ACCESSIBILITY OF URBAN PUBLIC TRANSPORT NETWORKS COMPONENT OF SUSTAINABLE DEVELOPMENT

Vasile, DRAGU[1] and Eugenia Alina, ROMAN[2]
[1]University Polithenica of Bucharest, v_dragu@yahoo.com
[2]Metroul S.A., alina.roman@metroul.ro

ABSTRACT: This paper aims to identify the influence of accessibility on sustainable development in transport starting from the necessity of using public transport in urban travel and from the link between accessibility and goods and passengers' social mobility. By means of this case study, the Bucharest mass transit network is topologically characterized and the accessibility of different points of interest is evaluated, in an attempt to establish the satisfaction degree of travel social need and the satisfaction of sustainable development measures. Original expressions were used in determining the accessibility and conclusions were reached regarding the correlations between accessibility and population density in the analyzed areas, which allowed for the evaluation of the quality of the service provided by the Bucharest metro.

1. INTRODUCTION

Sustainable transport is a complex system that must satisfy the mobility needs of present generations without damaging the environment and health factors and that must minimize energy consumption so that it is possible to meet the demand for mobility of future generations [9, 3, 14].

Urban transport development is not a sustainable one. Increasing road traffic in big towns led to unbearable congestion levels for the population and had major implications for social resources consumption and the quality of life in cities. The alarming development of urban road traffic that threatens cities with thrombosis is the main factor behind the increasing external cost of transport and is responsible for the continuous degradation of living conditions in cities. This uncontrolled growth of road transport is mainly caused by private transport in one's personal car.

Personal car travel is considered by users more convenient and comfortable, but in an urban area with intensive land use and high density of activity it is a congestion generator.

Traffic congestion is one of the most irritating problems of modern people, eager to satisfy their need for mobility [11]. It is the price paid for the multiple benefits derived from the concentration of population and economic activities.

Congestion reduction measures must be made public by the media at all levels. From education received in one's family, in school, or information received through the media, to central and local public authorities, all this contributes to increased responsiveness to stakeholders so that public transport in cities should be encouraged at the expense of travel by personal car.

Achieving a sustainable travel behavior will be the result of concerted policies meant to educate and change the mentality, so that one's personal car should no longer be perceived as a symbol of belonging to a certain social class or individuals that have a certain social status.

Encouraging public transport can be achieved through measures of improving transport conditions and through the design / development of public transport networks to provide good accessibility for areas and city residents. The quality of transport services is reflected by routes that satisfy the need for travel, by accesible stations, by connection with regional transport, by a certain frequency, by an appropriate schedule and by easy ways to purchase tickets. The quality of transport services linked to special conditions of comfort define the accessibility and attractiveness of public transport modes.

Modal choice is strongly influenced by place accessibility offered by transport networks when places are visited with high frequency and when there is an important transport and traffic flow. Therefore, the existence of high capacity transport networks is essential for meeting the criteria of sustainable development.

The problem of transport network design / development requires complex examination of traffic flow characteristics, infrastructure, means of transport and operating techniques because they determine transportation system performances and good accessibility.

Expanding networks to ensure a harmonious development of areas and to provide high quality transport services should not be an impediment to sustainable development [9].

Sustainable development of transport networks aims to increase zone accessibility because this is an important attribute both in the transportation system in the system of activities taking place outside the city.

The underground railroad network is a transportation network that meets the requirements of sustainable development. This is a high capacity network where the flow of passengers travels in conditions of safety, security, regularity and lack of congestion.

In this case study, the mass transit network is topologically characterized and the accessibility of different points of interest is evaluated, trying to establish the satisfaction degree of the social need for travel and the satisfaction of sustainable development measures.

2. TRANSPORT NETWORK ACCESSIBILITY

The accessibility feature represents the easiness (commodity) of reaching certain destinations and one of the most important elements in modal choice and sustainable development in transport. The easiness of reaching spatially separated places is evaluated by each person depending on varios subjective and objective factors, the modal choice being the result of a series of tests in which accessibility plays an important role, depending on the propensity of paying for benefits gained at the destination [7].

Accessibility is an indicator that characterizes trips to a certain destination in a specific transport vehicle, at a specific time and a strict route. The characterization is made from the cost and travel time point of view and also by some trip quality indicators (comfort, convenience, security, safety). All these, travel time, cost and trip quality indicators, determine a factor called movement impedance that must be overcome in order to initiate and complete the trip. Accessibility is defined as the reverse of impedance [4, 5, 15].

Each origin/destination pair belonging to a transport network may have, by scope, moment or route, a specific travel time, cost and quality attributes, depending on which one takes a number of trips between the two zones (figure 1).

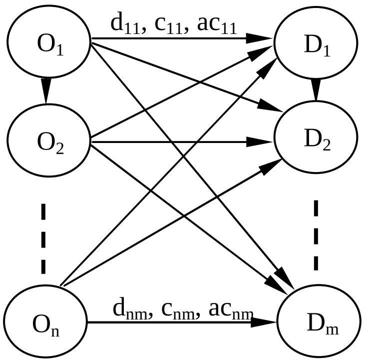

Figure 1. Travel characterization in terms of time, cost and quality indicators

Trips generated between different areas form a transport flow that turns into a traffic flow when it interacts with transport networks, means of transport and specific technologies of modes involved in the transportation process.

