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THE ROLE OF TRIP GENERATION MODELS IN SUSTAINABLE TRANSPORTATION PLANNING IN SOUTH-EAST EUROPE

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Abstract. The idea, representing a fundamental starting point in this article, is to confirm that the models for demand forecasting, in terms of planning urban development, gave the results of the forecasted period. In other words, the available models continue to be a valid theoretical basis to be used for planning the sustainable development of the cities. The presentation of model development in the cities of South-East Europe shows that the matter of city sustainability has always represented the focus of attention and has been the subject since the early '50s till the present day. Modelling trip generation in transportation studies in the cities of the former Yugoslavia has been taken as the basis for this paper, because it reflects all the stages modelling went through. Such situation was strongly influenced by foreign experience, especially that gained by Anglo-Saxons. Introducing procedures for analytical modelling that relate household socio-economic and land use characteristics to the intensity of land use represented the pioneering step in procedures for integral land use, activity intensity and transportation demand planning. In the cities of South-East Europe, all known methods of trip generation modelling were applied in transportation planning practice. Recently, Serbian researchers have acknowledged that the process of balancing demand for mobility resulting from the purpose, activity intensity and supply to the transportation system (infrastructure and services) terminates in forming the 'fields of improved accessibility' (i.e. the parts of the urban area more influenced by investments). The process of forming them causes 'pressure' to increase activity intensity (appearance is known as induced construction) that ends in inducing new demand. In this context, there are efforts to integrate trip generation models into ones of spatial distribution taking into consideration the above described conditions and creating the basis for balanced and sustainable development of the cities.

Keywords: sustainable transportation planning, trip generation, transport demand modelling.

1. Introduction

In the early '50s of the 20th century, analytic techniques for estimating the generation of transportation demand in terms of land use characteristics were developed in the world. Land use was observed in relation to its spatial position, the type of activity and the intensity of land use. The future volume of trips was estimated for each category of land use applying appropriate trip generation factors determined in the present state analysis. These first efforts were important because they modelled, for the first time, the relationship between transport generation and land use (among the most significant studies of that time were those conducted in San Juan (Puerto Rico) in 1948 and Chicago and Detroit carried out from 1953 to 1955). This was followed by a series of research that contributed to further improvement in relations between land use and trip generation (Mitchell, Rapkin 1984). The main researchers' efforts were reflected in a higher degree of demand modelling integration in terms of changing activity purpose/intensity. The feedback effect of newly provided accessibility and changes in land use parameters are emphasised (amongst many attempts of this kind the following models refer to: the model MEPLAN that was related to the conventional four-step model of London Transportation Study (LTS), Leeds Integrated Land Use Transport model – LILT; MEPLAN, the model by Marcial Echenique and Partners, introduces the elements of associated land rents (comparable prices); Putman-s Disaggregated Residential Allocation Model (DRAM) introduces the disaggregation of activities considering the type of activity and household income; DRAM, a restated model of land use planning/forecasting (PLUM-Projective Land Use Model, Goldner's in 1968, and Putman's in 1979), etc.). At this stage of transportation demand modelling, the urban environment started to be observed in the context of sustainable development (the term *sustainable development* is first mentioned in the material 'Our Common Future' (1987) – sustainable development is a kind of development that 'meets the needs of the present without compromising the ability of future generations to meet their own need'), while during the '90s, for the first time, sustainability was related to the urban environment at the Environmental Conference held in Rio de Janeiro in 1992.

Numerous research projects have been undertaken in the EU aiming at reversing the trends into a positive direction. They resulted in two major strategic policies:

- The policies related to land use planning aiming at reducing the need for travelling – these policies are usually long-term policies (also called policies for the future cities) that create new centres or regenerate neglected urban districts, thus changing the urban tissue and reducing radial expansion in cities and the distance between jobs and places of residence;
- Policies related to improving traffic accessibility by introducing a greater range of transportation alternatives – these policies are mainly intended for modern cities and start with the current situation. They are changing the traffic system in order to improve accessibility to alternative transportation modes and stimulating the revitalization of districts having high activity density and mixed land use.

The main feature of these policies is integration between land use planning and the transportation system.

The theory of traffic and urban planning shows that there is a feedback between land use and transportation where the spatial distribution of activities (intensity of use, origins and destinations of mobility) leads to demand for mobility. Traffic infrastructure is constructed and services are provided (public transport, parking) in order to deal with mobility. The so called 'fields of accessibility' produce the need for new objects in order to increase availability (Depolo 2006). That circle is constantly renewed in cycles (Fig. 1).

