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THE INFLUENCE OF BUCHAREST'S METRO NETWORK DEVELOPMENT ON URBAN AREA ACCESSIBILITY

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Abstract
The paper tries to evaluate the influence of the Bucharest metro network development on the urban areas accessibility and to characterize its homogeneity. In the case study the homogeneity index is determined according to which some conclusions regarding the actual metro network situation are drawn. The network poles accessibility was also determined, the quality of service of the inhabitants from the five studied areas being characterized. Some correlations between the accessibility and the population and between the accessibility and the population density were made, some conclusions upon the further network developments being drawn.
Keywords: transport network, topology, homogeneity, accessibility.

1. URBAN NETWORKS

Urban area shows the characteristics of commercial goods whose value is determined by the multiplicity of facilities that it benefits from.

The price arising from the real estate market is an indubitable proof of the way of determination. Often, a square metre area in city centre is more times expensive than in the suburbs, the propensity of paying being determined by the accessibility assured by the different networks of technical infrastructures (transport, telecommunications, commercial and administrative services) (Fujita and Thisse, 1996; Martinez, 1995).

The city concept, as multi-relational networks architecture, is fundamental to planners, no matter their specialization on different networks (transport, water, energy, gas, sewage, telecommunications and commercial networks) and also to land use specialists. Actually, within urban area, the most important place was given to construction works (civil or industrial) with different functions and destinations, utilities networks being subordinated to those (Sheffi, 1985).

Nowadays, the networks have gained specialists' and public opinion attention, by recognizing their importance in irrigating and serving the territory and also by an adequate understanding of location determinism.

The analyze must not stop to its positive aspect. Superposing different networks on the same territory needs frequent readjustments that might lead to less wanted chain reactions within urban area (artworks imposed by the intersections between cable networks and the road ones).

Each facility/service network brings up its own location framework, all infrastructures interaction bringing up a network of centres and also a network of networks. Every structure is conditioned by the others with connections among them determining networks hierarchy.

Every individual network is composed from elements with more or less predictable evolution. They can be observed and treated static or dynamic in concordance with their temporal stability. Although permanent global changes obstruct maintaining a stabile state, urban infrastructure dynamics is relatively low. The infrastructure investment value, their service time and indivisibility brings a certain resistance to change.

Solitary evolution scenarios of the urban networks and the geometrical configuration of the city have favoured a relatively static framework of urban infrastructures.

From the point of view of reaction speed to external actions the networks might be classified as slow, medium and fast adapting networks.

For example, an electric energy distribution network for domestic users implies other resources (financial and time) for extension and modernization than a transport network or an Internet network is faster than a sewage network because of the information flow transfer speed and material ones, respectively.

A distinction among different time scales characterizing the networks must be done. The previous examples took into account large time horizons, networks reconfiguration and structural changes. On short periods, the situations are different. For example, traffic on a road network might rapidly modify, comparable to telephony network diverting.

Cyclically, the city becomes scantier, validating the assertion that life has the propensity of extending, invading and assimilating new territories and environments. From local development centres, commercial or spiritual areas cities have become high accessibility/attractively points – spatially connected by transport networks that have determined the continuous process of activities geographical distribution (Ben Akiva and Lerman, 1985; Rahaman and Hossain, 2009).

Accessibility within a transport network, defined as easiness (commodity) of reaching spatially separated places, represents an icon of individual freedom that nowadays manifests as the multiplicity of movements between origin and destination points. In widely acknowledged that a movement will be achieved only when the benefits gained at destination will overcome transport costs, the so called movement impedance. This can be measured by time, distance, cost and generally resources consumption.

Reducing impedance values is a favourable premise in achieving displacements and leads to increasing zones accessibility within a transport network.

Accessibility is taken into consideration as a topological concept, the location of the network's poles leading to increasing or, on the contrary, decreasing zone's accessibility. This way, they might become less attractive for the movements between them. Locating network's poles on the territory and also within the network (the distance between successive transport lines' stations) is an advantage in the process of selecting network for a trip, in user's try to reduce the cost and time travel.

Network's poles are privileged places for the network itself and also for the entire served territory as central places that have often evolved to CBD (Central Business District) (Handy and Niemeier,1997; Mackiewicz and Ratajczak, 1996; Miller, 1991).

Overlaying different networks and analyzing the degree of coincidence of the poles, one might say that a high level of coincidence is specific to the central area, acting to unify space, poles' dispersion characterizing the tendency of diversification, growth of work diversity.

Actually, accepting the gravitational metaphor, each city area benefits from the proximity of a certain pole. Urban infrastructure and the city development are subject to the action of two forces: aggregation and diffusion. From this relative antinomy equilibrium arises, reflected by the correlation rank/importance – size of the urban areas. When aggregation forces prevail, the situation leads to mono-centric structure, where the highest accessibilities meet for most of the networks.

