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COMPARING THE ROAD NETWORKS OF RESIDENTIAL AREAS

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Abstract: In this study, the traffic flow of morning peak hour is analyzed in residential areas using dynamic traffic assignment method. A comprehensive analysis of the traffic assignment was performed in six different network topologies. The main goals were to compare different road networks and to identify significant similarities and differences of these patterns. By comparing results, a highly detailed picture of the differences crystallized between travel time, velocity and ratio of used routes.

Keywords: Traffic optimization, Route choice, Road networks, Urban street patterns, Residential areas

1. Introduction

The connection between urban structure and travel behavior [1] is a well-researched topic amongst urban designers and traffic engineers. Urban form and structure can influence not only the spatial growth of settlements, but also social and economic developments [2], [3].

Intensity of urban traffic depends on real estate, population density, and various road network types of settlements, road network hierarchy, and maturity of public transportation systems, modal split, social prosperity and land use. Due to connections among urban ecology, economy and society, their influence on urban traffic is very complex [4], [5].

The square grid network is one of the oldest planned urban forms. This urban pattern was the basis for plenty of ancient Hellenic and Roman settlements and still commonly used in modern times.

The foundation of planned cities was the grid network. In the last centuries, new street patterns have evolved in residential areas by urban designers to meet the requirements of the increasing numbers of residents and new demands of the cities. Loops and cul-de-sac street patterns have been utilized since the first half of 20th Century. The 1950s and 60s witnessed the formulation of the warped parallel, loop and lollipop, and lollipop-on-a-stick street patterns [6].

Relationship between speed and road safety is a deeply studied topic [7]. A reduced speed area, especially the 30 kmph or 'zone 30' as it is known, has a great number of benefits. The lower speed of the vehicles affects reduced vehicle-stopping distance that decrease crash rate and injury risk for every road user [8]. More than that, it can also reduce the emission of harmful substances [9]. As a consequence, 30 kmph zones have been spreading fast across Europe since the 1980s [10]. Taking into account the advantages of reduced speed area, it is adopted frequently in revitalized city centers.

The following section presents attributes of the analyzed residential areas, which applied 30 kmph zones. Different urban street patterns like square grid, loops and cul-de-sac as well as two-way and one-way streets could be compared. The method is made to analyze different traffic conditions representing traffic behavior of different traffic attractions [11]. Therefore, in this study different urban street patterns are compared to each other based on traffic assignment that did not examine the road networks of cities based on statistics and complex network theory [12], [13].

2. Methodology

2.1. Model setup

Determining boundary conditions is essential for analyzing method like topologies and characteristics of examined residential areas, the number of residents, surface area, population density and road hierarchy. This article elaborates exclusively on hypothetical road patterns instead of analyzing patterns of actual residential areas.

For analyzing different urban street patterns, a base grid model has been created, which represents the neighborhood areas. The project area is a 4x4 lattice, which is a 375 mx375 m web. The distance between parallel streets are 125 m that is an approximate value in a lot of European cities for instance Barcelona, Krakow, Vienna and Budapest.

9 blocks are determined by the streets of grid network and they are represented by the examined residential areas. The covered area is roughly 14000 m^2, and it is large enough to represent a minimal area of settlement that is self-contained in terms of basic education, medical facilities and commercial services [14], [15], [16].

The value of vehicle ownership in Hungary equals to 301 cars per 1000 people [17]. The vehicle ownership ratio, which strongly depends on the economic wealth of countries [18], is compared to the numbers of inhabitants in different residential densities.

Table I shows these values and the connection between the number of dwellers and car property value.

As *Table I* shows the number of inhabitants in the modelled area which are approximately between 2000 and 5500. Additionally, the number of cars is approximately between 600 and 1700 under Hungarian circumstances.

In the course of traffic assignment, larger values of maximum number of vehicles are also used as it is shown in *Table I*. This is required to ensure the comparison among variations of street patterns.

Table I

Connection between the numbers of dwellers and car property value

residential density (numbers. of floors)	min. population density [pp/km2]	max. population density [pp/km2]	min. number of inhabitants [No.]	max. number of inhabitants [No.]	min. number of vehicles [No.]	max. number of vehicles [No.]
low (1-2)	15000	21000	2110	2954	636	890
middle (3-5)	21000	25000	2954	3516	890	1059
middle-high (8-10)	26000	39000	3657	5485	1101	1651

After computing the theoretical maximum volume of traffic, different road types are defined. The examined area is bordered by arterial roads [19], which are two-way streets and there have one lane in every direction. The maximum permitted velocity is 50 kmph. Intersections between arterial roads are roundabouts.

