ISSN 1330-3651
UDC/UDK 656.121.021(497.5Zagreb)

MEASURING OF TRANSIT TRAFFIC IN CITIES

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Preliminary notes

The paper will use the method of recording vehicle registration plates by means of video cameras to collect data on transit traffic flows. The analysis is performed by processing the database by pairing the registration plates recorded at the entry and at the exit. A set of all vehicles that have been recorded within the analysed time both on the external entry into the bypass and on the external exit from the bypass represents transit traffic. A general model for measuring transit has been set. The model represents the contribution of the work, and it makes it possible to measure the transit and other traffic flows on different types of bypasses, of different types of cities. The model has been used to determine the share of transit traffic on the Zagreb bypass, i.e. on one approach to the City of Zagreb. The obtained results can make a significant contribution to urban traffic network planning and designing.

Key words: *transit traffic, transit traffic measuring, urban traffic, travel time*

Mjerenje tranzitnog prometa u gradovima

Prethodno priopćenje

U radu će se koristiti metoda bilježenja registarskih oznaka vozila pomoću videokamere za prikupljanje podataka o tranzitnim prometnim tokovima. Analiza se obavlja obradom baze podataka na način da se uparuju iste registarske oznake zabilježene na ulazu i izlazu. Skup svih vozila koja su u analiziranom vremenu zabilježena i na vanjskom ulazu i na vanjskom izlazu s obilaznice predstavlja tranzitni promet. Postavljen je opći model za mjerenje tranzita koji predstavlja doprinos rada, te je pomoću njega moguće mjeriti tranzitne i ostale prometne tokove na različitim vrstama obilaznica, različitih tipova gradova. Model se primijenio za određivanje udjela tranzitnog prometa na obilaznici Zagreba, odnosno na jednom prilazu Gradu Zagrebu. Dobiveni rezultati mogu dati značajan doprinos u planiranju i projektiranju prometnih mreža gradova.

Ključne riječi: *tranzitni promet, mjerenje tranzitnog prometa, gradski promet, vrijeme putovanja*

1 Introduction

Transit traffic means the traffic of vehicles that pass through a certain area without making any longer stays.

The bypass roads of the Croatian cities have been designed and constructed as a rule as roads whose basic purpose is to satisfy the transit requirements passing by these cities. These are the roads with high computation speeds and very few at-grade or grade-separated intersections. The road route is often even several kilometres away from the city centres.

From the aspect of traffic flows, these roads are intended exclusively for the saturation of the transit traffic flows. This is precisely the reason why it is necessary to measure and continuously monitor the transit traffic volume on these types of roads in order to determine the utilisation level of their capacities and to determine the possibility of using the bypasses for internal urban travels by integration into the urban traffic systems. Such integration would be extremely useful in the area of big Croatian cities such as Zagreb and Osijek where the traffic requirements of interior traffic exceed to a large extent the traffic capacities. Since in the wider urban centres of the mentioned cities there is no room to increase the capacities by constructing new roads or by widening the existing ones, the integration of bypasses into the urban traffic system is a logical solution.

In this paper a model of measuring the volume, i.e. share of transit traffic in the overall traffic flow will be analyzed. The model will be based on the combination of classical methodology for developing origin-destination matrices of traffic flows and new modern information and video-technologies. The model will be applied to determining the share of transit traffic on the Zagreb bypass road, i.e. on one approach to the City of Zagreb.

2 Research purpose and objectives

Fast development of motorization over the last two decades has caused an increasing misbalance between the traffic supply and the traffic demand, i.e. the traffic demand has been exceeding increasingly the traffic infrastructure capacity. Such a situation has resulted in ever longer periods with unacceptable level of service on the roads. The problem has been more stressed in the areas of major Croatian cities such as Zagreb and Osijek.

The bypasses of the Croatian cities, along with the current transit traffic, have a capacity reserve which could be used to satisfy the travel requirements between more remote urban areas. In this way a part of urban traffic would shift to the bypass roads thus significantly alleviating the current urban traffic network and increasing the level of traffic service in the cities.

The integration of bypasses into the traffic system of the cities assumes the construction of new interchanges, i.e. intersections at bypasses that will be in the function of local traffic. The majority of junctions will inevitably result in certain reduction of computation speed and the level of service for transit traffic flows; however, it is assumed that the benefit for the urban traffic system is much greater than the possible damage for distance traffic flows.