All previous efforts to understand urban processes described above indicate that the key to the sustainability of the cities lies between land use and mobility demand (traffic). Sustainability is manifested in reaching a balance between these two factors. The way to balance can be achieved and extent depends on whether all development assumptions and their connection have been taken into account (Jović, Djorić 2009 and 2010).

The idea representing a fundamental starting point in this article is that the researchers/planners of the cities have been engaged with this issue for decades and developed many models that helped them with making an impact on the processes. Development/implementation was often under the influence of many factors. However, there is no evidence the models for demand forecasting in terms of planned urban development gave results confirmed in the forecast period (Depolo 2009). In other words, the available models continue to be a valid theoretical basis to be used in planning the sustainable development of cities. The presentation of model development used in the cities of the former Yugoslavia shows that the matter of city sustainability always represented the focus of attention and has been the subject since the early '50s not only worldwide but also in the former Yugoslavia (Jović 2002).

2. The Role of Trip Generation Models in the Process of Modelling Transportation Demand

Trip generation is the first step in the conventional four-step transportation modelling process used for forecasting travel demand (Fig. 2). It predicts the number of trips originating or having a destination in a particular traffic zone. The zone of traffic analysis and its land use 'produce' or generate trips. Zones are also the destinations of trips and trip attractors. The analysis of attractors focuses on non-residential land use. Trip generation is usually focused on residences, and therefore trip generation is thought to be a function of the social-economic attributes of households.

Land use forecasting distributes predict changes in activities in a disaggregate-spatial manner among the zones.

The analysis of the first zone trip generation (and its inverse, attraction) presented in the transportation study of Chicago area was based on the 'decay of activity intensity with distance from the central business district'. At that time, the study was considered to be the state-of-the art. Data from extensive surveys were arrayed and interpreted on a-distance-from-CBD scale.

The analysis of residential trip generation is often undertaken using statistical regression. Car, mass public