The transport network, within the multitude and varied technical infrastructure networks, plays an essential role by the implications in the social-economical life of the city. Transport networks are the ones that favor or, on the contrary, stop the trade of goods and passengers. The external effects, specific and obvious for this kind of network, have an influence on transport development between different interest centers. One of nowadays most present effect is urban traffic congestion. This takes supplementary social resources consumption and unpleasant psychical effects on users.

It has became a certitude that urban development must be done in concordance and in correlation with transport networks development so that the city would be served, in all its areas, by high capacity infrastructures (metro or tramway), connections between territory evolution and the networks' one being observed almost everywhere.

A network serving a territory system might be characterized by properties like connexity, connectivity, homogeneity, isotropy and nodality. Connexity, connectivity and nodality properties have been already studied for Bucharest metro network in papers (Dragu and Burciu, 2006; Raicu et al. 2007, Raicu et al. 2009, *** 2004-2006). This paper will deal with the homogeneity property of the metro network in relation with distances (and so travel times).

Homogeneity represents the way that different elements of the territory system depend one on another through the network, no matter the particular aspects of the connexions affecting space-time correlation (Chen and Suen, 2010; Raicu, 2007).

It is characterized by the H(R) index that can be defined for a link, a trip or for the whole network. In this paper, the H(R) index will be determined for the main metro lines and also for the entire network. So, the index measuring the degree of homogeneity of a part or of the entire network is defined as in relation (1).

$$H(R) = \frac{1}{\sigma^2(\frac{d}{v})} = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}[\frac{d}{v} - (\overline{\frac{d}{v}})]^2}, \qquad (1)$$

where $\sigma^2\left(\frac{d}{v}\right)$ represents the dispersion of the chosen attribute (in this case, network's links travel times).

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2. CASE STUDY

In the case study, the homogeneity of the Bucharest metro network was evaluated for 2009 year. This was determined taking into consideration the distance between stations and the travel times for a known speed.

In Table 1 the characteristics of the Bucharest metro network (www.metrorex.ro) are presented and in Table 2 the homogeneity indexes values (H(R)) for the four metro lines and for the entire network are given.

TABLE 1 - BUCHAREST METRO NETWORK

Lines		Length [km]	Number of stations
M1	Pantelimon – Dristor	29,1	22
M2	Berceni – Pipera	18,9	14
M3	Preciziei – Anghel Saligny	15,25	15
M4	Gara de Nord – 1 Mai	3,7	4
Total		**66,95**	**55**
Urban area [km²]		**232,8**	
Network density [km/km²]		**0,29**	

For determining the homogeneity index relation (2) was used.

$$H(R) = \frac{1}{\sigma^2(d)} = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\left[d_i - \bar{d}\right]^2} \qquad (2)$$

TABLE 2 - HOMOGENEITY INDEX

Index / Lines	Length [km]	Number of stations [km]	Minimum distance between stations	Maximum distance between stations	Average distance between stations	$\sum_{i=1}^{n}(d_i - \bar{d})^2$	$\sigma^2(d)$	H(R)
M1	29,10	22	0,7	1,8	1,39	1,70	0,081	12,35
M2	18,90	14	0,9	1,9	1,45	1,12	0,086	11,63
M3	15,25	15	0,9	2,4	1,61	1,95	0,140	7,18
M4	3,70	4	0,7	1,5	1,23	0,28	0,095	10,46
Metro network	66,95	55	0,7	2,4	1,45	5,62	0,110	9,06

From Table 2 we can observe that three metro lines (M1, M2 and M4) have the homogeneity index bigger than the average index of the network and one metro line (M3) has it smaller. M3 line was developed in several phases, in different moments of time and that influenced negatively the homogeneity. The existence of several politics of network development and various construction techniques according to the execution plan can be observed.

Figure 1 illustrates the homogeneity of the four metro lines.

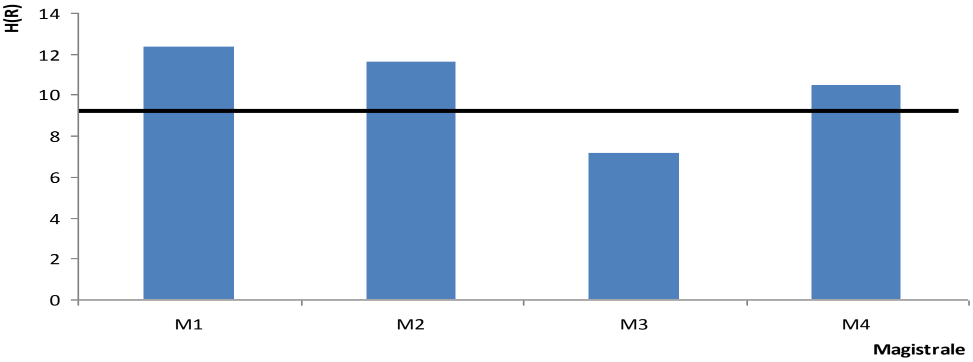

FIGURE 1 - THE HOMOGENEITY OF THE FOUR METRO LINES

Nodal metro network accessibility was determined for 2005 and 2009 years, taking into consideration the poles (stations) of the network (40 poles in 2005 and 43 poles in 2009).