The purpose and objective of this research is to define a method, i.e. a model which will provide the possibility of adequately measuring the quantity, i.e. share of transit traffic in the overall traffic flow on the bypasses. This will define the traffic volume that has direct benefit from the integration of bypasses into the urban traffic system (origin-destination and interior traffic) and traffic volume that will suffer certain damage (transit traffic).

3 Analysis of existing methods of collecting and analyzing data on volume and structure of traffic flows

The traffic count in any way is the basis for traffic planning, regardless of whether it refers to traffic network planning of a bigger area or to the design of a traffic interchange, i.e. intersection. The traffic count and the analysis of the obtained values yield the current traffic picture of a certain area or a traffic interchange. However, if the count is repeated within certain periods of time, it may also provide certain laws of the traffic flows.

There are various methods of traffic counts which are used depending on the purpose and intention of the count. The basic classification of the traffic count methods is the count at the cross-section or static count and the count of flows or dynamic count.

3.1 Counting at cross-section

The counts at cross-section include counting of vehicles that pass within a certain time interval through a certain road cross-section. Such methods yield data on the load of a certain road section; however, they do not yield any information on the physical movement of the traffic flows. Such methods are used to determine the road transversal cross-section and to determine and roughly dimension the interchange. The counts at cross sections are carried out in a very simple manner. This may be manual count by direct observation and recording on the tally sheets or some kind of automatic counters for traffic counts at cross sections. Apart from the traffic volume, this type of counts can easily determine also the structure of vehicles in the traffic flow, the driving speed, the vehicle platoons, and similar traffic flow parameters.

3.2 Traffic flow counts

Traffic flow counts mean counts that determine the physical movement of the traffic flow, i.e. give answer to questions "where from" and "where to" certain flows are coming and going. Consequently, such counts determine the intensity, direction and path of the traffic streams, creating a real basis of road network planning of wider areas. Besides, they are used also to determine the traffic flows at intersections with the aim of precise dimensioning of the intersection or designing of signalization (primarily light signalling) at intersections.

Traffic flow counts are much more complex than the counts at cross-sections. They require more time, more complex preparation, more staff for data counting and processing, more complex technology and they are less tolerant to possible errors. Because of all this they require also substantial financial resources in performing the traffic counts. The majority of traditional traffic count methods require the stopping of traffic which for today's dynamics and method of living is absolutely unacceptable. Also, any non-regular stopping of traffic endangers its safety.

3.3 Selection of the method for application in the transit measuring model on urban bypasses

Out of all the analyzed methods, the method of vehicle using GPS system is assumed to be the most adequate method for the analysis of traffic flows from the aspect of physical movement. Consequently, the implementation of this method would also yield the best results in measuring the transit flows at urban bypasses. However, at today's level of development and distribution of navigation devices and equipment in road vehicles there is no sufficient sample of vehicles that would provide relevant data. It is assumed that such condition will continue for the other ten years or so, until the majority of vehicles will have some kind of a factory-installed navigation system that will provide useful data about the physical movement of vehicles.

At the current level of development and distribution of navigation equipment the method of recording the registration plates is considered most adequate for the evaluation in order to obtain a new improved method which will make it possible to analyze the movement of traffic flows on fast urban bypass roads. Further in the paper an additional analysis and method elaboration will be performed and the attempt will be made to improve the method by advanced information and video-technologies.

4 Analysis of traffic and technical characteristics of urban bypasses

In developing the model of measuring transit on urban bypasses special attention should be paid to traffic and technical characteristics of such roads. The traffic and technical characteristics such as the road category, number of traffic lanes and the permitted speed have a very significant influence on the selection of the methodology and technology of measuring.

Bypass roads are roads that are located next to the built-up parts of the cities in order to shift the "through-traffic" (transit traffic) away from the urban centres [1]. They are constructed with the aim of increasing the throughput capacity of the traffic, reduction of travel time, improvement of the availability of space and increase of the level of traffic flow safety. Apart from the traffic impact, the bypasses have also high ecological and economic impact on the region in which they are located. On the one hand, they reduce the noise and air pollution in the urban areas and allow valorisation and development of space for the economic purposes along the bypasses. On the other hand, such projects are always accompanied by strong fear of a part of local population, i.e. owners of the business subjects that perform a certain service for which the shifting of a part of traffic from the city will have negative influence on their activity. There are also certain negative factors since bypasses occupy big areas mainly of agricultural lands or green surfaces.