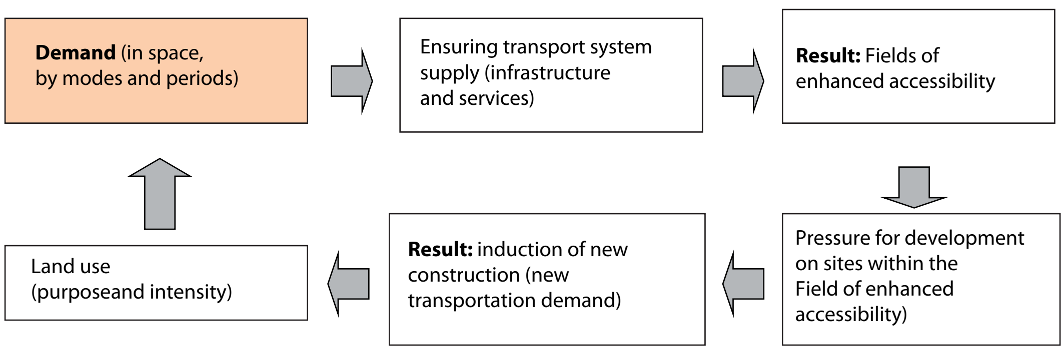

Fig. 1. Land use transportation relationship in the planning process

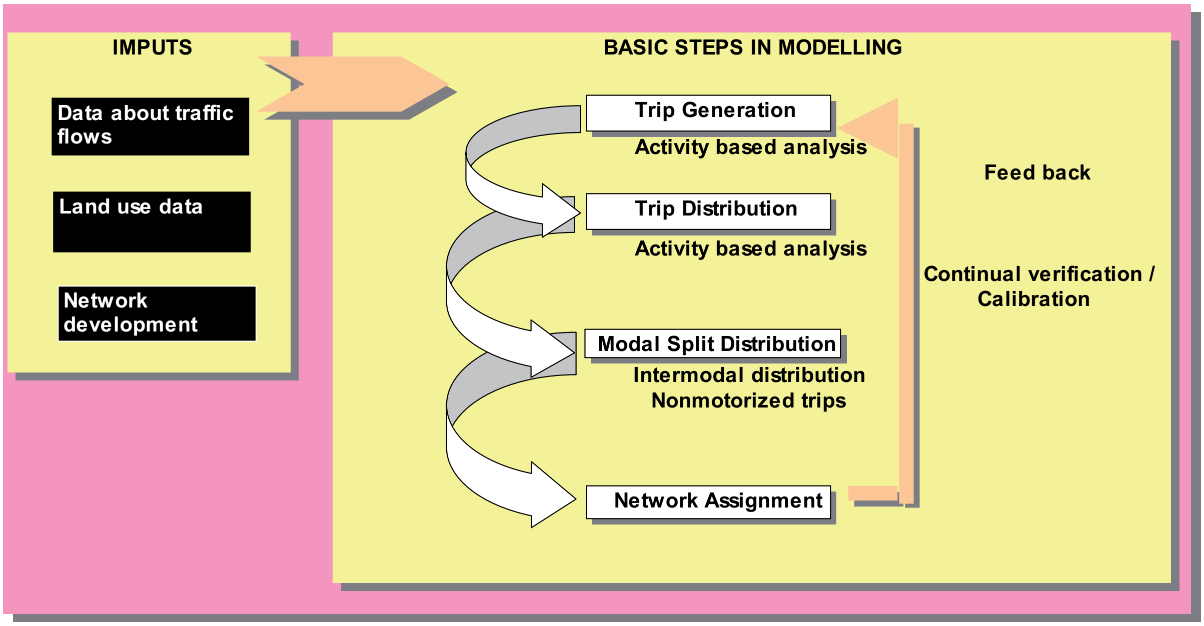

Fig. 2. A four-step procedure for demand modelling

transportation and walking trips are regressed on variables, including household size, the number of workers, age group, the type of residence etc. Measures for five to seven independent variables are usually available; additive causality is assumed.

Regressions are made at the aggregate (zone) level. Variability among households within a zone is not measured when data are aggregated. There is much variability lost by aggregation.

One of the techniques applied to the problems of residential trip generation is cross-classification.

3. Trip Generation Models for Planning a Sustainable Transportation System in the Cities of the Former Yugoslavia

3.1. Beginnings

The first papers in the field in the former Yugoslavia were related to researches in highway planning (E–5, Vrhnika–Postojna, Savska magistrala etc.) and belonged to the period of the early ‘60s. The first study on transportation in urban areas was one on transportation in Pancevo and was prepared in 1958 with a simplified methodological approach and modest forecasting elements (Jovanović, Jović 1978). Shortly after that, the development of the first studies on transportation in the cities led to improving their own models and experiences in this field.

Modelling trip generation in transportation studies in the cities of the former Yugoslavia was taken as the basis for this chapter, because it reflects all the stages modelling went through. It was strongly influenced by foreign experience, especially by Anglo-Saxon one. Introducing procedures for analytical modelling that relate household socio-economic and land use characteristics to the intensity of land use represented the pioneering step in procedures for integral land use, activity intensity and transportation demand planning.

After a disastrous earthquake in Skopje in 1963, the preparation of a new urban master plan, which included the preparation of transportation study, began (Saobraćajna studija Skoplja 1965). A whole set of traffic surveys (household surveys, surveys at the external cordon on passengers' public transport termini as well as recording traffic flow parameters in Skopje street network) were conducted. The models used in this study represent the first steps in trip generation modelling. They were based on the application of growth factors (related to activity growth in the forecasted year).

Mostar Transportation Study was prepared in 1968 (Saobraćajna studija Mostara 1968). Trip generation forecasts were prepared for three basic purposes of mobility (grouped into trips related and not related to the place of residence (home)). Household was considered as a measurement for home related trip generation (no specific traffic surveys were done for this study; all households were classified into seven classes according to the income and level of motorization).

A study on transportation in Sarajevo prepared in 1970 gives forecasts for the number of car trips based on the expected change in mobility (the number of trips per vehicle per day) and mileage during the year (Saobraćajna studija Sarajeva 1970). Data from Swedish cities, some USA cities and Dubrovnik were taken as analogue examples. Given differences in the degree of production and attraction of some urban zones, three corrective production and attraction factors related to the position of the zone within the urban area of the city were used. The predicted number of trips in public transport was based on the assumptions considering individual motorization development and the public transport system. For that purpose, vehicle-possessing households were observed separately, i.e. their mobility in public transport, and separately those with no vehicle. The simplest analytic procedure was applied based on the expected growth (growth factor), provided that the initial assumptions were related to research while the control of the forecast logic was based on comparative analysis with similar cities in Sweden and U.S. In comparison to the models used for town Mostar, trip forecasts were based on the assumptions given by the survey.