Accessibility should be treated differently for points of interest of passengers and goods. So, accessibility for points of interest situated in city centre is strongly influenced by the lack of parking spaces that may discourage many of the trips in one's own car. Finding a parking space and the cost of one strongly influences movement impedance.

In freight transport, the parking problem is different from that of private car parking because the times for supply may be much lower than for cars or a moment in time can be chosen so as to be outside rush hours. In this way, traffic jams because of freight transport is greatly reduced.

Residence accessibility is another problem that arises when making a journey. This occurs at work ending time or at any time people want to return home at peak hours. In this condition, the mathematical model variables are route and modes of travel. In this situation, the size of travel impedance becomes significant, but it must be overcome because it is a journey to be completed within a certain period of time.

The chain of activities performed is shown in Figure 2. Each destination turns each time into a new origin for another journey. At the last journey, the question of residence accessibility comes up (where O1 is the residence).

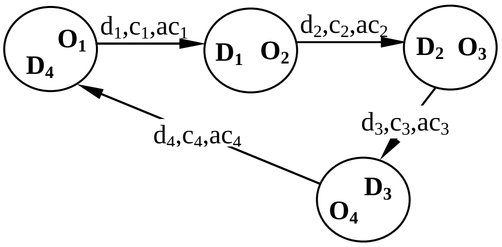

Figure 2. Trips pick-up scheme

The theoretical framework for determining generalized accessibility and the steps that need to be taken for that are presented in figure 3.

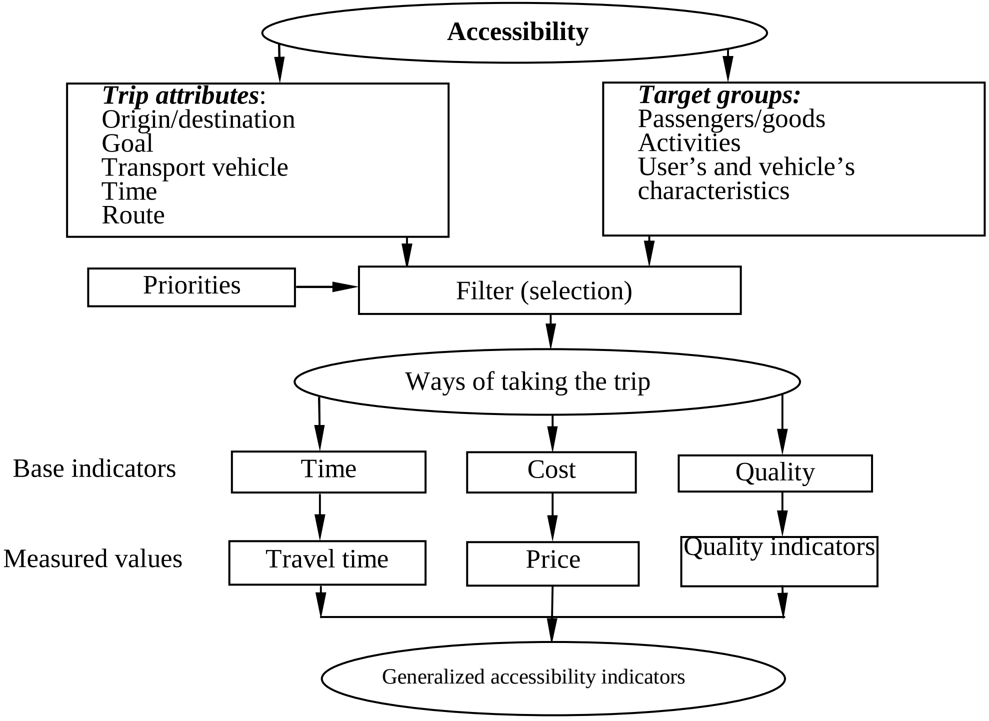

Figure 3. Generalized accessibility indicators (processing after [13])

The transport networks, through their accessibility feature, are said to influence passenger destination in terms of transport demand. Space activities, correlated with transport infrastructure accessibility, and related to the system technology, lead to different degrees of attractiveness of various places on the territory. Attractiveness is important for most "ex-ante" transport demand attributes [10].

Martinez has proposed a new measure of accessibility in accordance with the economic theory [6].

Taking into account that people get benefits from carrying out different activities, it is obvious that spatial location decisions should be correlated with the accessibility factor, depending on the utility function or the production function.

Any individual or business get benefits from undertaking accessible activities (located elsewhere), and are therefore connected to other activities that have the attractiveness property.

This state led to the idea of an accessibility/attractiveness vectorial representation, where accessibility is the benefit obtained directly from trip origins and attractiveness is the benefit gained from activities located in trip destination points.

3. TRANSPORT NETWORKS CHARACTERIZATION

The characterization of transport networks results from the need to ensure transfer of all the traffic flow that turns into transport demand.

Therefore, transport networks can be seen as the offer of the transport system, while traffic flow represents the demand that needs to be satisfied. The interaction between demand and offer is characterized by certain parameters that define the quality of the service.

