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ANALYSING THE CAPACITY OF THE URBAN ROAD TRANSPORT NETWORK USING A DYNAMIC ASSIGNMENT MODEL IN THE BISTRIȚA - TÂRGU MUREȘ GEOGRAPHICAL AXIS

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ABSTRACT. Analysing the Capacity of the Urban Road Transport Network Using a Dynamic Assignment Model in the Bistrița - Târgu Mureș Geographical Axis. Network capacity in a transportation system becomes an important measurement for transport planning and management because it addresses its capability to satisfy an efficient network traffic flow reducing the inefficiency of congestion phenomena. This work provides a discussion of road urban transport network capacity including existing definitions in literature and the validation of new measurement methods. The study explores some of the properties of network-wide traffic flow relationships in a large-scale complex urban street network using real-time simulated results obtained from a dynamic traffic assignment model, periodically updated by data from radar sensors through rolling horizon technics. The basic variables used in the methodology, such as network flows and speeds, are characterized using a network model calibrated in the urban area of the geographical axis Bistrița-Târgu Mureș. For a comprehensive yet simple analysis, equations, and graphs are utilized to resume the obtained results related to different days and several time intervals of the day. The focus of sustainable urban transportation development lies in realizing the untapped capacity potential of the existing road network and enhancing its operational efficiency without expanding its physical footprint. To quantify the supply capacity of road networks in mountainous cities, this paper converts the problem of solving the capacity of road networks into the problem of solving the minimum cut set in road networks from the perspective of road network capacity, using the idea of the auxiliary diagram method in graph theory. This procedure proved to be suitable for investigating the properties of

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network-level traffic flow relationships and concluding remarks include suggestions for further research in this highly promising area.

Keywords: *Traffic-flow relation, Intelligent Transport System, Dynamic assignment model, Road urban transport network, road network capacity, Geographic Axis Bistrița - Tg. Mures*

1. Introduction

A. Capacity

Capacity is an effective factor for evaluating traffic conditions and measuring a network's performance. The proper definition and quantification of network capacity have been topics of debate among researchers for decades. This concept was introduced by Ford and Fulkerson (1956), who developed an algorithm for the network maximum flow problem. Iida (1972), Asakura and Kashiwadani (1993), and Akamastu and Miyawaki (1995) extended that notion and proposed different programming approaches to estimate the capacity of a road network. Yang *et al*. (2000) introduced the concept of "reserve capacity" defined as ''the maximum common multiplier that can be applied to a given O–D matrix subject to the flow on each link not exceeding its capacity when the multiplied O–D matrix is assigned to the network by some equilibrium model'' (Yang et al., 2000). More recently, Daganzo and Geroliminis (2008) used variational theory to develop analytical expressions for the capacity of a street with blocks of diverse widths and lengths with no turns.

B. Network traffic theory

The origins of network traffic flow theory can be traced to the 1960's. Smeed (1966, 1968), Thomson (1967), Wardrop (1968), Godfrey (1969), and Zahavi (1972) were among the first studies to explore macroscopic relations of vehicular traffic in a network.

These methodological approaches dealt largely with the development of macroscopic models for arterials, which were later extended to general network models, and today highly spread thanks to the current extraordinary availability of real-time traffic data from sensors, floating car data and traceable personal mobile devices.

Accordingly, the evaluation of capacity at the network level has been receiving considerable attention more recently (Mahmassani *et al.*, 1984, 1987, and Williams *et al.*, 1987, 1995).

C. Actual urban networks, networks, capacity

However, actual urban networks are more complex. For highly idealized networks (completely homogenous and redundant) with slow-varying demand, Daganzo and Geroliminis (2008) suggested that if homogeneity conditions hold, these networks maximize their total flow for any given number of vehicles in the network. This can be referred to as ‘‘theoretical capacity’’ because it only depends on network structure and control and is independent of O–D patterns.

Nevertheless, in real-world urban networks, likely, the required homogeneity conditions do not hold. More practically, network capacity can be defined as the ‘‘observed’’ maximum network flow. This suggests that the observed maximum flow in networks tends to be lower than the theoretical capacity confirming the results of Knoop *et al.* (2013).

The maximum flow varies over time on a given road link and is influenced by various factors that have especially to deal with congestion. Accordingly, in the context of networks, capacity is the complex measurement of the maximum amount of data that may be transferred between network locations over a link or network path. Because of the number of intertwined measurement variables and scenarios, the actual network capacity is rarely accurate.