While preparing the urban master plan of Belgrade, in the second and third evaluation cycle referring to relation between land use and the transportation system, a methodological approach was proposed, in which trip generation was based on the forecast of trips related to work (the model for calculating trips from home to work was proposed by Harvard University (USA) professor Daniel Brand in 1971) using the following model form:

$$WtH = (PoP)\cdot(LFPR)\cdot(1-AR), \quad (1)$$

where: WtH – trips between home–work; $LFPR$ – zone employed population share (0.45); AR – the ratio of absence from work; PoP – population.

Trip destinations were proportional to the total number of employees in the zone. The applied trip generation model took into consideration only the basic characteristics of the zone based on the social-economic characteristics of the population (zone population, rate of employment) and the economic characteristics of the zone (employees/jobs) itself, which is in line with the methodological procedure where only trips related to work (considering the fact that complex transportation surveys were conducted, which among other things, included household survey, it is interesting that in the available documentation no adequate reliability tests for the proposed model were conducted; however, in this case, it can be also assumed that preference for the selected trip generation model was based on the fact that the observed area still has very dynamic growth, or perhaps there was a lack of basic information about land use and the intensity of land use; otherwise, the applied model has widely been used in transportation studies, particularly in the cities in Serbia – Čačak; Požarevac, Kragujevac) have been taken into consideration.

3.2. Models Based on the Use of Regression Analyses

For the very first time in transport planning practise, i.e. trip generation modelling as a model based on the use of regression analyses was applied in the transportation study by Zrenjanin prepared in 1973 (Saobraćajna studija Zrenjanina 1973). Given the Flux model (opportunity model group) was used for trip distribution and departures, i.e. arrivals have been forecasted per transportation zones. The basic postulate of this model was based on the fact that the number of departures (arrivals) for each zone was the function of land use, i.e. activity intensity was presented by the population size and the number of employees. All Origins/Destinations were grouped according to the periods of the day. The model was calibrated according to data representing the current state and the periods of the day; however, in the process of a statistical evaluation of the models, it was concluded that free particles of the formula should be eliminated. The number of origins/destinations was defined by the model of a general type (during a comparison of research data and the models of determined values, it was concluded that the number of arrivals determined by the model was much greater owing to poor reliability of data related to the number of jobs per zones playing a significant part in the model used to determine the number of arrivals; that is why it was determined that the model defining the number of arrivals per zone, which also provides better results, should be used to forecasting, given greater reliability of data):

$$Y = \Sigma\, a_i \cdot X_i, \quad (2)$$

where: Y – the number of origins/destinations; X_i – social-economic characteristic of the zone; a_i – the ratio and value determined by calibration on (against) the existing condition.

This procedure is a step forward compared to the previously described procedures, since the model was based on the calibration of the current state followed by the statistical verification of result rationality; thus, it can be assumed that the results of the forecasts were more reliable. The problems considering data on the social-economic characteristics of the area and activity purpose and intensity were an obstacle to preparing more complex models. However, at the same time it could be concluded, that the reliability of the forecasted results was more often related to the overall planned development of the city than it had been before.

In the transportation study of Novi Sad (Saobraćajna studija Novog Sada 1980), trip forecast was based on the analytic procedure, which, basically, represented the linear regression model (a stepwise regression program was used). Grouping trips into two basic groups was already performed in the analysis of the current state: trips related to home (home based) and those not related to home (non-home based) (a zone of residence was determined as the zone of production, no matter whether a trip began or ended in it, while the zone of attraction was the one related to the other end of the trip). In order to obtain a true idea of the statistical strength of correlation between particular characteristics (independent variables) and production and attraction (dependent variables), a correlation matrix was calculated in order to separate the variables relevant for model preparation. A general model was used:

$$Y_i = a_i + \Sigma b_{ij} \cdot X_i + b_{2i} \cdot X_2 + b_{3i} \cdot X_3 + b_{4i} \cdot X_4 + b_{5i} \cdot X_5, \quad (i = 1, 2, \ldots, n), \quad (3)$$

where: Y_i – zone production and attraction; X_i – independent variables interpreting the intensity of land use and socio-economic averages within the zones; a_i, b_{ji} – parameters of the equation (j = 1, 2 ... 5)

This approach was possible due to a high level of the interaction between land use planning and a transportation system and was developed by coordinating the preparation of the urban master plan with the transportation study, and due to a high quality information base. The procedure already applied in the phase of trip generation analysis, allowed the verification of future spatial organisation that could be considered as a forerunner of planning a sustainable transportation system.