The quality of the transport service can be quantified in travel time, infrastructure quality, access without discrimination and equal treatment.

A network serving a territory system might be characterized by properties like connexity, connectivity, homogeneity, isotropy and nodality.

Connexity is a topological concept that enables the characterization of links between network nodes. The concept comes from graph theory and in order to characterize transport networks strong and simple connexity is used.

A network has strong connexity if there is a path that connect all nodes and there aren't any isolated nodes. Simple connexity means that there is a path consisting of non-oriented arcs between any of the graph vertices.

Connectivity is also defined in topological terms and it enables the evaluation of the multiplicity of links ensured by the network among its nodes. Connectivity characterization is made through the α, γ and β indices.

The α index is defined as the ratio between the actual number of circuits of the graph associated with the transport network and the maximum number of circuits of the graph that would have the same number of nodes. From this definition it follows that the α index varies between 0 and 1. The index is zero when the network graph doesn't have any circuit and it's 1 when there is a maximum number of circuits.

The γ index measures the importance of direct links between the nodes of the graph, regardless of the indirect links provided by connexity. Adding a direct connection between two network nodes that are already indirectly interrelated leads to a net. That is why the γ index can be considered as an indicator of network graph density. The γ index is defined as the ratio between the number of arcs of the graph associated with the transport network and the maximum possible number of arcs of the graph with the same number of nodes. Like the α index, the γ index also varies between 0 and 1.

The β index is used for estimating the connectivity degree and it is defined as the ratio between the number of arcs and the number of nodes belonging to the analyzed transport network. This index is easier to calculate, but less conclusive for the purpose.

Homogeneity represents the way in which different elements of the territory system depend on one another through the network, regardless of the particular aspects of the connexions affecting space-time correlation. Any transport network has a certain degree of homogeneity of the links provided. The underground railroad network in Bucharest is a homogeneous network in terms of maximum speed and travel times.

Network *isotropy* means that all network connections are equivalent in terms of the relations provided between system elements.

Nodality permits the characterization of network nodes in terms of relational capabilities for the system. If connectivity allows network-wide assessment of the possibilities of establishing direct and alternative links between nodes, then nodality differentiates between system elements according to the relations between them [9]. As with other properties, several nodality indices can be highlighted. In this paper two nodality indices were calculated: generalized nodality and Shimbel nodality.

For defining the generalized nodality index, we are considering the $G'[R]$ non-oriented graph associated with the analyzed transport network and which corresponds to the $\lfloor \rho'_{ij} \rfloor$ matrix. The $\lfloor \rho'_{ij} \rfloor$ matrix elements are:

$$\rho'_{ij} = 1 \text{, if } \rho_{ij} \text{ or } \rho_{ji} = 1 \tag{1}$$

$$\rho'_{ij} = 0 \text{, if } \rho_{ij} \text{ or } \rho_{ji} = 0 \tag{2}$$

Associated matrix M is given. By hyopothesis, it has

$$\rho'_{ij} = 0 \text{ for all } i = j \tag{3}$$

From matrix M, the following can be calculated:

$$N_{1,i} = \sum_{j=0}^{n} \rho'_{ij}, \quad i = 0, n \tag{4}$$

The N_1 nodality vector elements indicate the number of links of node i with all other nodes. The N_1 vector is called direct accessibility vector.

When calculating M^2 and N_2 we obtain indirect accessibility. The M^2 matrix elements show the number of links with two stops between nodes on the matrix raw and column.

Similarly, M^3, N_3,…, M^n, N_n can be calculated.

The Nodality vector allows a hierarchy of nodes without considering the nodes degree.

After performing a number of *p* iterations, all nodes will be connected at least with a *p* degree path. Particularly, the farthest nodes are linked with a *p* degree path. Then the network diameter is equal to *p*.

Summing up the nodality matrices of order 1, 2,…, p, we obtain a nodality matrix where each element indicates the number of relations of all orders between nodes corresponding to that item.

This is the matrix of generalized nodal accessibility, M_g. From this matrix we can get the generalized nodality vector, $N_{g,}$ for all network nodes.

$$\sum_{n=1}^{p} M^{p} = M_{g} \qquad (5)$$

The Shimbel nodality index eliminates the redundancy implied by the model for determining the generalized nodal. The redundancies are explained by the existance of the direct links in network with return in the same node. The successively calculation of matrices amplify this redundancy and the generalized nodality vector puts in the top of hierarchy the privileged nodes of this overall.

To avoid this redundancy, retaining only the shortest paths between nodes, it can be proceed as follows: the matrices P_1, P_2,…, P_n will be calculated from matrices M, M^2,…, $M^{n.}$ To determine matrix P_i from matrix M^i, the place of new items is marked in relation to matrix M^{i-1}. The main diagonal elements are equal to zero. If *i* has the same value as any nonzero element it can not be a part of matrix P_i.

The Shimbel nodality vector doesn't have the meaning of generalized nodal accessibility. Each value of the node is a measure of the links through the shortest paths from that node to all the other nodes of the graph [9].

