Reducing Traffic Congestion Through Optimal Planning

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Abstract. The increasing mobility has led to unbearable levels of congestion and a deterioration in the quality of life due to its negative externalities. Today, Bucharest city has reached a degree of motorization of about 700 vehicles per 1000 inhabitants and it is constantly growing. Under these conditions, correlated and simultaneous measures are needed to reduce traffic congestion. Among them, it is rigorous planning of trips distribution, modal split and route assignment, and large-scale use of public passenger transport. Rigorous transport studies need to be conducted to determine the current transport demand and to formulate some empirical laws for estimating its evolution. The paper discusses the models for estimating transport demand, as they are of great importance in establishing the capacity of the transport infrastructure, the size of the investments to be made as well as the amortization duration of the invested funds. The paper presents an original case study conducted for a city using a synthetic gravitational model to identify the transport demand and the parameters of travel as well as their influence on transport potentials. This highlights the differences between planning models and their implications in conducting traffic studies.

Keywords: Congestion · Passenger transport · Optimal planning

1 Introduction

Rapidly increasing population induces growing cities and increasing car ownership. Mobility is a fundamental component in all models of spatial structure. Mobility, expressed in circulation/movement, plays a role of particular importance in all the functions of society, being both a condition and a consequence. [1] Spatial mobility is correlated and depends on traffic infrastructure, means of transport, technologies, but also on the connection between urbanism and transport. Consequently, transportation and land use problems become significant issues due to their economical effects. Interaction between land use and transportation is the basic factor for the trip generation. This interaction is also strengthened through planning models. The conventional planning paradigm primarily builds the environment and afterwards tries to overcome the existing transportation problems. Through transport planning models the users' travel needs are identified, the transport demand is estimated, trips are sorted by destinations, arranged by modal choice and after that assigned to links on a transport network. Each of these stages has a decisive role in achieving a quality transport in conditions of maximum

L. Moldovan and A. Gligor (Eds.): Inter-Eng 2021, LNNS 386, pp. 651–660, 2022.
https://doi.org/10.1007/978-3-030-93817-8_58

efficiency and effectiveness. Among these conditions, the travel time must fall within a time frame assumed by the transport operator.

The sharp increase in the degree of motorization has led to congestion in large cities with major implications on the quality of life of residents.

The overarching role of mobility and transportation in modern societies has generated a fast growing field of social-science-based mobilities research. This rising field focuses on large-scale as well as regional movements of people, goods, capital, and information. The cross-fertilization of disciplines and academic traditions in this field brings about strong and innovative approaches concerning the future of cities that integrate the human as well as the systematic and the global scale of current transformations [2].

The current main challenge of any urban system deals with the externalities produced by the road transportation system. It is well-known that about 50% of pollution steams from road transport and, in particular, from internal combustion engines [3]. Within this context, different actions have been deployed in the last few decades to reduce pollution, such as acting on the vehicle technology or different types of fuels, and through different and sophisticated mobility/travel demand management policies or traffic flow control strategies [3].

Although the term congestion is used extremely frequently, it has different interpretations from stakeholders who, with often divergent interests and points of view, interfere on the transportation market. We can name here: *the person in charge of the transport infrastructure development strategy, the infrastructure user, the traffic engineer, the transport beneficiary and the transport economist*. For each of them the notion of congestion has different meanings depending on the degree of involvement in the transportation process [4].

Environmental sustainability entails improvement in the quality of urban environment and reduction of emissions and energy consumption (greenhouse gasses emission variation; pollutant emission variation; impact variation in other sectors). By contrast, social sustainability entails improvement in the quality of life and social equity (e.g., easy access to transportation) and improved safety (e.g., reduction in the frequency of accidents). Finally, economic sustainability entails making mobility of people and goods more efficient and effective and ensuring that the economic benefits produced by the project are greater than the costs [5].