On the inner roads 30 kmph zone is used and they are divided into 9 blocks by the residential areas. And it is called the inner side of the model. The priority rules at the inner intersections are defined by priority to the right.

Fig. 1 shows the residential part of the examined area, the inner roads and the boundary arterial roads.

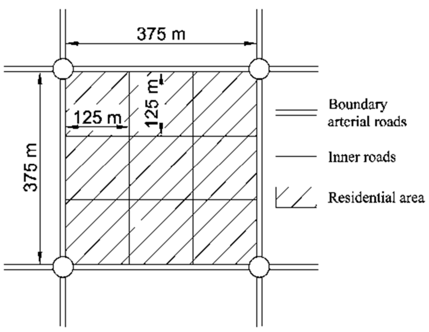

Fig. 1. Setup of the model

2.2. Examined models

The aim of this study is to compare different street network patterns under different traffic conditions. Six different models are analyzed. The most significant differences among models are directions and types of streets (two-way or one-way) and presence of loops or cul-de-sacs. *Fig. 2* shows the examined urban street patterns.

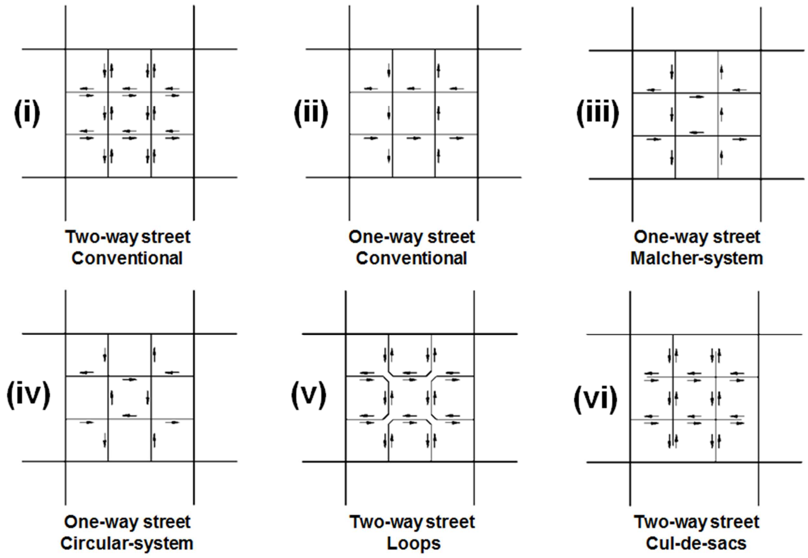

Fig. 2. Examined urban street patterns

The first case (i) is one of the most conventional layouts. It has two-way streets and the left turns are allowed into every direction at the intersections. Three different one-way street layouts are analyzed in this paper (ii), (iii), (iv) to find some significant differences among them [20]. The second case (ii) is a particularly used one-way street layout. The third model (iii), which is called Malcher-system, is also a one-way street pattern. The special attribute of this layout is the alternate numbers of inward and outward directions of streets at the intersections. If the number of the inward direction in the intersections equals to one, the outward direction numbers are three and vice versa. The fourth case (iv) is also an one-way street pattern and the system is called circular. This layout is similar to case (ii). Every intersection has two inward and two outward directions, but the direction of straight ahead direction is banned. In the fifth case (v) two-way loop streets are examined. This layout does not have any inner intersections, which is its characteristic feature. This way, the intersection delay is minimal in a 30 kmph zone, but the traffic reaches the arterial road in a more concentrated way than it would otherwise do. The sixth case (vi) (cul-de-sacs) has two way inner roads with cul-de-sacs and loops.

2.3. Traffic assignment

The behavior of vehicles in the models in different traffic conditions were the base of traffic flow comprehension among models. For computing this, traffic generation and attraction zones were needed to define representing trip generation, trip distribution and route assignment.