4. CASE STUDY

The mobility needs of Bucharest residents are satisfied by means of surface public transport (tram, trolleybus, bus) coordinated by RATB and by the subway network coordinated by METROREX.

The paper analyzes the metro network because it is the most important transport network. This represents 4% of the length of the public transport network, but it carries an important flow of passengers (20% from the total number of passengers who use the public transport system). Hence, development proposals should be rigorously analyzed and correlated with the socio-economic development of served areas.

On November 16, 2009 the Bucharest underground reached 30 since the first metro line started operating. The first metro line was 8.1km long, it had 6 stations and it followed the course of the Dâmboviţa river. Today the metro railway measures 66,95 km, it has 4 lines that have 49 stations. The metro railway infrastructure covers an urban area of 305 square km, leading to a network density of 0.22km/km^2.

The first metro section was built using the technology with cover molded enclosure walls, which is based on the idea of using floor coverings, thus creating gallery premises. According to this idea, the roof of the station is molded before other elements of the structure. It is supported by the ground, by molded walls and metal poles. Later, other constructions were made using a drilling shield and prefabricated concrete blocks. From this brief description it can be seen that initially, the underground railway line was not aimed at meeting a social need for traveling, but rather at completing the construction easily. The connexity, connectivity, homogeneity and isotropy properties of the metro line were analized in papers [2, 12, 13, 16]. So, in this case study the nodality property will be analized.

In order to determine the generalized nodality index, matrix M was constituted and the direct accessibility vector, $N_{1,}$ was obtained (Table 1).

Table 1. Matrix and vector of direct accessibility

$$M= \begin{array}{c|cccccccccccc|} & M_1 & M_2 & M_3 & M_4 & M_5 & M_6 & M_7 & M_8 & M_9 & M_{10} & M_{11} & M_{12} \\ M_1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ M_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ M_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ M_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ M_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ M_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ M_7 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ M_8 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ M_9 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\ M_{10} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\ M_{11} & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ M_{12} & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 \end{array} \; ; \quad N_1= \begin{array}{c|c|} M_1 & 1 \\ M_2 & 1 \\ M_3 & 1 \\ M_4 & 1 \\ M_5 & 1 \\ M_6 & 1 \\ M_7 & 3 \\ M_8 & 3 \\ M_9 & 4 \\ M_{10} & 3 \\ M_{11} & 3 \\ M_{12} & 4 \end{array}$$

The 12 nodes of the nowaday underground railroad network are: M_1- 1 Mai, M_2- Preciziei, M_3- Berceni, M_4- Anghel Saligny, M_5- Pantelimon, M_6- Pipera, M_7- Basarab, M_8- Eroilor, M_9- Piaţa Unirii, M_{10}- Dristor, M_{11}- Nicolae Grigorescu, M_{12} – Piaţa Victoriei.

Figure 4 presents the map of Bucharest with the 19 areas for the study of accessibility, on which the underground network was superimposed. This was done using a software specialized for solving transport problems, TransCAD. The meaning of the areas of study and the stations corresponds to the numbering of the districts and stations names that are found in [17].