3.3. Models Based on Category Analysis

Unlike the urban development of other cities in the world, which, more or less, followed their historical concept, urban processes in the cities of the former Yugoslavia had a form of creating the inverse matrix with a high concentration of development at the edge of urban territory and a relatively low level of development in the central city zones (similar to suburbanisation observed in numerous European cities in the last decades of the 20th century).

Urban development processes described and connected with transportation research that have continuously been implemented since the early '70s, gave indications to the planners that at the stage of trip generation modelling, the city territory should be stratified into sections with similar urban characteristics for the following reasons:

- the urbanization process of a similar type (and trend) will continue in the future, having in mind that the level of saturation (this trend dramatically stopped after the disintegration of the former Yugoslavia; with the construction of new residential zones of mass housing in the periphery of cities, after the war ended, housing construction dramatically decreased in order that since 2000, along with the first signs of economic recovery in Serbia, it has developed in dispersion under a strong influence of the real estate market) has not been reached yet;
- new residential zones in the cities are by the rule, the settlements of highly concentrated population and with basic social-economic characteristics closer to the upper-middle class population;
- new residential areas typically generate a large number of passenger car trips due to the high initial level of motorization, which is rapidly approaching the saturation level.

In Osijek transportation study (Jovanović, Jović 1981), creating the trip generation model started with defining urban subsections with relatively balanced urban characteristics (population density, spatial concept, equipment for central facilities, accessibility to the public transport system etc). The assumption was that the impact of urban structure and form determined the method and lifestyle of some household categories, and thus determined their behaviour in traffic through the number of trips they generated during the day. The urban territory of Osijek was divided into four distinctive sections:

- *central zone*, featured by the homogeneous and fragmented matrix of high density and high activity concentration and a ragged street network that offers a high level of accessibility;
- *zones in other built-up areas*, mostly intended for housing, with a lower concentration of residents and users, with a lower level of street network development and often for mono-functional homogenous activities;
- *rural and suburban zones*, characterized by middle and low population density, an infrequent street network and a lower level of general traffic services;
- *new residential zones* of high population density and development indices usually organized in macro-block units with main approach roads served by organized public transport and a relatively sparse residential street network that produced limited direct accessibility for the users.

The analysis of the number of trips generated by households during the day at the zone level was conducted in relation to the households with a different motorization level. The following form of a general model was established:

$$PUT_{dom} = f\,(MOT_{dom}, LOK_{dom}), \tag{4}$$

where: PUT_{dom} – the number of trips generated by the household of the corresponding category; MOT_{dom} – households according to their car possession; LOK_{dom} – households according to their position in the city territory.

Trip generation factors were defined in the form of a matrix according to these postulates. The presented data indicated that new residential zones appeared to be a specific traffic generator. Further analysis was directed towards additional levels of stratification and determining their impact on household mobility. Among analysed variables, average monthly household income appeared to be the most significant one (five household categories were formed with an average annual income between 1110 and 2800 USD – data refer to 1981). By inclusion of this variable, a three-dimensional matrix having a simplified form of display was obtained and given by a two-dimensional matrix (Table 1).

In the transport master plan of Belgrade, finished in 2008, a model also based on category analysis was applied for forecasting zonal trips (Saobraćajni master plan Beograda 2008). It was calibrated to the data obtained from the transport model of Belgrade (Jović *et al.* 2007). The trip generation model comprised the following: the number of households according to income category (seven household categories were established according to the range of monthly income), according to the number of members employed in the household (four household categories were identified) and a correspondent number of trips generated by *X*-type household located in *Y*-type zone. In that way, a three-dimensional matrix was obtained, two dimensions of which were household social-economic characteristics and the third one was the number of trips per day (Fig. 3).