Currently, models and methods for calculating road network capacity include the cut-set method, the traffic distribution simulation method, the space–time consumption method, and linear programming.

As early as the 1950s, (Ford and Fulkerson, 1956; Beckmann, *et al.*, 1956) proposed the network maximum-flow problem for calculating road network capacity based on capacity, and the cut-set method was used to analyze road traffic problems.

The main idea of the cut-set method is to use the maximum-flow minimum-cut theorem to calculate road network capacity, which more accurately reflects the intrinsic relationship between the physical structure of road networks and traffic demand. Subsequently, Masuya and Saito (1989) utilized network flow cut-set theory to determine the capacity of a road network. Siregar, Agah, and Arifin (2015) evaluated the impact of two-way road medians, investigated the adjustment factor for road capacity calculation based on the median type, and validated the results.

Starting from these remarks, this paper aims to initiate a discussion on the definition and quantification of urban transport network capacity, providing a talk of existing definitions in the literature and the validation of new measurement methods.

This study explores some of the properties of network-wide traffic flow relationships in a large-scale complex urban street network using simulated results obtained from a dynamic traffic assignment model.

D. Network model analysed

Using a calibrated network model of the Bistrița-Târgu Mureș urban area, the traffic flow relationships are explored, focusing on the effect of traffic congestion on network capacity. The remainder of the paper is as follows. After a review of network capacity definitions in the general context of transportation, the second section discusses the methodological approach used to explore and subsequently calibrate network-wide traffic flow relationships. The third section presents the case study and describes the network simulation specifications.

The fourth section shows the modelling results, indicating the effects of congestion on network capacity. The last section concludes the paper by summarizing the main findings and specifying directions for future research. Travel times or costs per origin-destination pair for each route in the geographical axis studied.

Origin–destination (OD) flow models estimate the number of vehicles in a given transportation network that are travelling between origins and destinations within a specific time interval (Bauer *et al.*, 2018). Such estimations answer questions related to traffic congestion and evaluate the performances of theoretical models (Ben-Akiva *et al.*, 1998) and accessibility measures of public transport in urban areas (Benenson et al., 2011). OD flows can be estimated by traffic simulation from the travellers' daily or weekly activity programs (Horni *et al.*, 2016).

2. Materials and methods

A. Theoretical concept

The concept of transport infrastructure capacity is complex. The nominal capacity of most transport terminals and infrastructure is the traffic they can handle within a time frame and normal conditions in terms of reliability. It is jointly defined by static and dynamic considerations (Rodrigue, 2020):

- Static capacity refers to the infrastructure and available land as bigger terminals, or larger roads (more lanes) have conceptually more capacity. Static capacity cannot be easily changed without expanding the facility or the infrastructure, which tends to be capital-intensive and requires additional land. This can be a complex proposition in areas of limited land availability (or high land cost);
- Dynamic capacity relates to superstructure, labour, and technology, which can be improved upon. For instance, a more efficient terminal operation strategy can increase its physical throughput and capacity without resorting to additional land. The dynamic capacity of a road system can also be improved with a better synchronization of traffic lights. The intensity and density of utilization are improved with more efficient superstructure and management.

Dynamic modelling is used in the analysis of the study. Dynamic traffic assessment methods were developed as an evolution of "traditional" static assessment. Dynamic models can be used to produce forecasts of traffic patterns, traffic variations and variations in congestion levels. Such models can be successfully used to forecast traffic flows to better adapt traffic policies to real situations on the ground. These models can also be used for prediction and control (e.g., for traffic operators) as well as for on-line control. Dynamic models are an alternative to static models in combination with traffic demand models or temporal models. As a modelling technique, like static modelling, dynamic modelling allocates several trips to specific periods within network route matrices, resulting in time-varying traffic flows. Trip matrices are usually defined as the number of trips in an hour or quarter of an hour.

The dynamic traffic pattern shows how traffic flows through the links in the network. Unlike static models, dynamic models take into account not only the quantity of traffic but also the quality of traffic, taking into account its evolution over time.

A dynamic traffic model produces the following results:

- Travel times or costs per origin-destination pair on each route;
- Levels of variation over time of traffic flow on each route;
- Variations over time of travel times, flows, and speeds by link;
- Combined results (total kilometres travelled on the network; total time travelled on the network, etc.).