By analyzing the available literature on this topic it was found that there is no simple method to determine the impact of bypass road on a certain place or region. This influence depends on many factors such as the traffic volume, route position, distance from the city centre, number of interchanges, size of the cities, level of economic development of the city, urban development plans, etc. Based on the detailed analysis of all the mentioned factors it is possible to determine the impact of the bypass on a certain city or area.

The studies on concrete examples of cities before and after the construction of bypasses have shown that in the majority of cases the positive effects significantly exceed the negative ones [5]. The main positive effects of constructing bypasses may include:

- reduction of traffic congestion in centres;
- reduction of noise and air pollution in cities;
- reduction in the number and severity of traffic accidents;
- improved accessibility of certain parts of the city;
- valorisation of land along the bypass, especially in the vicinity of interchanges.

As a very important external effect which is often forgotten it is necessary to emphasize the lowering of the rank of the main road through the city after the construction of the bypass road. After the construction of the bypass the main road through the city may be re-categorized from the category of the main road into a form of a local road. This re-categorization results in the reduction of various criteria, i.e. restrictions for the construction in a wider area of the road thus positively influencing the development of the landscape and the possibility of constructing various facilities that could not have been constructed earlier. On the example of the Republic of Croatia, in a city through which a state road is passing, after the construction of the bypass road, the bypass will become the state road and the old section of the state road will be re-categorized into a local urban road. With this measure the road protective zone through the city will be reduced from 25 to 10 metres, allowing denser intersection raster, more flexible intersection modelling and a number of other benefits.

Urban bypasses are as a rule roads planned for high traffic loads, and they are the extension of the network of state or international motorways, or state roads. In certain cases urban bypasses can be partly state intercity roads or motorways. The city bypasses should be designed in such a way as to allow continuous and safe movement of the traffic flows, transit traffic, origin traffic, destination traffic and internal traffic between remote parts of the city. As a rule, the bypass roads have to be free of any parking, loading or unloading of goods and higher transversal traffic. They take over the transit traffic and a large part of intercity and local traffic, and by means of adequate number of traffic solutions of the interchanges provide regular distribution of traffic from a certain origin towards a certain destination and bring it as close to the city as possible, "the main traffic magnet of a certain area".

According to the functional classification the urban traffic network is divided into the primary and secondary one. The primary traffic network includes urban motorways, fast urban roads, urban avenues, urban roads and feeder streets. The secondary traffic network includes approach streets and parking lots. Urban bypasses are classified in the primary traffic network and may be urban motorways, urban fast roads or urban roads.

Major cities that are located at the points of intersecting, diverging or merging of state motorways require bypasses in full motorway profile with grade-separated interchanges (with two or more levels). For the mid-size cities bypasses in the profile of fast road with grade-separated intersections (two levels) are adequate, whereas bypasses of minor cities are two-lane roads with one lane per direction and with intersections at one or two levels.

On urban bypasses of big cities that have full motorway profile, there is usually no direct toll collection because of the need of specific configuration of the interchange which is required by the closed toll collection system, and which is not adequate for urban areas. In the countries which have an open toll charging system (vignettes) the motorway bypasses of big cities are included into the toll charging system. Along the urban bypasses of big cities, usually also the accompanying catering facilities are located, with petrol stations, parking lots for passenger and freight vehicles, as well as for buses, with hotels, restaurants, shops and other facilities.

Based on the analysis of the examples of bypasses in the cities in the Republic of Croatia and the European cities it was found that the majority of bypasses of the big cities in Croatia and in Europe are motorway roads, Fig. 1. If the route location is analyzed it can be concluded that the bypasses are laid in the close vicinity of the town at distances of up to 10 km from the town centre. Significant misbalance between the bypasses of the Croatian and European cities is noticed in the number and the distance between the interchanges on the bypasses. Whereas on the majority of the analyzed bypasses of the European cities, regardless of whether these are big, mid-size or small cities, the average distance between the interchanges does not exceed 3 km, in Zagreb this distance is almost twice as long. This leads to the conclusion that the bypasses of the European cities significantly participate in the needs of the local traffic, whereas the Croatian bypasses are mainly in the function of the long-distance transit traffic, Fig. 1.