Table 1. A trip generation model based on category analysis – Osijek model in terms of household economic power, possession of a car and its location in the urban area

Households with no car						
Zone type	Income category					
	1	2	3	4	5	average
Rural and suburban	5.48	6.31	6.25	7.27	8.94	5.92
Other constructed area	5.00	6.86	6.03	8.22	8.19	5.81
Central zones	5.12	7.39	6.38	6.70	4.90	5.92
New residential zones	4.81	7.34	7.00	6.81	8.42	6.07
Average	5.24	6.77	6.14	7.33	7.61	5.96
Households with one passenger car						
Zone type	Income category					
	1	2	3	4	5	average
Rural and suburban	6.49	7.38	8.04	8.30	10.00	7.42
Other constructed area	6.85	7.38	8.56	9.28	9.68	7.42
Central zones	7.25	7.21	8.14	6.75	8.12	7.54
New residential zones	7.06	6.84	9.99	9.94	6.54	7.67
Average	6.68	7.25	8.60	8.78	9.00	7.56

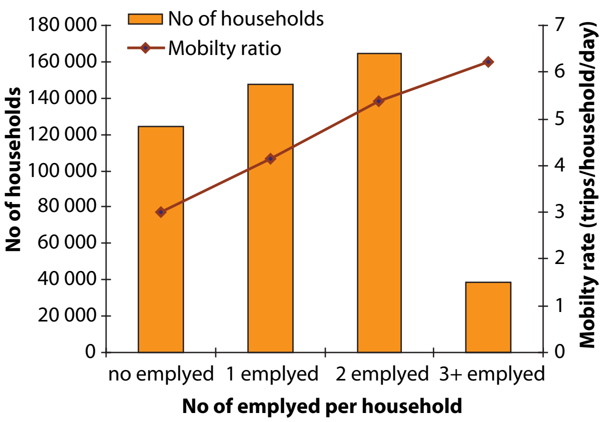

Fig. 3. A trip generation model based on category analysis – Belgrade, 2008

3.4. The Application of Trip Generation Factors

The first research inspired by trip generation factors and aiming at determining the dependence between the number of generated trips and land use parameters was conducted in 1973, within the transportation study of Čačak (Saobraćajna studija Čačka 1973). The number of trips was identified at four basic urban areas for which the generation factor was defined as the density of trip generation (the number of trips per 1ha of the area). Each area, for which the accompanying number of trips was calculated, was associated with the corresponding land use parameters: population density expressed in the number of inhabitants per hectare and job density expressed in the number of employees per hectare. The basic matrix that relates generating factors according to appropriate spatial units and corresponding land use parameters was established. These analyses had no wider significance since they did not include sufficient sample; however, they presented a continuance of research in the field of applying category analysis.

The previous results as well as those of the analysis conducted in Subotica in 1978 and some other cities have shown that some improvements were possible through the stratification of cities in relation to population size and the average values of land use parameters (Jovanović, Jović 1978). In other words, the results of the analyses showed that trip generation density acted differently for the cities different in size and with different average land use parameters (different urban forms). These analyses were used to define the general matrix of trip generation factors for the cities with the population between 50 000 and 100 000 applying appropriate average values of land use parameters (Table 2).

The use of trip generation factors in location analyses in Serbia originates from the '90s. It was used for the first time for the purposes of a project in Belgrade that was supposed to innovate solutions to financing location development costs in a way to, as precisely as possible, connect these costs to the locations and to divide them in detail according to hierarchical levels of infrastructure systems (Depolo 1998). A model for calculating the costs of road reconstruction and/or construction based on the use of trip generation factors was elaborated according to the approach developed in the United States (Depolo 2005). The proposed procedure was based on the fundamental assumption that every new location generated a particular

Table 2. Trip destinations for medium-sized cities and corresponding average land use intensity values

	CITIES	
Number of trip destinations generated by:	50 000 inhabitants. The average values of land use intensity G_s = 21 inhabitants/ha G_z = 8 employees/ha	100 000 inhabitants. The average values of land use intensity G_s = 40 inhabitants/ha G_z = 15 employees/ha
Suburb and suburban settlements	9	22
Wider urban area	37	224
Wider city centre	125	–
City centre	315	935

traffic volume which, through location (internal) network, and over the gathering streets, flew into the primary city communications causing the need for their reconstruction (if they already exist) or their construction (in accordance with development plans). Influence 'assigned' to construction in a location was proportional to the projected volume of generated traffic, i.e. to its distribution to peripheral primary communications (or communication) and to the calculated load and utilisation of the capacity offered (Francombe, Le Flohic 1985; Leake, Gray 1973; Guidelines for Trip… 1967; Gantvoort 1971).