B. Analysis of the Dynamic Capacity Evaluation System of Bistrița-Târgu Mureș

B.1 Technical characteristics

Table 1. Structure Geographical axis of road transport under analysis

Geographical axis zone	*Communication ROAD*	*Distance (km)*	*Travel time*
a. Bistrița-Tg. Mureș	DN15A/E578	91.4 Km	1 h 39 min
b. Bistrița – Tg. Mureș	DJ 173	94.4 Km	1 h 24 min
c. Bistrița- Tg. Mureș	DN 15 E	105 km	2 h
d. Bistrița-Tg. Mureș	DJ 154 A/DJ154J	115 km	2 h 20 min
e. Bistrița-Tg. Mureș	DJ 151/DC16	120 km	2h 25 min+min înt

Source: *the author*

Table 2. Organisation of Geographical Axis Zone

Zone type	**Number of axis**	**Geographical axis**	**type of transport**
a.	2	Bistrița-Tg. Mureș	car
b.	3	Bistrița-Râciu-Tg. Mureș	car
c.	3	Bistrița-Reghin-Tg. Mureș	microbus
d.	4	Bistrița-Breza-Glodeni -Tg. Mureș	microbus
e.	30	Table 3	bus

Source: *the author*

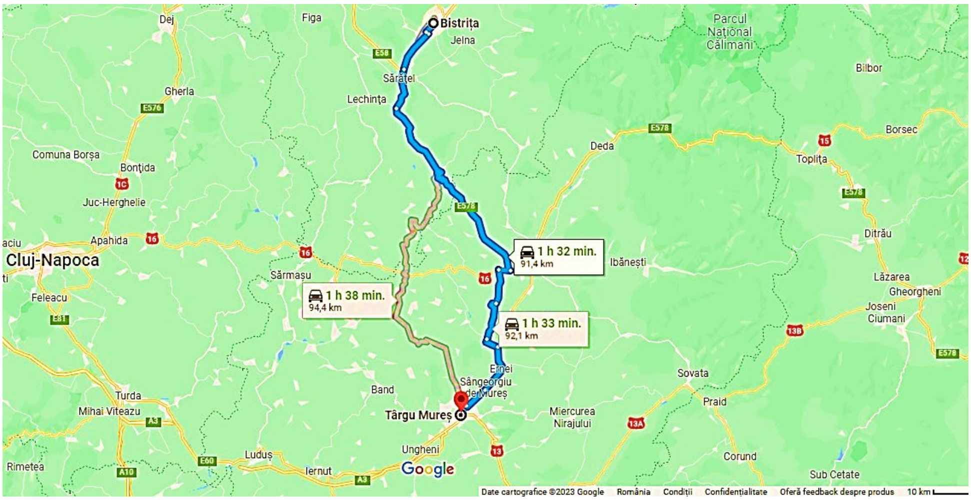

Fig. 1. Location of the Geographical Axis Zone Bistrița-Târgu Mureș distance travelled by personal vehicle.

Source: https://www.google.com/maps

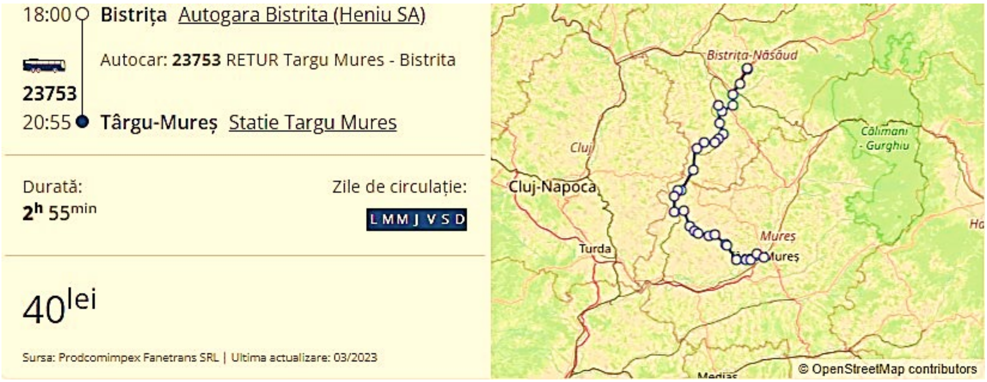

Fig. 2. Geographical axis Bistrița-Târgu Mureș by public bus transport
Source: https://www.autogari.ro/Transport/Bistrita-TarguMures