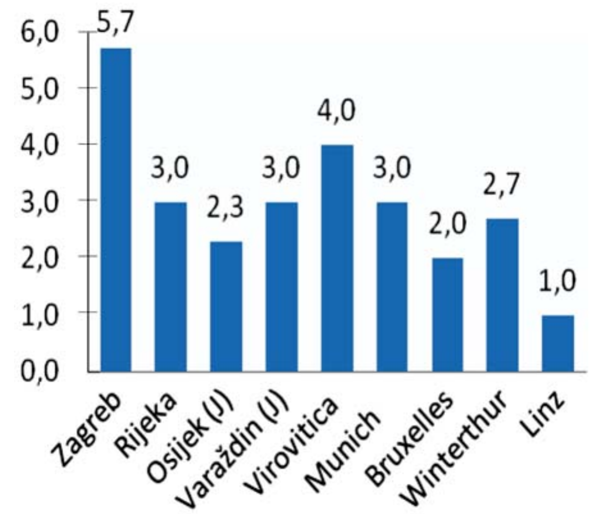

Figure 1 Average distance between the interchanges at bypasses

Analysis was used to determine also certain facts that will have a significant influence on the design of the transit traffic measuring model on urban bypasses. The basic characteristics of the bypass road essential for the model include:

- the majority of bypasses are motorways with several lanes per direction;
- at the majority of bypasses the permitted speed exceeds 100 km/h;
- the bypass sections are as a rule longer than 10 km;
- at bypasses of major cities there is a large number of entries and exits (interchanges);
- on bypasses there are high traffic loads (large number of vehicles), Tab. 1.

Table 1 Basic characteristics of bypasses of Croatian and European cities

	Republic of Croatia					European countries			
	Zagreb	Rijeka	Osijek (J)	Varaždin (J)	Virovitica	Munich	Brussels	Winterthur	Linz
Number of citizens	780 000	144 000	115 000	49 000	23 000	1 300 000	149 000	96 000	96 000
Bypass length / km	40	12	19	15	8	54	70	11	7
Number of interchanges	8	5	9	6	3	19	37	5	8
Average distance between interchanges / km	5,7	3,0	2,3	3,0	4,0	3,0	2,0	2,7	1,0
Minimal distance between interchanges / km	2,8	2,0	1,3	1,5	4,0	0,8	0,3	1,0	0,8
Maximum distance between interchanges / km	8,5	5,0	5,5	4,5	4,0	4,7	4,0	5,0	2,0
Minimal air distance of the bypass from city centre / km	6,5	0,9	1,9	2,9	1,8	10,0	5,0	2,0	1,7
Road profile	MW	MW	2 lanes	2 lanes	2 lanes	MW	MW	MW	MW

5 Development of methodology

The methodology for the measuring of the transit volume on urban bypasses has been developed on the basis of general theoretical findings on the traffic flows and laws of traffic flows on traffic networks within and outside the cities and on the basis of findings about the current methods of developing origin-destination matrices of traffic flows.

For determining of the methodology of measuring the transit traffic volume on urban bypasses the bypass of the City of Zagreb was used as an example of a bypass of a big city. As part of this paper the Zagreb bypass was considered to be the motorway on the periphery of Zagreb from the interchange of Zaprešić to the interchange of Popovec. The total length of the bypass is about 40 kilometres with eight interchanges out of which three are interregional intersections of two motorways whereas the remaining interchanges are of local character.

As the basic frame for measuring the transit volume the analysis of the traffic flows on every external entry to the bypass and every external exit from the bypass has been planned. The external entry to the bypass is considered to be every entry which is not from the direction of the city, and the external exit is considered to be every exit from the bypass which is not in the direction of the city. In this way the analysis will include only those traffic flows that account also for a certain share of transit. Thus, a high share of origin, destination and local traffic will be pre-eliminated from the research sample. It should be noted that this methodology attempts to determine only the share of transit traffic, rather than the total distribution of traffic in relation to the physical movement, thus making it possible already at the very beginning, to eliminate from the sample a certain kind of traffic.

For the simplification of the methodology, the analysis of every entry individually and subsequent synthesis of the obtained results have been planned.

The traffic flow analysis plans the determination of each single vehicle on the external entry and determination of every single vehicle on the external exit. The determination of transit from the data obtained at the entry and at the exit would be performed by pairing, i.e. identification of the same vehicle at the entry and at the exit. Thus, a vehicle which is identified at one external entry and at any external exit would be classified as transit traffic flow, and the vehicle identified at an external entry and not identified within the measuring time at an exit would be classified as destination traffic flow.