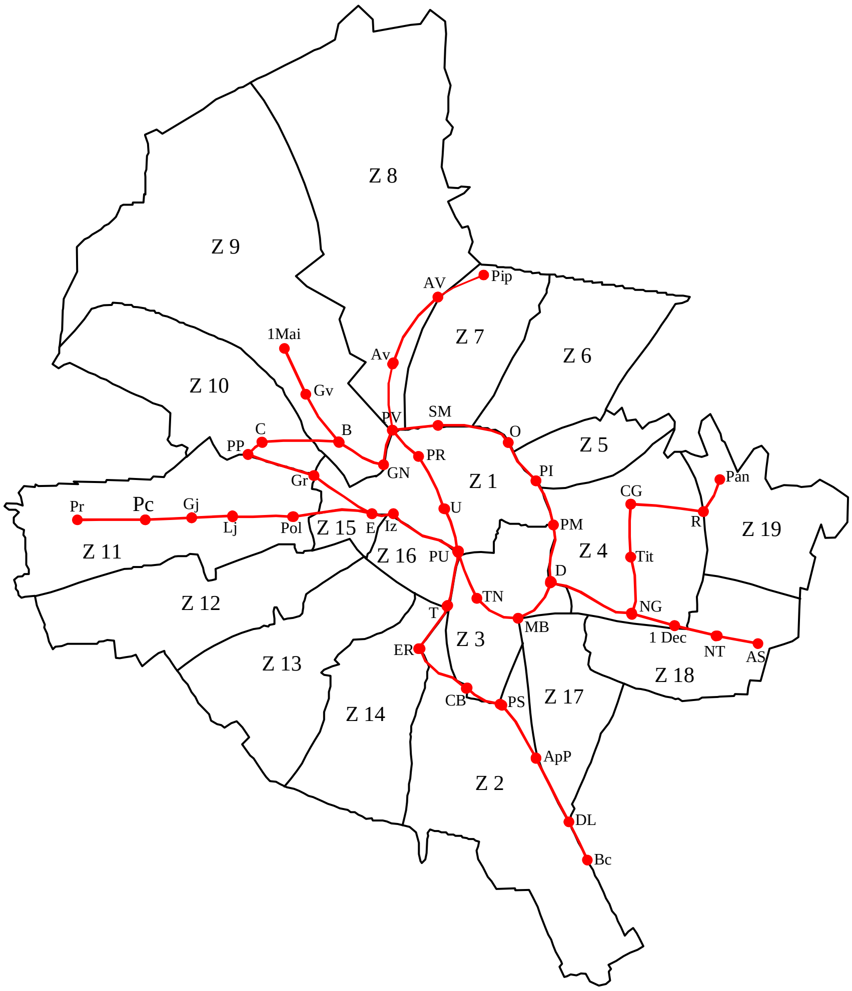

Figure 4. The situation of the metro network in the areas of study

The vector of direct accessibility shows that nodes M9 – Piaţa Unirii and M12 – Piaţa Victoriei have the best direct accessibility (each has 4 links).

If the sum of all direct links (26) is divided by 2, then the number of arcs of the analyzed network results.

Indirect accessibility is obtained by calculating M2 and N2. It is noted that in M2 a M1 – M1 link of second degree already appears, a link M1 – M7 – M1, 3 M7 – M7 links corresponding to relations M7 – M1 – M7, M7 – M12 – M7, M7 – M8 – M7. Redundancies are on the main diagonal of the M2 matrix. When eliminating this redundancy we can see that the best positioned node is M10 – Dristor, because it has the most links composed of two arcs.

Further, the M3, M4 and M5 matrices were calculated and therefore corresponding nodality vectors and vector generalized nodality, Ng, resulted. Their situation is shown in Table 2.

Table 2. The nodality vectors corresponding to the current situation

Node Vector	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	M_{11}	M_{12}
N_1	1	1	1	1	1	1	3	3	4	3	3	4
N_2	3	3	4	3	3	4	8	8	11	11	5	11
N_3	8	8	11	5	5	11	22	22	34	27	17	34
N_4	22	22	34	17	17	34	64	64	94	85	37	94
N_5	64	64	94	37	37	94	180	180	277	225	119	277
N_g	*98*	*98*	*144*	*63*	*63*	*144*	*277*	*277*	*420*	*351*	*181*	*420*

From the analysis of the values presented by the generalized nodality vector, one can notice that there are two nodes on the first position (M_9 – Piaţa Unirii and M_{12} – Piaţa Victoriei), one node on the second position (M_{10} – Dristor) and two nodes on the third position (M_7 – Gara Basarab and M_8 – Eroilor).

The Shimbel nodal vector brings three nodes on the first place (M_9, M_{10} and M_{12}). The Shimbel matrix and vector are presented herein (**table 3.**).

Table 3. The Shimbel matrix and vector for the current situation

$$P_5 = \begin{array}{c|cccccccccccc|}
 & M_1 & M_2 & M_3 & M_4 & M_5 & M_6 & M_7 & M_8 & M_9 & M_{10} & M_{11} & M_{12} \\
M_1 & 0 & 3 & 4 & 5 & 5 & 3 & 1 & 2 & 3 & 3 & 4 & 2 \\
M_2 & 3 & 0 & 3 & 5 & 5 & 4 & 2 & 1 & 2 & 3 & 4 & 3 \\
M_3 & 4 & 3 & 0 & 4 & 4 & 3 & 3 & 2 & 1 & 2 & 3 & 2 \\
M_4 & 5 & 5 & 4 & 0 & 2 & 4 & 4 & 4 & 3 & 2 & 1 & 3 \\
M_5 & 5 & 5 & 4 & 2 & 0 & 4 & 4 & 4 & 3 & 2 & 1 & 3 \\
M_6 & 3 & 4 & 3 & 4 & 4 & 0 & 2 & 3 & 2 & 2 & 3 & 1 \\
M_7 & 1 & 2 & 3 & 4 & 4 & 2 & 0 & 1 & 2 & 2 & 3 & 1 \\
M_8 & 2 & 1 & 2 & 4 & 4 & 3 & 1 & 0 & 1 & 2 & 3 & 2 \\
M_9 & 3 & 2 & 1 & 3 & 3 & 2 & 2 & 1 & 0 & 1 & 2 & 1 \\
M_{10} & 3 & 3 & 2 & 2 & 2 & 2 & 2 & 2 & 1 & 0 & 1 & 1 \\
M_{11} & 4 & 4 & 3 & 1 & 1 & 3 & 3 & 3 & 2 & 1 & 0 & 2 \\
M_{12} & 2 & 3 & 2 & 3 & 3 & 1 & 1 & 2 & 1 & 1 & 2 & 0
\end{array} \; ; \qquad N_s = \left|\begin{array}{c}
\mathit{35} \\ \mathit{35} \\ \mathit{31} \\ \mathit{37} \\ \mathit{37} \\ \mathit{31} \\ \mathit{25} \\ \mathit{25} \\ \boldsymbol{\mathit{21}} \\ \boldsymbol{\mathit{21}} \\ \mathit{27} \\ \boldsymbol{\mathit{21}}
\end{array}\right|$$

Nodal accessibility for the underground network was established for the 2005 and the 2009 network respectively, considering that the network is outlined according to its stations that represent the network poles (40 poles in 2005 and 43 in 2009).