Panel 1. Zone E: Connecting axis of bus transport

BISTRIȚA-SĂRATA-SĂRĂȚEL-HERINA-TONCIU-LECHINȚA-SÂNGEORZU NOU-BRĂTENI-SĂLCUȚA-SÂNMIHAIU DE CÂMPIE-ZORENI-BUDEȘTI–TÂGU-SĂRMĂȘEL-SĂRMAȘU-BALDA-MIHEȘU DE CÂMPIE-RAZOARE-SAULIA DE CÂMPIE–MASTICASEȘI–LEURINTA–GRĂBENIȘU DE CÂMPIE–DRACULEA BANDULUI-BAND-TIPTELNIC-BERGHIA-SÂNTIOANA DE MUREȘ-NAZNA-SÂNCRAIUL DE MUREȘ-TG. MUREȘ

Source: the author

C. Geographical Axis Assessment System for Road Transport

The research of the Geographical Axis Assessment System for road transport is based on the theory presented by Smeed (1966), who considered the number of vehicles that can accommodate it and defined N as the number that can use a single road. Several investigations were carried out and some results emerged, finding a fairly precise relationship between the amount of traffic N on a road and the traffic speed v between intersections.

This relationship is expressed as where N is the number of cars using the road per hour, w is the width of the road (in kilometres), and v is the average speed of traffic (in kilometres per hour). In the formula stated by Smeed following the NAg analysis, the number of geographical axes composing the system increases, the number between the two geographical axis increases, and the N and W value also grows.

The variable NAg depends on the value of the parameters N and W.

Panel 2. Formula

N- number of cars using the road per hour W- width of the road (in kilometres) NAg-number of geographical axis V-traffic speed between the axis
N÷W+NAg - 2*V

Source: the author

3. Results and discussions

A. Formula application

We applied the five directions of the geographical axis illustrated in Table 1.

Worksheets 1 and 2 analysed the route travelled by car.

Sheet 1

Geographical axis zone	Communication ROAD	Distance (km)	speed	number of geographical axis
a.	DN15A/E578	91.4 Km	55 km/h	2
N÷W+NAg - 2* V	2÷91.4+2-2*55=47.7-110=62.3			

Source: the author

Sheet 2

Geographical axis zone	Communication ROAD	Distance (km)	speed	number of geographical axis
b.	DJ 173	94.4 Km	65 km/h	3
N÷W+NAg - 2* V	3÷94.4 +3-2*65=34.46-130=95.54			

Source: the author

Worksheets 3 and 4 analysed the route travelled by microbus.

Sheet 3

Geographical axis zone	Communication ROAD	Distance (km)	speed	number of geographical axis
c.	DN 15 E	105 km	70 km/h	3
N÷W+NAg - 2* V	3÷105+3-2*70=38-140=102			

Source: the author

Sheet 4

Geographical axis zone	Communication ROAD	Distance (km)	speed	number of geographical axis
d.	DJ 154 A/DJ154J	115 km	70km/h	4
N÷W+NAg -2* V	4÷115+4-2*70=32.75-140=107			

Source: the author

Worksheet 5 analysed the route travelled by bus.

Sheet 5

Geographical axis zone	Communication ROAD	Distance (km)	speed	number of geographical axis
e.	DJ 151/DC16	120 km	75 km/h	30
N÷W+NAg -2* V	30÷120+30-2*75=34-150=116			