Zones have been defined for trip generation and distribution, and they have two types. *Fig. 3* shows the defined zones and the used Original-Destination (OD) matrix. The first parts of them are called outer zones and they are situated at the ends of arterial roads (8 pieces, gray ones). Other parts of zones are called inner zones and they are situated in the residential area next to the inner or arterial roads (36 pieces, white ones). The residential area is divided into 9 blocks by inner streets. By the same token, every block has 4 inner zones nearby the adjacent roads.

OD matrixes were created among the 44 defined zones. In this work, not every traffic option among zones was used for traffic modelling. Inward traffic, traffic from outer to inner zones, and outward traffic, traffic from inner to outer zones were analyzed. Therefore, the simulations did not contain the presence of through traffic, traffic from outer to outer zones, and the presence of inner traffic, traffic from inner to inner zones. *Fig. 3* shows the boundary conditions.

Parking spaces are represented by inner zones. They are abstracted, because in real life there are not enough spaces to contain as many vehicles as defined in this study. This method, the results of traffic efficiency has been compared in six different cases.

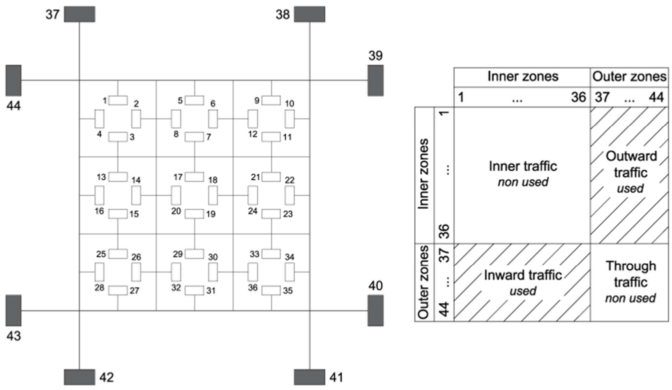

Fig. 3. Layout of model and OD matrix with inner and outer zones

VISSIM microscopic traffic simulation software Dynamic Assignment module is used for traffic assignment. The program optimizes the user equilibrium [21]. Only cars are involved in the models. Pedestrians, bicyclists and public transportation lines were not defined. In reality, the conflicts between pedestrians and drivers are considerable [22]. The base parameter of convergence criteria was the travel time. The simulation stopped either when the convergence criteria was fulfilled, meaning the current travel time being under 5% to the former travel time, or when it reached the 20th simulation step. The examined time period was one hour.

2.4. Different assignment cases

All 6 examined urban street patterns are loaded with 54 different OD matrixes with the following conditions. Firstly, every matrix element (inward and outward traffic severally), which is higher than 0, are equal. For example, in case of inward traffic, based on the similar loading of OD matrix among the inner and outer zones, the same number of vehicles can reach every inner zone (36) from every outer zone (8). Secondly, if traffic load of the network equals to 1, the volume of generated traffic in the network equals to 288 vehicles in the analyzed time period.

Fig. 4 shows the analyzed 54 traffic conditions. Meaning that traffic volume among zones is based on the second boundary condition. In the case of the greatest traffic loads, when traffic volume per zones equals to 9, at the network 2592 vehicles are generated under 1 hour. Moreover, the *Fig. 4* also shows the proportion of inward and outward traffic.

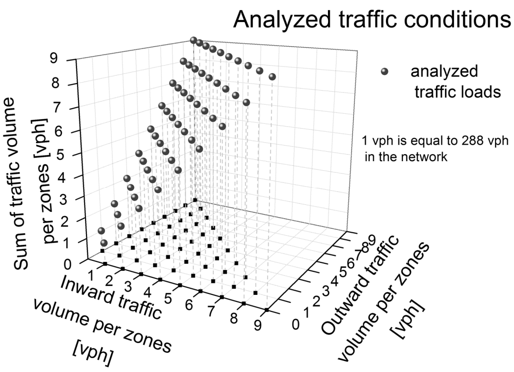

Fig. 4. Examined traffic conditions

When the summarized traffic equals to 6 the traffic loads of the network equal to 1728 vehicles per hour. It equals to approximately the car coverage of middle-high residential density in Hungary as it is shown in *Table I.*

3. Results

The results of the simulations showed differences among street patterns. Analyzed patterns are compared to each other based on average travel time, average velocity and the number of alternative routes in the network. Isobar charts are used to show results in *Fig. 5, Fig. 6* and *Fig. 7*. In these charts, the inward traffic is represented by the horizontal axis, and the outward traffic is represented by the vertical axis. The represented cases are that the same as in *Fig. 4.*

3.1. Travel time

Fig. 5 shows the evaluation of travel time in 54 different traffic loads of six diverse models. Lower travel time is represented by lighter colors and higher travel time is represented by darker colors.