Table 4. shows the accessibility of each zone, calculated as the sum of accessibility for all the poles that are analyzed, when the underground is the only means of transport used for traveling from one point to another.

Table 4. Features of the underground network in each zone

Index Zone	NA	NL	PDA	PIA	FRV	PA 2005	PA 2009
Z 1	29	18	276	226	350	368	403
Z 2	7	4	52	112	70	50	51
Z 3	15	10	143	148	210	188	218
Z 4	16	9	150	142	190	120	173
Z 5	2	1	20	22	20	28	31
Z 6	2	1	20	22	20	27	31
Z 7	3	2	33	50	30	46	50
Z 8	8	4	58	66	80	79	83
Z 9	12	8	82	88	140	112	118
Z 10	6	3	60	66	60	91	91
Z 11	9	5	70	130	90	65	90
Z 12	0	0	0	0	0	0	0
Z 13	0	0	0	0	0	0	0
Z 14	4	2	26	56	40	56	67
Z 15	3	2	28	14	40	34	36
Z 16	8	6	81	44	120	106	117
Z 17	6	4	54	70	80	57	61
Z 18	3	2	28	52	30	0	34
Z 19	3	2	40	44	30	22	28

In Table 4., NA is the number of arcs which originate in the respective pole, NL the number of transport lines that cross the respective pole, PDA the number of directly accessible poles, PIA the number of poles accessible with one transfer, FRV represents the running interval (the number of metro trains that pass through the pole in one hour's time) and PA is the number of poles accessible in 30 minutes.

To establish the above mentioned indicators, usual values in the exploitation of the underground railway network have been used (the running intervals between trains, the duration of the stop at stations and a transfer duration from one line to another of 6 minutes.) [17].

The graph in figure 5 shows the accessibility of the study zones for the development of the 2005 and the 2009 network respectively. From the chart was removed the Z1 zone because, due to very large differences of 2.8 for accessibility to the following areas, this warp chart.

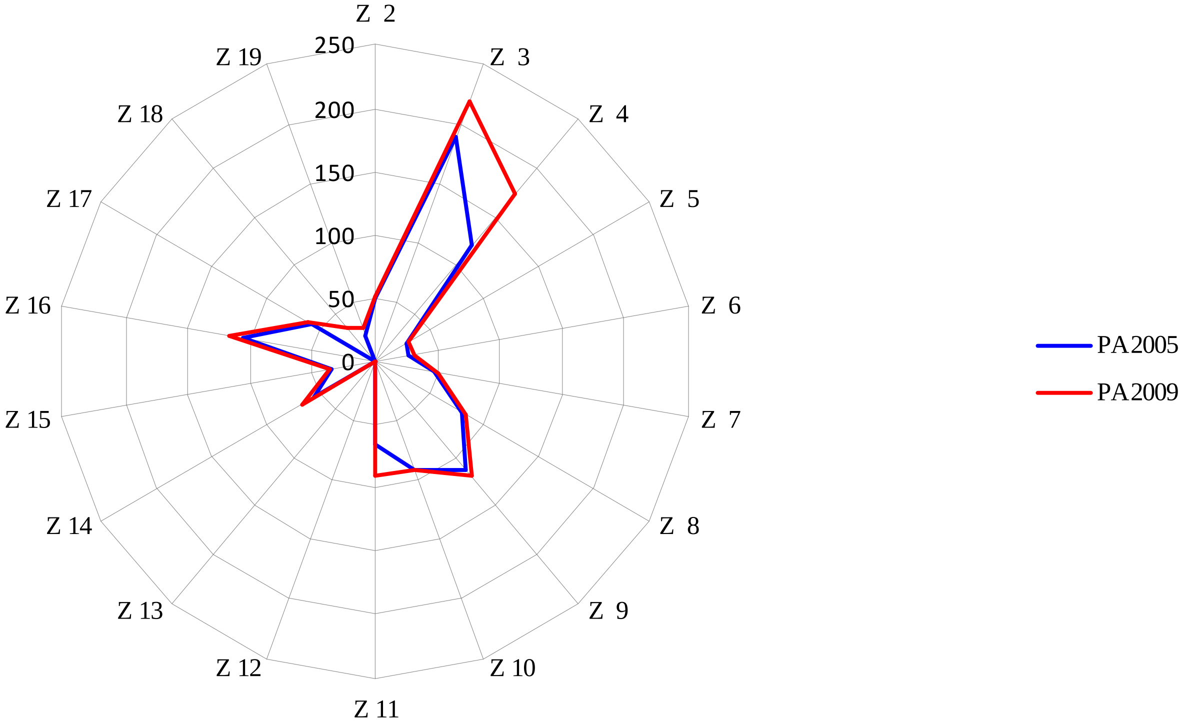

Figure 5. Accessibility of study zones (2005 and 2009)

Table 5 presents demographic information and the characteristics of the underground railway network for the study zones in Bucharest.