Based on the theoretical findings it has been assumed that for the measurement of the transit volume on the bypasses of the major cities it will be necessary to analyze a very large number of vehicles in the traffic flow in order to obtain approximately reliable results. The need for a relatively big sample results from the fact that according to theoretical findings the share of transit traffic on the approach to big cities, and they correspond as a rule to the main bypass interchanges, should not exceed 20–30 percent. When this percentage of incoming traffic is divided further into several possible exit points, a sample is obtained of only several percent of the total incoming traffic flow at a certain measuring point. For the example of the City of Zagreb it has been assumed that at certain measuring locations as many as up to 1 500 vehicles in one hour will have to be processed.

Based on the mentioned assumptions and facts it is necessary to select and adapt the methodology which will be used to describe vehicle identification.

In selecting the methodology it is necessary to take into consideration the basic traffic and technical characteristics of urban bypasses and the nature of the respective traffic flows since this affects significantly the possibility of measuring the transit. The next criterion was the complexity of research, i.e. the required human and technological resources.

The bypasses of the big cities are, as a rule, roads of high level of serviceability, mostly in the profile of fast road or motorway which means that they have at least two traffic lanes per direction. High speeds tend to be developed on such roads. The bypasses of smaller cities are usually two-lane roads, but they also permit mostly speeds significantly higher than on the urban roads. The interchanges on the bypasses are mostly at two levels with full program or semi-program of denivelation. In the cities in which the motorways reach the boundary parts, the entry, i.e. exit to the bypass can pass through a toll booth. All these characteristics influence the selection of the method of developing an I-O matrix in order to measure the transit volume.

Due to high traffic volumes and high speeds it is necessary to select a method which will make it possible to collect a large number of data at high recording speed. Since the interchanges are mostly denivelated, there is no stopping on the bypasses, the method should provide data collection without interaction with the driver or the vehicle. Also, the bypasses have been mostly categorized as motorways where the movement of pedestrians and stopping of vehicles is prohibited so that the method has to make it possible to collect the data at relatively large distances. Since the urban bypasses are relatively long roads with a large number of points at which measurements have to be performed, such studies require engagement of substantial human and technological resources, which, naturally, affects also the price of research. Therefore, the method has to enable analysis with the optimal usage of resources in order to optimize also the price of research.

By previous analysis of the existing methods and characteristics of urban bypasses, for the development of the model, the method of recording the registration plates has been selected. The method was tested at one entry to and at one exit from the Zagreb bypass. The recording of registration plates was performed by:

- manual recording of the plates onto a form;
- audio recording (reading of plates using sound recorder);
- video-recording of the traffic flow.

The measurement locations could be set only on the overpasses of the local roads above the motorways since staying of persons or parking of vehicles on the motorway is not allowed.

Manual recording of the registration plates on the form was not possible since at the test locations the permitted speed of vehicles amounted to 130 km/h (36 m/s), which means that the registration plate was within the field of vision in which it could be identified for less than 1/2 second. Since the headway at certain periods was even less than two seconds it was not possible to identify and record the plate on a form.

The same problems occurred in audio recordings. With this method, also due to the speed of vehicles, the operators could not read the entire registration plate. An attempt was made to implement the method conditionally, so that the operators would read only the numerical part or the city code and the letters, which was possible with a high degree of operator's concentration. However, due to the presence of a high percentage of missed vehicles, as well as the possibility of comparing only a part of the plate, the tests always gave insufficiently precise results.

The video recordings have proven to be an optimal way for the analysis of the registration plates. Video-recording can record all vehicles and characters on the registration plates. Since the tests were performed using non-professional user cameras, certain problems occurred in the readability of the video-recordings. Based on the previous experiences in the application of video-technology in recording the traffic flows and infrastructure it was assumed that it will be possible to carry out certain improvements of the quality of the recording and reproduction of the video-recordings which will result in a satisfactory percentage of recognized characters.

Based on the previous analysis, the method of recording the registration plates by means of video-recording and subsequent analysis of the recordings as well as pairing of the characters at entries and at exits has been taken as the basic and optimal method for measuring the transit traffic on urban bypasses.

6 Mathematical aspect of transit measurement

The analysis of the traffic flows based on the physical movement of flows, i.e. one segment of such an analysis – determining of the transit flows, can be mathematically defined using the theory of sets. For this analysis a simpler approach to the theory of sets will be used i.e. the intuitive or naïve theory.