The average travel time [s] equals to the means of travel time of every single vehicle between inner and outer zones in one simulated case in the network.

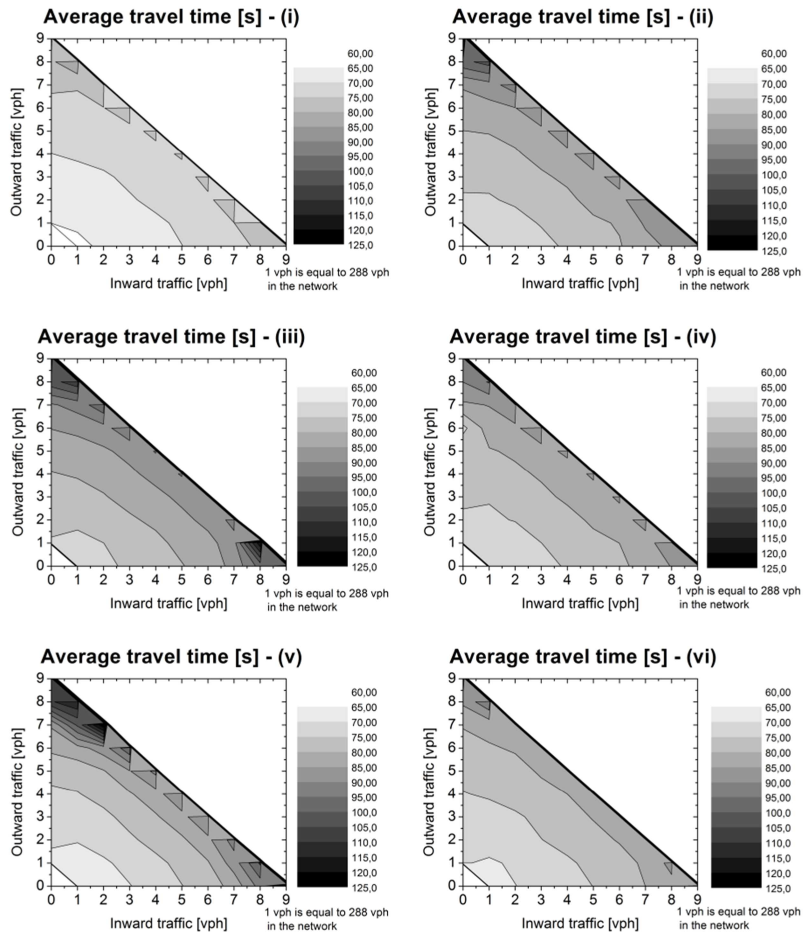

Fig. 5. Average travel time by vehicles [s] in 54 different traffic loads of 6 models

The first case (i), a regular two-way street, has a minimal average travel time in most of the cases; case (vi) has similar corresponding results. The initial values of one-way streets (ii), (iii), (iv) are a little bit higher than two-way street (i) values. Case (v) acts similarly in case of low traffic loads. But the streets of the network are saturated in case of high, almost clearly inward or outward traffic loads. Therefore, congestion evolves, the streets are oversaturated and outer intersections reach their full capacity. This phenomenon does not take place when the amount of summarized traffic is the same, but the proportion of inward and outward traffic is similar.

3.2. Velocity

The average velocity [kmph] equals to the means of velocity of every single vehicle between inner and outer zones in one simulated case in the network.
Fig. 6 shows the average velocity under the analyzed 54 traffic conditions in the 6 models. Lower velocity is represented by darker colors and higher velocity is represented by lighter colors.