Trip generation factors were also used for the analysis of locations for constructing shopping malls in Belgrade (Jovic *et al.* 2007). They were used to analyzing the market areas for future shopping centres. For two analysed locations, except for housing, there was a range of specific traffic flow generators (Republic Medical Centre, Main Railway Station, Belgrade Fair Complex, Complex of Government Institutions and two largest football stadiums (Partisan and Red Star)). In our case, Belgrade Fair Complex is singled out because it represents a specific traffic flow generator/attractor. In order to determine trip generation factors, fair performances were systematized into groups according to the intensity of visits (three groups of exhibitions were identified: large, medium and small). A generating factor was calculated based on the number of visitors and was adjusted to the surface of each rented square meter of the exhibition area (Fig. 4) (Lovreta 2003).

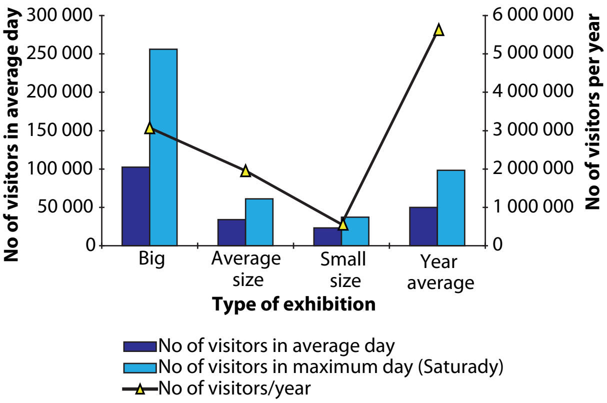

Fig. 4. Trip generation factors defined for Belgrade Fair Complex

4. Conclusions

During the '70s, the models based on trip generation factors imported from abroad were prevailing in the planning practice of the former Yugoslavia. In a certain number of studies, the models were derived from data analysis obtained by surveys – they were localized, and became more reliable in comparison to those based on analogue examples. In a number of these models, a certain type of category analysis was used aiming at better connection between the model and the features of the urban area (they used to be referred to as corrective factors), which provided them a greater degree of adaptation to local conditions and a higher degree of reliability. The models based on similar postulates have also been developed, but for different transport means (mostly by motorized means) providing for the possibility of trip generation modelling and for modal split distribution. Within this period of model development, their role in evaluating the compliance of traffic demand resulting from a particular model of spatial organisation with the transportation system was prominent.

At the next stage, the models were based on more complex linear equations obtained on the basis of multiple correlation analysis, which caused, in even greater extent, the integration of the influence of land use and activity intensity into the process of modelling trip generation. The models had a relatively complex structure and relied upon the use of a larger number of independent variables in describing trip generation. Their use-value had great potential, which, however, was not exploited because of the inability of local planning services to provide for independent variables forecasting data (land use, socio-economic data). Consequently, the models were used in a smaller number of cities with developed services and relevant databases.

First, trip generation models based on category analysis were applied in big cities with a characteristic form of the urban matrix where new residential construction was located in free and suburban areas. Such construction influenced a specific form of the spatial distribution of trips, which was not properly supported by distribution models. Accordingly, models for category analysis were used for trip generation modelling.

The models based on trip generation factors were in use in the '70s. However, mass application began after 2000 when foreign investors started operating the real estate market. They were mostly used at the preparatory stage of surveying in shopping centres for the purpose of location analysis. The application of these models was based on foreign experience. Their localisation began with the transport model for Belgrade, at the very beginning of which, comprehensive research on specific traffic generation factors was conducted (Jović *et al.* 2007). Establishing the local values of generating factors according to the purpose and activity intensity of land use is currently in progress (Vukanović *et al.* 2007).

The aforementioned shows that all known methods of trip generation modelling were applied in the practice of transportation planning in the cities of the former Yugoslavia. Recently, researchers in Serbia have discovered that the process of balancing mobility demand resulting from the purpose, activity intensity and the supply of the transportation system (infrastructure and services) results in forming the 'fields of improved accessibility' (i.e. parts of the urban area more influenced by investments) that causes 'pressure' to increase activity intensity (the appearance known as the induced construction), which results in inducing new demand (Depolo 2006). In this context, there are efforts to integrate trip generation models into those of spatial distribution, which would take into consideration the above described conditions and create the basis for the balanced and sustainable development of the cities.

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