According to the intuitive theory, a set is defined as a collection of objects that together form one whole. The objects of the sets are called their members. A set cannot contain several equal elements, and the order of counting the elements in the set is not important. The members of the set can be of various types: numbers, letters of the alphabet, people, vehicles, other sets, etc.

Based on the mentioned theoretical bases it is concluded that the analysis of the share of transit flows on the bypasses can be mathematically modelled using the theory of sets.

In order to determine the share of transit flows the vehicles on entries into bypasses and on exits from the bypasses are analysed. The vehicles at a certain entry or exit define a collection of objects. Since each vehicle is determined by its registration plate, there cannot be several equal elements in the set. Because of various driving speeds the order of counting in certain sets is variable, which in case of the sets is unimportant.

This leads to the conclusion that sets of vehicles at entries to bypasses and exits from bypasses contain the basic characteristics of mathematical sets.

The problem of determining the transit volume on the bypass can be mathematically set through the theory of sets in the following way, Fig. 2:

- let n be the number of interchanges on a certain bypass
- let there be at every interchange one external entry U and one external exit I
- let U_i be a set of vehicles that entered the bypass on external entry i ($i = 1 \ldots n$)
- let I_j be a set of all vehicles that left the bypass on external exit j ($j = 1 \ldots n$).

The transit flows for one entry and exit can be defined in such a way that:

T_{ij} is the set of all vehicles that from the external entry i go to external exit j. T_{ij} is defined by expression, Fig. 3:

$$T_{ij} = U_i \cap I_j . \tag{1}$$

Accordingly, the overall transit on the bypass can be defined by a union of all the transit cross-sections for individual combination of entries and exits:

$$T = T_{11} \cup T_{12} \cup ... \cup T_{nn} . \tag{2}$$

Because of the fact that a vehicle that has entered at one of the entries can appear at only one exit, the sets T_{ij} are disjunctive sets, i.e. their intersection is an empty set:

$$T = T_{11} \cap T_{12} \cap ... \cap T_{nn} = 0. \tag{3}$$

Thus, with certain assumptions, the total transit can be defined also by the sum in the following way:

$$T = \sum_{i=1}^{n} \sum_{j=1}^{n} \left| T_{ij} \right| , \tag{4}$$

where $|T|$ – is the number of vehicles in set T, i.e. the number of vehicles in transit (cardinal number).

In order to obtain the share of transit traffic on external entries to the bypass, the number of the members of set U have to be divided by the number of members of set T. Set U represents a union of sets of vehicles that entered the bypass on all external entries, and the complement of set U, $|U|$, represents the number of members of the set, i.e. the number of vehicles at the entry:

$$\left| U \right| = \sum_{i=1}^{n} \left| U_i \right| . \tag{5}$$

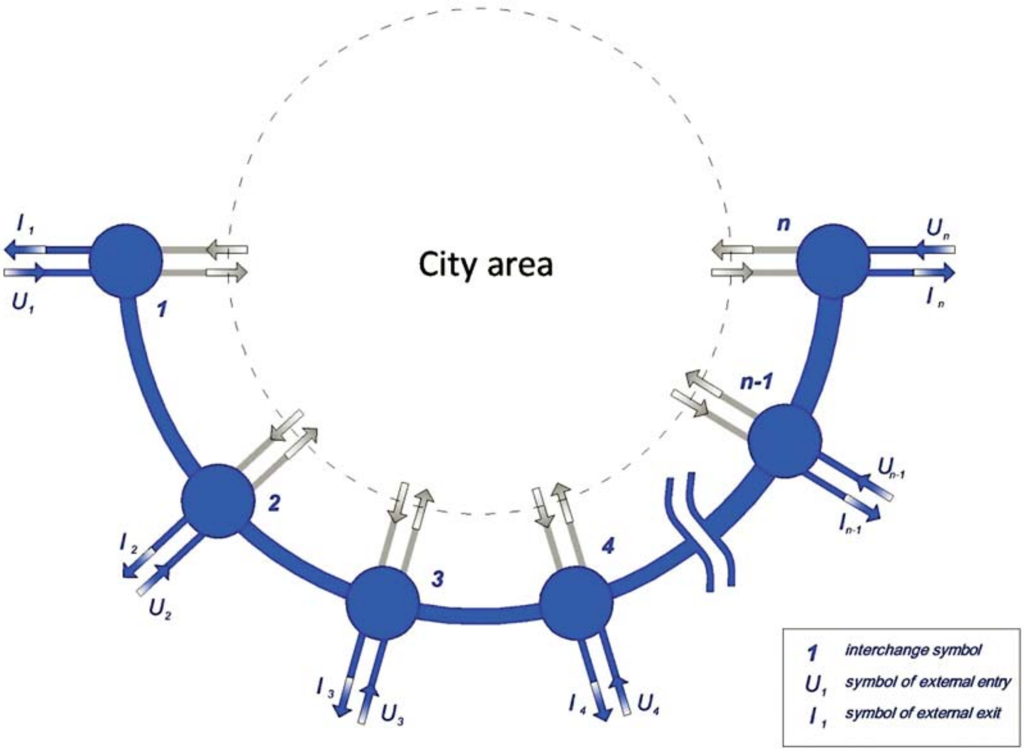

Figure 2 Graphical presentation of transit measuring model using the theory of sets

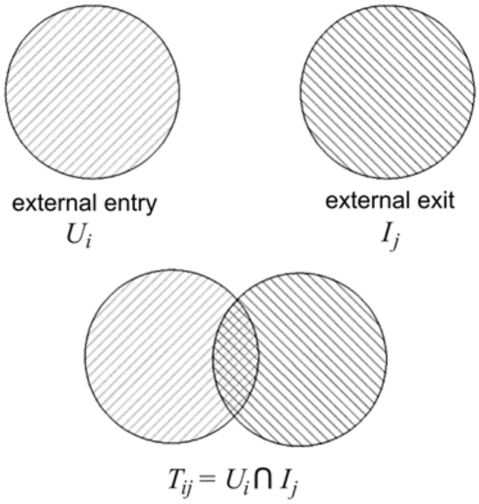

Figure 3 Determining transit for one combination of entry and exit

7 Setting the model

Based on the studied and developed theoretical basis about traffic flows on urban traffic networks, and the analyzed and improved methodology and technology for the analysis of the movement of traffic flows in such networks, with special emphasis on the transit flows, it is possible to set a general model for measuring the transit on urban bypass roads. The model consists of eight elements, i.e. steps in a sequence. The presentation of the model with the description of the basic steps is presented in Fig. 4.

It is assumed that according to this model, i.e. form, it is possible to measure the transit and other traffic flows on various types of bypass roads, different types of cities. By implementing the mentioned model it is possible to obtain the traffic picture of the bypass road for the period of measurement. In order to obtain the total traffic picture of the bypass, i.e. the basic indicator of the traffic volume on a road – the AADT (average annual daily traffic), the model has to be implemented several times during a day, a week and a year. With such measurements it is possible to obtain a precise traffic picture of a bypass of a certain city. Determining of these timeframes, i.e. periods during which the measurements have to be performed, these methods of calibration of results in order to obtain a picture of AADT make possible further analysis and additional processing of the basic model.

8 Conclusion

The volume, i.e. share of transit traffic in the overall traffic on the traffic network of a town or a city is one of the major data in planning the construction of new or reconstruction of the existing bypasses. Therefore, when planning such roads it is necessary to determine as precisely as possible the volume of transit traffic that uses the bypass exclusively for passing by a town and the volume of origin, destination and local traffic that is also present on the bypass road.

Based on the assumption of the possible share of transit traffic flows on urban traffic networks, obtained from the theoretical basis, the existing classical methods have been analyzed and compared, with which it would be possible to determine the transit flows. Among the analyzed methods, the method of recording the registration plates has been selected.

The selected method has been evaluated by implementing advanced information and video-technology in such a way as to record the registration plates by video-cameras, and to process the data in one of the digital databases.

Using the mentioned analyses and the field tests a model has been defined, which by measuring the traffic flows at all external entries to the bypass and at all external exits from the bypass has made it possible to determine the overall share of transit traffic on the bypass road.

