. The hourly representation of average travel speed highlights the intervals with difficult circulation. For each survey point is possible to represent a speed histogram. Built for data collected in the point taken for example, it has the allure presented in Figure 8. The histogram of speed shows the speed profile at a counting site. A normal curve, with the same mean and standard deviation, is plotted to help gauge the skew of the speed distribution. The vertical markers show the speed percentile, speed pace and posted speed limit.

**Speed Histogram**

**SpeedHist-68**

**Site:** Str. Gh. Sincai.1.0N

**Description:** Pitesti

**Filter time:** 20:37 Wednesday, November 14, 2012 => 23:00 Friday, November 16, 2012

**Filter:** Cls(1 2 3 4 5 6 7 8 9 10 11 12) Dir(NESW) Sp(10,160) Headway(>0)

**Scheme:** Vehicle classification (ARX)

**Fig. 8.**

**Speed histogram**

In Figure 9 is presented the speed report, a time-based plot of average vehicle speed per selected integration period. The report also shows a plot of maximum vehicle speed, and a horizontal line for the posted speed limit (PSL = 60 km/h). The green line shows the average speed of 85% of vehicles which crossed the monitored road section in the considered period. These data are fundamental for calibration of modeled transport network and of sub-model for transport demand.
assignment. The data regarding speed variation, corroborated with velocity dispersion and flow stacked by speed bins, are the base of calibration of volume-delay functions, specific to each time interval and each link type.

![Speed report](image)

**Fig. 9. Speed report**

The report issued as velocity dispersion is a time-based graph indicating relative speed densities (Figure 10). This report is useful for establishing the relationship between speed and traffic density in the measuring location. On this kind of graph is easy to identify the congestion periods, particularly.

![Velocity dispersion](image)

**Fig. 10. Velocity dispersion**

In Figure 11 is shown the diagram of flow stacked by speed bins in which the total number of vehicles is differentiated in speed classes, from 10 to 10 km/h. There are many other types of reports (predefined or customizable) that system offers and which are very useful in transport and traffic studies, not only in the calibration and validation stages of transport model / sub-models.

4. Conclusions

Emphasizing once again the importance of calibrating each modeling stage in order to obtain a valid transport model, in this paper were indicated calibration procedures (related to those offered by VISUM software) which, based on traffic volumes and information about average traveling speeds of vehicles, lead to overall transport model calibration, as a result of calibrating Origin - Destination relations and, consequently, of trips generation.
Flow Stacked by Speed Bins

There were detailed the categories of data provided by the software of counting system with pneumatic tubes which were used for calibration and validation of traffic model for Pitesti Municipality. The most important types of reports and how they are used in these procedures were also explained. Bringing a wide range of benefits, including the one related to how it processes and displays counting results, the pneumatic tube system has proved a very useful tool in the stages of collecting data on traffic flows (traffic volumes on vehicle categories, vehicles classification, average speeds), but also in the procedures of calibrating and validating the transport sub-models.

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