Table 5. Demographic information and underground railway network characteristics for the study zones

Zone	**Area [km^2]**	**Population [No. of residents]**	**Population density [residents/km^2]**	**Accessibility**		**Relative variation [%]**
				2005	2009	
Z 1	10,28	131978	12841	368	403	9,51
Z 2	19,67	160426	8155	50	51	2
Z 3	8,76	68727	7845	188	218	15,96
Z 4	13,71	164839	12021	120	173	44,17
Z 5	4,22	43036	10199	28	31	10,72
Z 6	11,32	60225	5318	27	31	14,82
Z 7	9,23	62258	6744	46	50	8,70
Z 8	27,18	321984	11848	79	83	5,10
Z 9	33,90	356651	10522	112	118	5,36
Z 10	13,02	73306	5631	91	91	0
Z 11	16,65	167391	10051	65	90	38,47
Z 12	13,93	92121	6615	0	0	0
Z 13	12,51	51239	4097	0	0	0
Z 14	9,52	54701	5743	56	67	19,64
Z 15	1,37	8648	6300	34	36	5,88
Z 16	2,52	23137	9164	106	117	10,38
Z 17	6,64	31055	4678	57	61	7,02
Z 18	8,85	21912	2476	0	34	-
Z 19	9,55	51712	5414	22	28	27,27
Total Bucharest	232,80	1945343	8356	1449	1682	16,08

The data analysis presented in table 5 shows that the size of the gain in accessibility is as: 0% - 3 areas, 1-10% - 7 areas, 11-20% - 5 areas, over 20% - 4 areas. The average gain for the entire network is approximately 16%.

Adjustment functions and correlation coefficient (R^2) between the number of population respectively density and accessibility for the 19 areas are presented in table 6

Table 6. Adjustment functions and correlation coefficients

Correlation Adjusment functions	Anul 2005		Anul 2009	
	Population Number – Accessibility	**Population Density– Accessibility**	**Population Number – Accessibility**	**Population Density– Accessibility**
Linear	$y = 291{,}43x+80161$ $R^2=0{,}0663$	$y = 21{,}733x+6009$ $R^2=0{,}3955$	$y = 251{,}3x+80141$ $R^2=0{,}0601$	$y = 19{,}655x+5926{,}5$ $R^2=0{,}3948$
Exponential	$y = 52884e^{0{,}0036x}$ $R^2=0{,}1068$	$y = 5692e^{0{,}0029x}$ $R^2=0{,}3328$	$y = 52394e^{0{,}0032x}$ $R^2=0{,}1034$	$y = 5670{,}7e^{0{,}0025x}$ $R^2=0{,}3118$
Parabolic	$y = -2{,}9803x^2+1302{,}5x+$ $+40993$ $R^2=0{,}1742$	$y = -0{,}072x^2+45{,}86x+$ $+5074{,}3$ $R^2=0{,}4615$	$y = -2{,}355x^2+1131x+$ $+40605$ $R^2=0{,}151$	$y = -0{,}0493x^2+$ $+38{,}083x+ 5098{,}2$ $R^2=0{,}4376$
Polynomial of 3 degree	$y = 0{,}0233x^3-14{,}519x^2+$ $+2482x+20744$ $R^2=0{,}2054$	$y = 0{,}001x^3-0{,}5448x^2+$ $+94{,}286x+4243$ $R^2=0{,}5179$	$y = 0{,}0168x^3-11{,}77x^2+$ $+2300{,}2x+13275$ $R^2=0{,}1833$	$y = 0{,}0004x^3-$ $-0{,}2465x^2+$ $+62{,}57x+4526$ $R^2=0{,}4528$

The data analysis presented in table 6 shows that the best adjustment is obtained for the polynomial of degree 3 which has the highest correlation coefficient value, but the quality of corelation is extremely low because the value of coefficients R^2 is small.

5. CONCLUSIONS

Accessibility is a characteristic of transport networks which can influence the modal choice of users. Good accessibility of transport networks, especially when it comes to urban public transport, leads to the selection of the respective mode for movement, with considerable effects on the sustainable development of the transportation system and society.

The use of high capacity public transport networks leads mainly to the reduction of congestion in cities, which results in the increase of transport and life quality, as well as to long-term social development.

When an item of transport infrastructure provides good accessibility to urban zones (and not only), the means of transport that uses that network is likely to be preferred by users when making a modal choice. When the means of transport which is selected for traveling, as a result of choice based on multiple criteria with different degrees of importance, is a means of transport that belongs to the public network it means that we are heading towards the development of a sustainable transport system which will contribute through its qualities to the attainment of that superior stage in social development, that is sustainable development.

From the analysis of the nodality of the underground railway network, one notices that both the generalized nodality and the Shimbel nodality bring on the first two places the same three nodes, M_9 – Piaţa Unirii, M_{12} – Piaţa Victoriei and M_{10} – Dristor (from the Shimbel vector the nodality value for the three nodes is over 37% lower than the average of the whole network). From the analysis of these nodes, one can easily see that they hold central positions, which explains the fact that all the other nodes can be reached with minimum consumption of resources. This also explains the high value of the pieces of real estate in the center of the capital which benefit thus from good accessibility using the underground network. The analysis of zone accessibility in 2009 indicated that the central zone has the best accessibility (403 poles reached in 30minutes), more than 3,5 higher than the network average. This is correlated with zone population density (zone 1 has the biggest density), but not with the number of residents. The analysis performed on the development of the network from 2005 to 2009 has led to the conclusion that in terms of accessibility zone 4 gained the most (over 44%), whereas zone 1 had only 9,5% , which makes it rank only 10th in terms of relative gain. This leads to the conclusion that the central zone has lost some of its accessibility, and therefore we may witness a change in the traveling behavior of the city residents, who may turn to other centers of interest that have become more accessible lately.