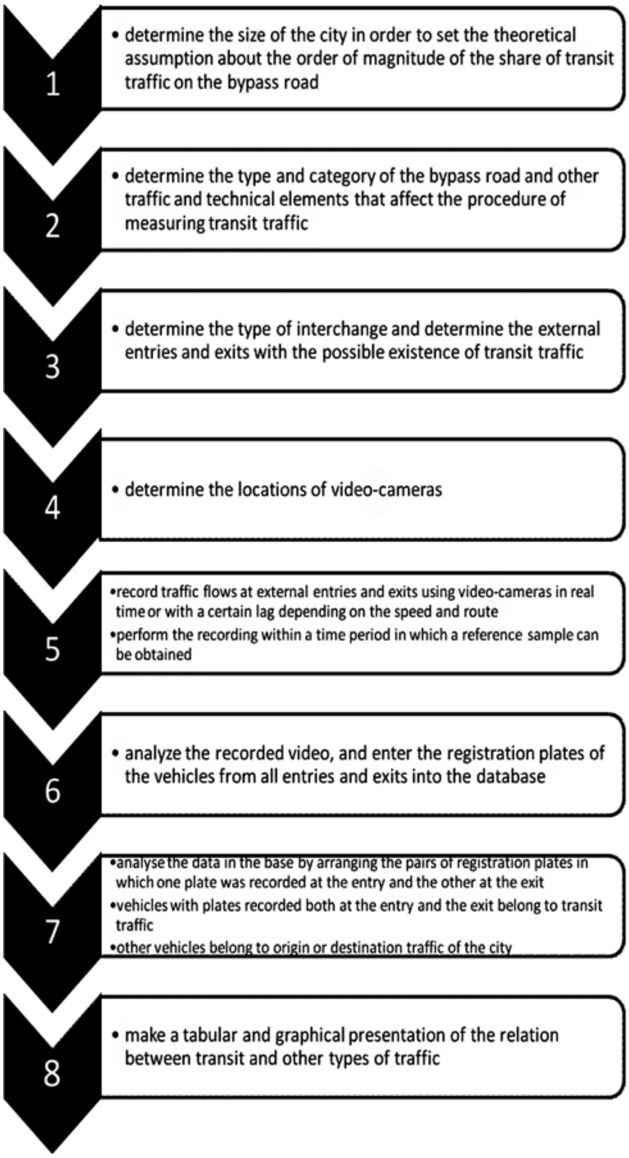

Figure 4 Model of transit traffic measuring at urban bypass roads

In order to check the functionality of the model, the model was applied to determining the share of transit traffic at one approach to the Zagreb bypass, i.e. on one approach to Zagreb. Therefore, an analysis was carried out, regarding the traffic flows at two external entries to the bypass on one approach (one from a motorway and one from a double-lane two-directional road), and at all the exits. The research was performed on a characteristic day during two hours in off-peak traffic load of the bypass.

By implementing the model the basic values of the transit traffic share on one approach to Zagreb within a measured time have been obtained. The measured share was 20 percent of the overall traffic on the analyzed approach.

However, the measured results do not represent the true share of transit during a characteristic day. For such information a longer-term analysis of at least 16 hours should be performed. Therefore, a certain calibration and correction of the results based on the general knowledge about the traffic flows in the city area was performed. In this way an average share of transit traffic on one approach to Zagreb has been obtained, of about 11 percent which fully confirms the theoretical assumption that the share of transit on approaches to the cities of 500 000 to 1 000 000 inhabitants amounts to 7 to 15 %.

9 References

[1] Crowther, G. Traffic in Towns, Her Majesty's Stationery Office, London, 1963.
[2] Ceder, Avishai. Transportation and Traffic Theory, Proceedings of the 14th International Symposium on Transportation and Traffic Theory, Transportation Research Institute, Israel, 1999.
[3] Guy, B. P.; Fricker, J. D. Guidelines for Data Collection Techniques and Methods for Roadside Station Origin - Destination Studies, Purdue University, SAD, Indiana, West Lafayette, 2005.
[4] Korte, J. W. Grundlagen der Strassenverkehrsplanung in Stadt und Land, Aachen, 1957.
[5] Elias, W.; Hakkert, S.; Plaut, P.; Shiftan, Y. The Influence of a Bypass Road on Urban Development and Safety, Association for European Transport and Contributors, 2006.
[6] Dadić, I.; Šoštarić, M.; Kostelić, R. Problem of Integration of Croatian Motorways in Cities Traffic Networks, ICTS 2009, 12th International Conference on Transport Science, Portorož, Slovenia
[7] Božičević, D.; Vidović, K.; Šoštarić, M.; Tasliđić, V. Croatian Motorways as a Solution to Traffic Issues in Big Cities, 15th world congress on ITS, New York, SAD, 2008.

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