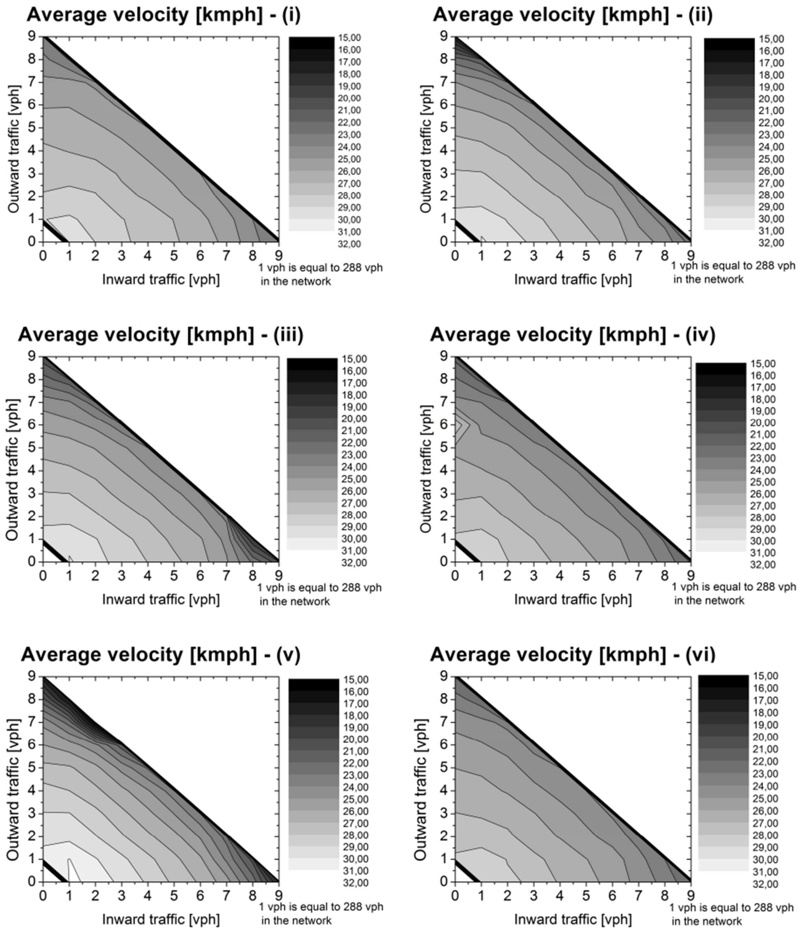

Fig. 6. Average velocity by vehicles [kmph] in 54 different traffic loads of 6 models

Taking one-way streets into consideration, it can be seen that they act similarly to each other. Traffic efficiency in case (iv) is a bit higher than in the others. Taking the results into account, case (i) and case (vi) have the highest average velocity for most of the cases. This phenomenon is explained by the number of alternative paths that drivers can use. As it was mentioned earlier, case (v) does not contain any intersections in the residential areas of the models. Consequently, the road users do not gather time delay at inner intersections and they can reach higher speed. But when outward traffic volume is higher, the values of average velocities decrease, at the same time the boundary intersections can be congested.

3.3. Ratio of used routes

Additionally, traffic conditions are also characterized by the number of used routes of vehicles. For this computing, the proportion of actually used routes and least used routes are applied.

Value of the least used roads among the zones equals to 288 taking both inward and outward traffic into consideration. Under this condition, details can be acquired, on how the increasing traffic influences the amount of used routes and how saturated traffic conditions affect route choice.

Results are indicated in *Fig. 7.* Dark gray equals to 1. It means that the ratio of used routes and the least used routes are equal. Lighter gray shows that the number of used paths is higher than the number of least used routes. Arrows shows the cases when the value of ratio of used routes is equals to 1.

Based on the results case (i) has the greatest ratio of used routes. This way, the number of alternative paths is higher in this case than in every other cases. The case (vi) has similar values in number of used routes and the pattern of isobar graphs like in case (i).

The cases of one-way streets (ii), (iii), (iv) act a little bit different from each other. The conventional one-way street (ii) and the circular system (iii) has fewer alternative paths than the Malcher-system (iv). The differences need further investigation.

Interrupted oversaturated traffic flow can be easily caused for urban roads by increased traffic. The model (v) is vulnerable under increased traffic conditions due to the absence of inner intersections. Traffic cannot spread out in the inner part of the model, and it reaches the arterial roads in a concentrated way. Moreover, when heavy outward traffic exists, vehicles from inner roads have difficulty in turning onto arterial roads because, the continuous traffic makes shortens time gap between vehicles in arterial roads. The congested inner roads hampered the further generation of vehicles. As a result, fewer vehicles were generated than necessary.