Bucharest ranks 4th in the top of the most congested cities in Europe compiled by the car navigation company TomTom. The company has compiled a report (*TomTom Traffic Index*) showing traffic congestion in 416 cities in 57 countries. In the global ranking, on the first 5 places is the city of Bengaluru (in India), with a congestion index of 71% (the percentage of additional time spent traveling compared to the hours spent outside peak hours) followed by the Philippines capital Manila (71%), the capital of Colombia, Bogota (68%), Mumbai (65%) and the city of Pune (59%) also in India [6].

In the European top, on the first 5 places are Moscow (59%), Istanbul (55%), Kiev (53%), Bucharest (52% compared to 41% in 2015) and St. Petersburg (49%) and on the 14th places, 15th and 17th respectively are Paris (39%), Rome (38%) and London (38%). The level of congestion increased between 2018 and 2019 (in the last report an additional 239 cities were included in the list of congested cities), only a number of 63 cities registered measurable decreases [6].

From the data supplied by the Driving Licenses and Vehicle Registration Directorate of the Ministry of Internal Affairs – DRPCIV, information was obtained regarding the number of vehicles registered in Bucharest. [7] From the analysis of the number of vehicles registered in the period 1990–2019, it is concluded that the evolution was a rapidly increasing one, after a polynomial type function of degree 2, this having the highest correlation coefficient [8].

2 Transport Planning Model

Classic congestion reduction measures focus exclusively on the development of road infrastructure leading to land usage, degradation of the natural landscape, increased risk of accidents (due to increased road width) and attracting new traffic, which will again lead to congestion and the process is cyclical until the expansion of road infrastructure is no longer possible. Thus is described a vicious circle of possibilities to eliminate congestion [9, 10].

Since 2013, the European Commission has developed a guideline for the Development and Implementation of a Sustainable Urban Mobility Plan (SUMP), according to which each urban locality must achieve a SUMP through which to achieve a sustainable urban planning in transport [11].

In the SUMP for Bucharest-Ilfov Region, 2016–2030 it is presented the four stage transport model through which the travel planning in the analyzed region was made (SUMP Bucharest Ilfov, p. 241–278). [12] After the development of the transport model, measures were proposed to reduce congestion and to promote a sustainable urban mobility (good accessibility, safety and security, environment, economic efficiency, quality of the urban environment) but which have not yet shown their usefulness and especially efficiency.

A more recent treatment of urban transport planning is the one based on TOD policies - Transit-Oriented Developments [13]. Today, many cities have developed large financial investments to use, mainly public transport to achieve sustainable mobility. The TOD areas are compact, mixed-use developments that make it easier to walk, bike and use public transport through their urban design. Consequently, they are seen as a way to environmental sustainability by conserving resources and energy, using better use of urban space, reducing the number of kilometers traveled by vehicles and encouraging the use of greener modes of transport [14].

TOD offers many social, environmental, economic benefits but also for health. It is associated with high-density, mixed-use urban development that brings many opportunities closer to residential locations and facilitates the choice of sustainable modes of transport (walking, cycling or using public transport). Therefore, TOD affects travel behavior mainly by increasing choice options and encouraging the use of non-motorized modes of transport. People living in TOD are expected to have a more sustainable, active lifestyle and less dependence on their personal car [15].

The classic transport planning model comprises four main stages (trip generation, trip distribution, modal split and traffic assignment) by which the transport demand is estimated and on its base the public transport supply is designed [16].

Transport modeling and planning are the main tools that can be used to achieve efficient transport in cities [17].

The origin - destination matrix is the result of the second stage of the model. In a transport study this matrix must be rigorously dimensioned, because it represents a transposition of human behavior in the transport process [18]. The matrix provides the total number of trips having the origin zone i (g_i) or the destination zone j (a_j), and the model used seeks to determine the g_i trip distribution by destinations and a_j trip distribution by origins on a certain network [19].

Basically, two methods are used in trip distribution stage [20, 21]:

Growth factor methods (constant factor method, average factor method, Detroit factor method, FRATAR method, FURNESS method).