The problem that arises, however, is that of the zones which are *defavored* because of the lack of the underground railway network (the north zones, which have grown into residential and commercial centers, the south and south-west highly residential zones) which were not included in the 2009 development either, and remain isolated from the high capacity network.

We estimate that the development of the network at the 2009 moment was made only to complete a work that began before 1989 and not as a result of satisfying the obvious need for traveling of the residents in that area, it being well-known that the industry in the area in which the underground railway network was developed has disappeared almost entirely.

In an attempt to see if there is any correlation between the number, respectively population density and the areas accessibility, we revealed that there is a very poor correlation for the third degree of polynomial function of adjustment. This makes us think that the network is not properly serving large population areas or those with high density.

To sum up, the development of the network must only take place in accordance with the commuting needs of the citizens as they result from the studies whose aim is to identify an ”ex-ante” demand, correlated with urbanistic and territory organization studies, meant to encourage commuting on short distances that one can walk or travel by non motorized means of transport. When this is not possible due to zonal or regional peculiarities, there should be developed a network of urban transport in order to provide good accessibility to the zones with a high density of socio-economic activities [8].

It is thus asserted that cities must never be allowed to grow but to the extent to which they can benefit from public transport in conditions of economic lucrativeness. If this service is oriented towards high capacity public transport as well (underground or tram), then we can assume that the evolution of cities tends towards sustainable development.

BIBLIOGRAPHY

1. *Ben Akiva, M., Lerman, S.R.* Discrete Choice Analysis: Theory and Application to Travel Demand, MIT Press, Cambridge, 1985
2. *Dragu, V., Burciu, Ş.,* Accesibilitatea unei reţele de transport public urban, Conferinţa Cercetarea de excelenţă – Premiză favorabilă pentru dezvoltarea spaţiului românesc de cercetare, Braşov 2006, Vol. II, Editura Printech, Bucureşti, ppL4-13
3. *Fistung, D., et. al* Dezvoltarea durabilă a transporturilor din România – Recomandări pentru strategia naţională de dezvoltare, Grupul român pentru transport durabil, 2002
4. *Handy, S.L., Niemeier, D.A.* Measuring Accessibility: An Exploration of UIssues and Alternatives, Environment and Planning, A 29, 1997, pp. 1175-1194
5. *Mackiewicz, A., Ratajczak, W.* Towards a new definition of topological accesibility, Transportation Research., 30B/ 1, 1996, pp. 47-79
6. *Martinez, F.J.* Access, the economic link in Land Use - Transport interaction, Transportation Research, 29B, 6, 1995, pp. 457-470
7. *Morris, J.M. et al* Accessibility indicators for transport planning, Transportation Research, 13A, 1979, pp. 91-109
8. *O'Sullivan, S., Morrall, J.* Walking Distances to and from Light-Rail Transit Stations, Transportation Research Record 1538, TRB, National Research Council, Washington D.C., 1996
9. *Raicu, S.* Sisteme de transport, Editura AGIR, Bucureşti, 2007
10. *Raicu S.* Transport – urbanism/amenajarea teritoriului, Club metropolitan, anul II, nr. 6, 2010, pp. 8
11. *Raicu S, Popa Mihaela .* Congestia traficului rutier în mediul urban-Nevoia de clarificări, Club metropolitan, anul I, nr. 6, 2010, pp. 12
12. *Raicu, S. et al.* About the high capacity public transport networks territory functions, Urban Transport XV – Urban Transport and the Environment, Editor C.A. Brebbia, WIT Press, ISBN 978-1-84564-190-0, 2009, pp. 41-51
13. *Raicu, S., ş.a.* Asupra unei caracterizări globale a reţelelor infrastructurii destinate transportului public, Conferinţa Capitala în etapa calitativă a modernizării infrastructurii, Bucureşti, 10-11 oct. 2007, pp.137-146
14. *Rojanschi, V., Grigore, F.* Evaluarea integrată a impactului asupra mediului a activităţilor socio-economice, în volumul Conferinţei naţionale pentru dezvoltare durabilă, Bucureşti, 13 iunie 2003, ISBN 973-8449-16-2, pp. 419-426
15. *Stutz, E.J.* Accesibility and the effect of scalar variation on the powered transportation connection matrix, Geogr. Analysis, 5, 1973, pp. 62-66
16. *** Contract de cercetare - Soluţii pentru creşterea atractivităţii transportului public urban. Studiu de caz pentru Bucureşti şi aria metropolitană, PNCDI-AMTRANS – 2004-2006, director de proiect prof.univ.dr.ing. Şerban RAICU
17. *** www.metrorex.ro