4. Conclusion

Grid urban pattern is a historical urban layout model. It has been used from ancient to modern times. In 20th century a plenty of residential areas were built to solve the housing problem. These new residential areas were simultaneously designed with new kinds of street patterns to make the neighborhood comfortable and livable.

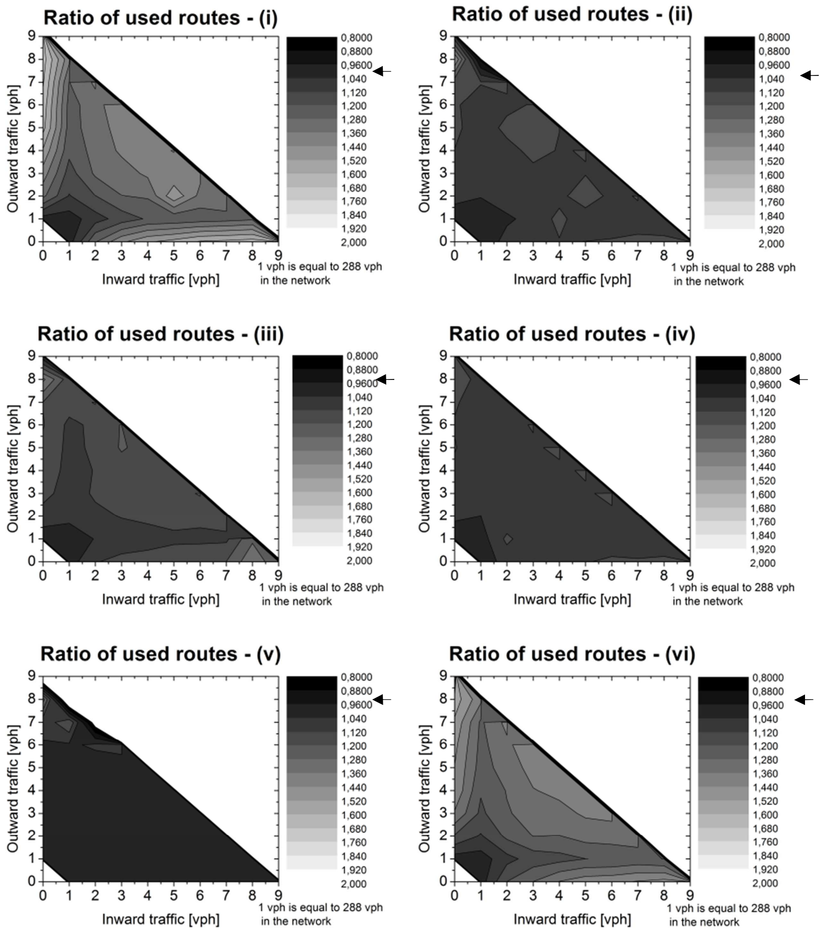

Fig. 7. Ratio of used routes in 54 different traffic loads of 6 models

The aim of the study was to analyze neighborhoods under diverse traffic conditions. Based on the results, the benefits and the drawbacks of street patterns were presented.

The usage of one-way streets, streets with loops and cul-de-sac are demonstrated by the preceding sections. The amount of speed, travel time and the number of alternative paths can be influenced by different street patterns.

Three different behavior types could be identifying based on the reaction under oversaturated traffic flow. The general layout as the two-way street (i) is contained in the first group. The (vi) case also belongs to the first group as the result shows, but it has to be mentioned the ordinary cul-de-sucs, which have different layout (only sticks) may act differently. The second group is made up of different one-way streets (ii), (iii), (iv). The street layouts act similarly in general, but there are some disparities that future research is to clarify. It must be noted that the overly complex one-way street patterns can be confusing not only for the banned through traffic but also for everyday users.

The third group, the most sensitive street pattern is case (v), streets with loops. It acts uniquely during increased traffic load. Under low traffic loads the efficiency of network is similar to the two-way street (i), but under high traffic load the efficiency of the road network is diminishing sharply.