Synthetic methods using gravity type models or opportunity models.

The model presented below is called *the composed gravity model*, because it starts from estimating the number of internal trips (trips made inside the origin zone) and then the remaining trips (external trips) are distributed to the adjacent zones depending on the distance. So, it is a model that uses as a function of travel impedance the distance between zones, but the travel time or cost of travel also can be used.

The transport flows of the destination zones are determined by the number of jobs, commercial, administrative and other elements that can attract travelers, and the transport potentials of the origin zones by the number of the population that moves.

In finding out the elements of the distribution matrix, it is assumed that the transport flows from the origin and destination zones are known, which define the generated trips, as follows:

$$\begin{aligned} g_1 &= n_{11} + n_{12} + \cdots + n_{1n} \\ g_2 &= n_{21} + n_{22} + \cdots + n_{2n} \\ g_n &= n_{n1} + n_{n2} + \cdots + n_{nn} \end{aligned} \tag{1}$$

respectively the attracted trips:

$$\begin{aligned} a_1 &= n_{11} + n_{21} + \cdots + n_{n1} \\ a_2 &= n_{12} + n_{22} + \cdots + n_{n2} \\ a_n &= n_{1n} + n_{2n} + \cdots + n_{nn} \end{aligned} \tag{2}$$

Graphically, the situation can be represented as in Fig. 1, from where the trips made between all the areas in which the study locality was divided can be identified.

The n_{ij} values can be determined graphically in Fig. 2.

The meanings of the notations in Fig. 1 are as follows:

H_i represents the travel density at the level of the destination zone a_j, measured in trips/km;

h_i - travel density for origin zone's internal trips, trips/km;
$d_{ij\ max}$ - maximum travel distance in the studied area;
d_{ij} - travel distance of interal trips (it is considered that i = j).

Considering that a_j it is determined by the surface of the triangle ABC and n_{ij} (for i = j) by the surface of the trapezoid AEDC, the following relations can be written:

$$H_i = \frac{2 \cdot a_j}{d_{ij\ max}} \tag{3}$$

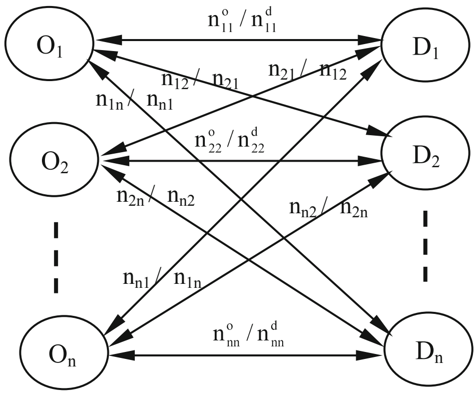

Fig. 1. Geometric interpretation of trips.

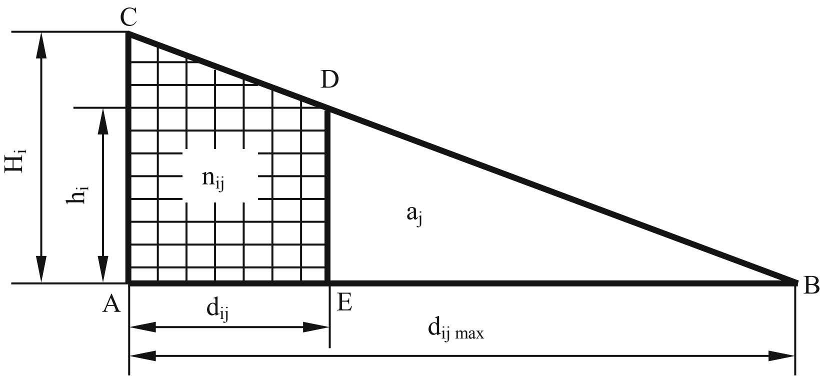

Fig. 2. Geometric interpretation of internal trips

$$h_i = \frac{H_i\left(d_{ij\ max} - d_{ij}\right)}{d_{ij\ max}} \tag{4}$$

$$n_{ij} = \frac{(H_i + h_i)\, d_{ij}}{2} \tag{5}$$

The relation (5) is valid when $i = j$. In order to determine the values of n_{ij}, with the condition $i \neq j$ the following relations are used:

$$\frac{n_{12}}{a_1^{'}} = \frac{g_2^{'}}{d_{12}} \cdot \frac{1}{\frac{g_2^{'}}{d_{12}} + \frac{g_3^{'}}{d_{13}} + \cdots + \frac{g_n^{'}}{d_{1n}}} = \frac{g_2^{'}}{d_{12}} \cdot \frac{1}{A} \tag{6}$$

$$\frac{n_{13}}{a_1^{'}} = \frac{g_3^{'}}{d_{13}} \cdot \frac{1}{\frac{g_2^{'}}{d_{12}} + \frac{g_3^{'}}{d_{13}} + \cdots + \frac{g_n^{'}}{d_{1n}}} = \frac{g_3^{'}}{d_{13}} \cdot \frac{1}{A} \tag{7}$$

$$\frac{n_{1n}}{a_1^{'}} = \frac{g_n^{'}}{d_{1n}} \cdot \frac{1}{A} \tag{8}$$

$$\frac{n_{n\ n-1}}{a'_n} = \frac{g'_{n-1}}{d_{n\ n-1}} \cdot \frac{1}{A_n} \tag{9}$$

where g'_i andi a'_j represents the corrected values of the transport flows.

If the differences between the planned values and those resulting from the matrix are large, then the methods of growth factors are used to correct the values [21].

The indicators can also be calculated with the values from the O-D matrix:

– average travel distance in each zone, $\overline{d}_i$

$$\overline{d}_i = \sqrt{\frac{d^2_{max} g_i}{\sum_{i=1}^{n} g_i}}\ (km) \tag{10}$$

– the average distance traveled in studied area, $\overline{D}$,

$$\overline{D} = \frac{\sum_{i=1}^{n} g_i \overline{d}_i}{\sum_{i=1}^{n} g_i}\ (km) \tag{11}$$

– moment of transport, M,

$$M = \sum_{i=1}^{n} \sum_{j=1}^{n} n_{ij} d_{ij} (cal\,km) \tag{12}$$

3 Case Study

For a city divided into five zones, the transport flows of the origin and destination zones (Table 1), the matrix of distances (Table 2), as well as the maximum distance traveled in the studied area ($d_{ij\ max} = 7$ km) were determined by specific procedures.

It is mentioned that the locality used for the case study is a hypothetical one, the numerical values used being similar to a locality with mixed type areas, considering that trips are made inside the residential areas as well.

The number of trips made between city zones and specific travel indicators must be determined. The values of H_i, h_i şi n_{ij} for $i = j$ are determined using the relations (3), (4) and (5). The results are presented in Table 3.

The transport flow matrix is corrected with the n_{ij} values calculated for $i = j$, using relations:

$$g'_i = g_i - n_{ii} \text{ and } a'_j = a_j - n_{ii} \text{ for } i = j = 1, 2, \ldots, 5. \tag{13}$$

It is obtained the transport flow matrix presented in the Table 4.

To determine the number of trips from i to j, with $i \neq j$, we use the relations (6),…, (10) customized for i = 1, 2,…, 5 and j = 1, 2,…, 5. The results are shown in Table 5.