Source: the author

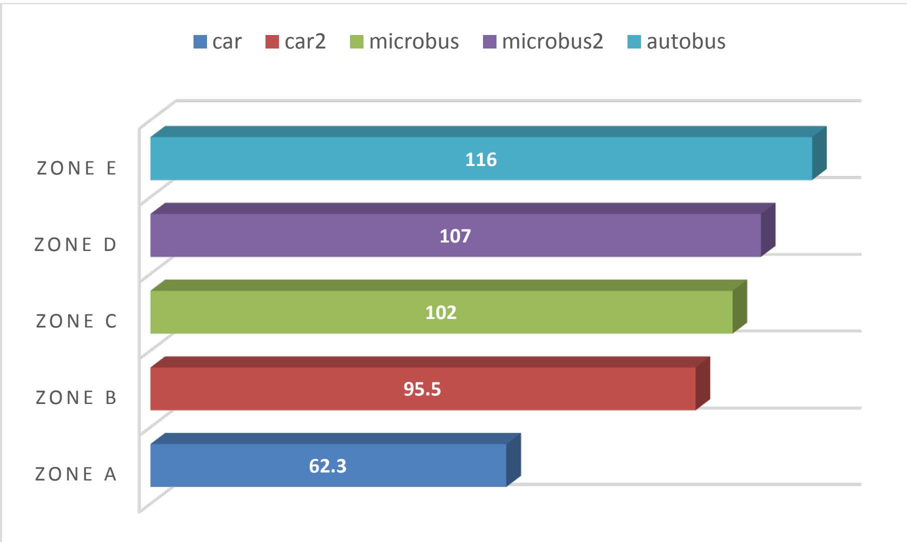

Fig. 3. Difference in road transport flow dynamics along the geographical axis.
Source: the author

B. Impact analysis

The dynamics of road transport flows increase with the diversification of the number of axes that the road transport network comprises.

The results presented by the graph in Figure 3 show that the diversification of the transport axis increases the transmission capacity.

Zone E shows the highest branching which means the connecting axes between two main geographical axis capacity in structure is higher than in Zone A.

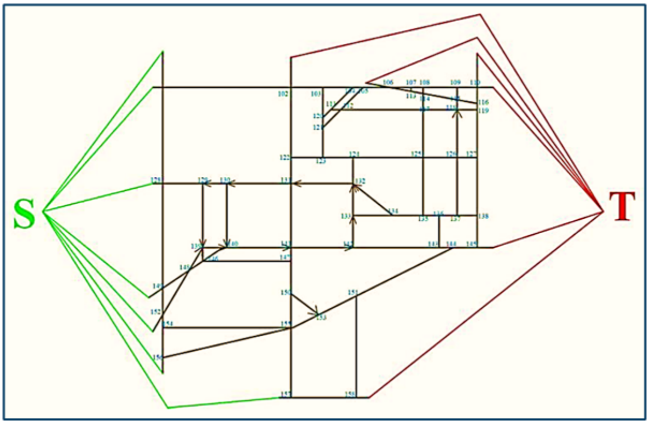

Fig. 4. Road transport network under construction zones a. and b. between two geographical axis S and T. *Source: the author*

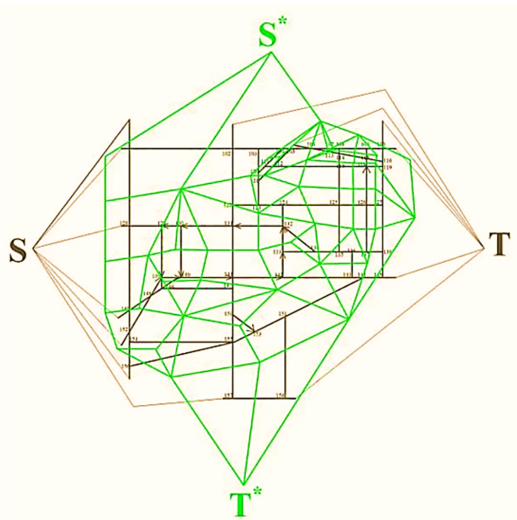

Fig. 5. Road transport network located under construction zones c., d. and e. between two main geographical axis S and T and two supporting secondary axes. Transport capacity is high, increasing fluctuation in road transport capacity. *Source: the author*

5. Conclusion

Network capacity in a transportation system becomes an important measurement for transport planning and management because it addresses the question of whether or not the system has adequate ability to handle continuing economic surges and traffic congestion. In transportation, capacity has traditionally been measured at individual elements of the network, such as links and nodes, however, these measures do not constitute the network capacity. Therefore, recent studies in the literature have suggested well-defined relationships between network-wide average flow, density and speed exist for urban networks.

In this context, this work provides a discussion of road urban transport network capacity including existing definitions in literature and the validation of new measurement methods. The study explores some of the properties of network-wide traffic flow relationships in a large-scale complex urban street network putting forward an innovative approach dealing with comprehensive data mining and analysis from different sources of data (radar sensors and floating car data) including real-time traffic estimations provided by a dynamic assignment simulation model.

The basic variables used are traffic flows and travel speeds characterized using a network model calibrated in the geographical axis.

For a comprehensive yet simple analysis, equations and graphs are utilized to resume the obtained results related to different days and several time intervals. It was noticed that the network behaves differently depending on the traffic context and the corresponding flow-speed relationships were obtained for congested and uncongested conditions.