Traffic efficiency of street patterns is not the only important measurement method in residential areas. Street quality, parking facilities, walkability and green spaces are also important feature of transportation and livability. Parking movements also have a great effect on the traffic and viability of the street.

In the future, comparing efficiency of different current existing urban street layouts in residential areas in Budapest at macroscopic level and traffic with monitoring are going to be analyzed in residential areas and central business districts, where 30 kmph zones exist.

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References

[1] Handy S. Methodologies for exploring the link between urban form and travel behavior, *Transportation Research, Part D, Transport and Environment*, Vol. 1, No. 2, 1996, pp. 151–165.

[2] Rossi-Hansberg E., Wright M. L. Urban structure and growth, *The Review of Economic Studies*, Vol. 74, No. 2, 2007, pp. 597–624.

[3] Anas A., Arnott R., Small K. A. Urban spatial structure, *Journal of Economic Literature*, Vol. 36, No. 3, 1998, pp. 1426–1464.

[4] Næss P. Urban form and travel behavior, Experience from a Nordic context, *Journal of Transport and Land Use,* Vol. 5, No. 2, 2012, pp 21–45.

[5] Banister D. *Unsustainable transport*, City transport in the new century, Routledge, London, 2005.

[6] Southworth M., Ben-Joseph E. *Streets and the shaping of towns and cities*, Island Press, Washington D.C, 2003.

[7] Berta T., Torok A. Layout effect of roadway on road vehicle speeds, *Pollack Periodica*, Vol. 4, No. 1, 2009, pp. 115–120.

[8] Knoflacher H. Findings of 30 kmph-zones in Vienna, (in Hungarian) *Városi Közlekedés*, Vol. 32, No. 5, 1992, pp. 263–268.

[9] Casanova J., Fonseca N. Environmental assessment of low speed policies for motor vehicle mobility in city centers, *Global NEST Journal*, Vol. 14, No. 2, 2012, pp. 192–201.

[10] Vis A. A., Dijkstra A., Slop M. Safety effects of 30 km/h zones in the Netherlands, *Accident Analysis & Prevention*, Vol. 24, No. 1, 1992, pp. 75–86.

[11] Tóth J., Juhász J., Schvanner N. Forecasting road journey time and urban traffic regulating systems, (in Hungarian), *Városi Közlekedés*, Vol. 49, No. 5, 2009, pp. 278–281.

[12] Kisgyorgy L., Vasvari G. Analysis and observation of road network topology, In: Z Leng, Y H Wang (Eds.) *Proceedings of the 19th International Conference of Hong Kong Society for Transportation Studies*, Hong Kong, China, 13-15 December 2014, pp. 253–259.

[13] Hegyi P. Road patterns of housing estates in Hungary, *Pollack Periodica*, Vol. 10, No 1, 2015, pp. 83–92.
[14] Meggyesi T. *Urban planning methods,* (in Hungarian) TERC Kereskedelmi és Szolg. Kft, Budapest, 2009.
[15] Perényi I. *Urban planning,* (in Hungarian) Tankönyvkiadó, Budapest, 1978.
[16] Liu W., Zhou B., Yang J. Residential environment evaluation and strategy research of city planning and construction of Xi'an City, *Journal of Convergence Information Technology*, Vo. 7, No. 18, 2012, pp. 240–248.
[17] *Központi Statisztikai Hivatal*, Regional characteristic of road transport, (in Hungarian) 2013.
[18] Borsos A., Koren C., Ivan J., Ravishanker N. Long-term safety trends as a function of vehicle ownership in 26 countries, *Transportation Research Record, Journal of the Transportation Research Board*, Vol. 2280, No. 1, 2012, pp. 154–161.
[19] Miyagawa M. Hierarchical system of road networks with inward, outward, and through traffic, *Journal of Transport Geography*, Vol. 19, No. 4, 2011, pp. 591–595.
[20] Koller S. *Traffic engineering and transportation planning,* (in Hungarian) Műszaki Könyvkiadó, Budapest, 1986.
[21] PTV AG, *PTV VISSIM 7.0 Fundamentals*, Karlsruhe, PTV AG, 2014.
[22] Kovács Igazvölgyi Z. Analyses of pedestrian characteristics at zebra crossings on one way roads, *Pollack Periodica*, Vol. 8, No. 2, 2013, pp. 67–76.