Table 1. Transport flows

Area	Origin (g_i)	Destination (a_j)
1	900	1100
2	800	700
3	1100	1000
4	700	800
5	1000	900

Table 2. The matrix of distances

d_{ij}	1	2	3	4	5
1	2	3	4	6	3
2	3	1	4	5	6
3	4	4	2	3	5
4	6	5	3	1	2
5	3	6	5	2	2

Table 3. Trips made inside the areas

i	1	2	3	4	5
H_i	314.29	200.00	285.71	228.57	257.14
h_i	224.49	171.43	204.08	195.92	183.67
n_{ij} $(i = j)$	539	186	490	212	441

Table 4. The corrected transport flow matrix with internal trips

i	1	2	3	4	5
g_i'	361	614	610	488	559
a_j'	561	514	510	588	459

Table 5. Primary trips distribution matrix

Dest.	Orig.						
	1	2	3	4	5	Total	g_i
1	539	184	137	73	167	1100	900
2	133	186	170	108	103	700	800
3	89	151	490	160	110	1000	1100
4	53	108	180	212	247	800	700
5	94	80	95	190	441	900	1000
Total	908	709	1072	743	1068	4500	–
a_j	1100	700	1000	800	900	–	4500

It is observed that the sum of the distributed values differs from the values of the generation and attraction flows (exceeding is greater than 20%) which requires corrective iterations for balancing. After each iteration, the correction coefficients C_i (i = 1,2,…, 5) were calculated for each zone and iteration (Table 6). The coefficients were used to multiply the rows/columns of the O-D distribution matrix to obtain the convergence of the solution.

Table 6. Correction coefficients used in iterations

Coefficient	1	2	3	4	5
C_1	1.2114	0.9873	0.9328	1.0767	0.8427
C_2	0.7608	1.1331	1.1247	0.9044	1.1641
C_3	1.1088	0.9971	0.9560	0.9650	0.9667
C_4	0.9534	0.9963	1.0185	1.0204	1.0132
C_5	1.0195	1.0014	0.9921	0.9913	0.9923

The distribution matrix obtained after iteration 4 is shown in Table 7.

Table 7. Distribution matrix obtained after four iterations

Dest.	Orig.						
	1	2	3	4	5	Total	g_i
1	526	132	89	55	98	900	900
2	201	204	172	126	97	800	800
3	137	171	499	189	104	1100	1100
4	65	99	148	203	185	700	700
5	150	93	100	234	423	1000	1000
Total	1079	699	1008	807	907	4500	–
a_j	1100	700	1000	800	900	–	4500

The average travel distance, calculated with relation (10) is shown in Table 8.

The average distance traveled by the entire area, calculated with the relation (11) is 3.1596 km, and the moment of transport is 13176 km.

Table 8. Average travel distance for each zone

	Average travel distance (km)				
Area	1	2	3	4	5
	3.130	2.951	3.461	2.761	3.300

4 Conclusions

In reducing traffic congestion, transport planning models play an important role due to the way in which the generating and attracting potentials of the zones, in the case of the most numerous trips, trips to work, are correlated by the O-D matrix.

A determination and then a correct calibration of the OD matrix are decisive for the next stages (modal split and traffic assignment) because the transport demand will be correctly estimated and in this way the supply, especially the public transport supply will be designed so as to respond to the travel needs of the inhabitants this being a method of reducing traffic congestion.

The paper presents a distribution model that initially determines the number of internal trips (these are important because they can be made on foot or by non-motorized means) and then the remaining trips (external trips) are distributed to other zones depending on the distance. It is mentioned that the value of the distance between the zones is not always the Euclidean distance but the influence of congestion can be included by adding an additional distance between the zones. It is mentioned that the accuracy of the model is consistent with the accuracy of the data entered (distances between zones and generating and attracting potentials of the zones, elements that can not always be known rigorously or changes in socio-economic activities of the city can occur - the most eloquent example is the emergence of the COVID 19 pandemic which radically changed the size and structure of transport demand).

The case study highlighted that the composed gravitational model works well for the distribution of zones' generated trips, and convergence to the generated and attracted traffic values is achieved relatively quickly. For the case study considered, the convergence was achieved in a percentage of 5% after only three iterations and after the fourth convergence was 2%, which attests to the ease of application of the model even for large cities.

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