It is intended that the relations derived from this study are calibrated for our own traffic data set, but it is well conceivable that they can better describe datasets of other countries, with similar characteristics in terms of network topology and transportation attitude.

Further research needs to be conducted to investigate the temporal and spatial stability of the proposed. Moreover, to account for the heterogeneity of congestion, alternative traffic measures using trajectories might be examined in future studies.

REFERENCES

1. Akamastu, T., Miyawaki, O., (1995), *Maximum network capacity problem under the transportation equilibrium assignment*, Infrastr Plann Rev, 12, p. 719–729.
2. Asakura, Y., Kashiwadani, M., (1993), *Estimation model of maximum road network capacity with parking constraints and its application*, Infrastr Plann Rev, 11, p. 129–136.

3. Beckmann, M., McGuire, C.B., Winsten, C.B. (1956), *Studies in the Economics of Transportation*, Yale University Press, Yale, CT, USA, 266 p.
4. Bauer, D., Richter, G., Asamer, J., Heilmann, B., Lenz, G., Kölbl, R. (2018), *Quasi-Dynamic Estimation of OD Flows from Traffic Counts Without Prior OD Matrix*, IEEE Trans. Intell. Transp. Syst., 19, p. 2025–2034.
5. Ben-Akiva, M., Bierlaire, M., Koutsopoulos, H., Mishalani, R. (1998), *DynaMIT: A simulation-based system for traffic prediction*, Proceedings of the DACCORD Short Term Forecasting Workshop, Delft, The Netherlands, February, pp. 1–12. Available online: http://www.es.lancs.ac.uk/cres/daccord/workshop.html, last accessed on 24 September 2023.
6. Benenson, I., Martens, K., Rofé, Y., Kwartler, A. (2011), *Public transport versus private car GIS-based estimation of accessibility applied to the Tel Aviv metropolitan area*, Ann. Reg. Sci., 47, p. 499–515.
7. Daganzo, C.F., Geroliminis, N. (2008), *Existence of urban-scale macroscopic fundamental diagrams: some experimental findings*, Transp Res BMeth, 9, p. 759–770.
8. Ford, L.R., Fulkerson, D.R., (1956), *Maximum flow through a network*, Can J Math, 8, p. 399–404.
9. Godfrey, J.W., (1969), *The mechanism of a road network*, Traffic Engineering and Control, 11 (7), p. 323-327.
10. Horni, A., Nagel, K., Axhausen, K.W. (2016), *The Multi-Agent Transport Simulation MATSim*, Ubiquity Press, London, UK.
11. Knoop, V., Hoogendoorn, S., van Lint, J.W.C. (2013), *Impact of traffic dynamics on macroscopic fundamental diagram*, Transportation Research Board, 92nd Annual Meeting, Washington DC, No. 13-0595.
12. Iida, Y., (1972), *Methodology for maximum capacity of road network*, Trans Jpn Soc Civ Eng, 205, p. 147–150.
13. Mahmassani, H.S., Williams, J.C., Herman, R. (1984), *Investigation of network-level traffic flow relationships: some simulation results*, Transportation Research Record: Journal of the Transportation Research Board, No. 971, p. 121-130.
14. Mahmassani, H.S., Williams, J.C., Herman, R. (1987), *Performance of urban traffic networks*, Proceedings of the 10th International Symposium on Transportation and Traffic Theory, Elsevier Science Publishing, p. 1-20.
15. Rodrigue, J.-P. (2020), *The Geography of Transport Systems*, Routledge, New York, 456 p.
16. Smeed, R.J. (1966), *Road capacity of city centres*, Traffic Engineering and Control, 8 (7), p. 455-458.
17. Thomson, J.M. (1967), *Speeds and flows of traffic in central London: 2. Speed-flow relations*, Traffic Engineering and Control, 8 (12), p. 721-725.
18. Wardrop, J.G. (1968), *Journey speed and flow in central urban areas*, Traffic Engineering and Control, 9 (11), p. 528-532.
19. Yang, H., Bell, M.G.H., Meng, Q. (2000), *Modelling the capacity and level of service of urban transportation networks*, Transp Res Part B-Meth, 34(4), p. 255–275.
20. Zahavi, Y. (1972), *Traffic performance evaluation of road networks by the α-relationship*, Parts I and II, Traffic Engineering and Control, 14 (5, 6), p. 228-231, 292-293.