Figure 2 illustrates the metro network in the studied areas and in Table 3 the accessibility of every administrative sector (taking into consideration only the subway transport) is presented.

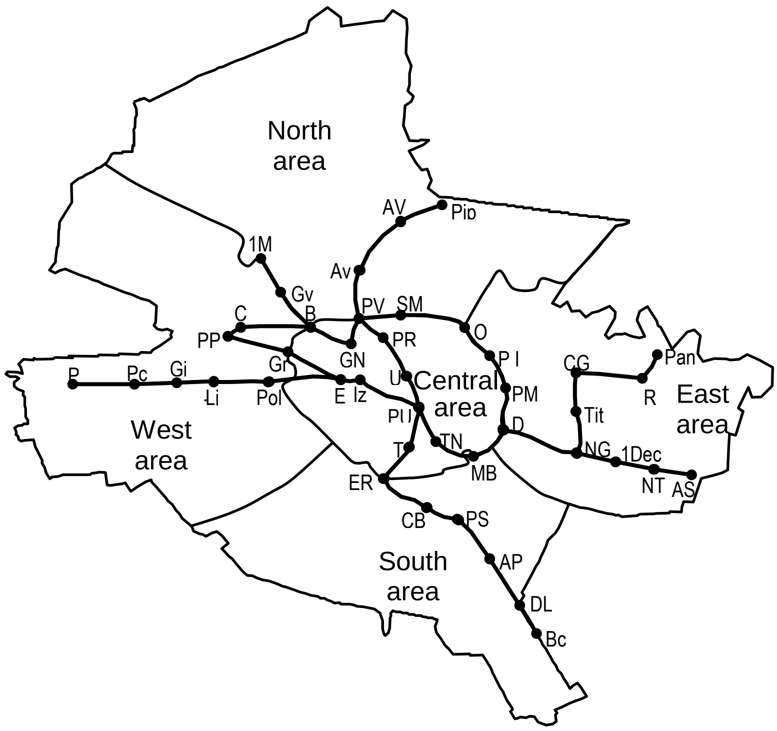

FIGURE 2 - THE METRO NETWORK IN THE STUDIED AREAS

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TABLE 3 - METRO NETWORK CHARACTERISTICS

Pole	Index	Station	NA	NL	PDA	PIA	FRV	PA 2009	PA 2005
1	Central zone	Gara de Nord	2	2	22	20	30	28	28
2		Piaţa Victoriei	4	2	32	10	40	31	31
3		Ştefan cel Mare	2	1	20	22	20	32	28
4		Obor	2	1	20	22	20	31	27
5		Piaţa Iancului	2	1	20	22	20	31	28
6		Piaţa Muncii	2	1	20	22	20	31	25
7		Dristor	3	2	28	14	50	34	28
8		Mihai Bravu	2	2	28	14	40	36	32
9		Eroii Revoluţiei	2	1	13	28	20	31	27
10		Tineretului	2	1	13	28	20	36	29
11		Timpuri Noi	2	2	28	14	40	39	35
12		Piaţa Unirii	4	3	40	2	60	41	39
13		Universitate	2	1	13	28	20	38	30
14		Piaţa Romană	2	1	13	28	20	32	28
15		Izvor	2	2	28	14	40	40	38
16		Eroilor	3	2	28	14	40	36	34
17		Grozăveşti	2	1	20	22	20	32	32
18		Basarab	3	2	22	20	40	28	27
		Total	**43**	**28**	**408**	**344**	**560**	**607**	**546**
19	North Zone	Basarab	3	2	22	20	40	28	27
20		Griviţa	2	1	3	19	20	17	14
21		1_Mai	1	1	3	19	10	14	12
22		Piaţa Victoriei	4	2	32	10	40	31	31
23		Aviatorilor	2	1	13	28	20	27	25
24		Aurel Vlaicu	2	1	13	28	20	25	23
25		Pipera	1	1	13	28	10	18	18
26		Ştefan cel Mare	2	1	20	22	20	32	28
27		Obor	2	1	20	22	20	31	27
		Total	**19**	**11**	**139**	**196**	**200**	**223**	**205**
28	West zone	Preciziei	1	1	14	26	10	10	9
29		Păcii	2	1	14	26	20	14	11
30		Gorjului	2	1	14	26	20	18	13
31		Lujerului	2	1	14	26	20	22	15
32		Politehnica	2	1	14	26	20	26	17
33		Grozăveşti	2	1	20	22	20	32	32
34		Petrache Poenaru	2	1	20	22	20	31	31
35		Crângaşi	2	1	20	22	20	28	28
		Total	**18**	**10**	**152**	**216**	**190**	**209**	**183**
36	South zone	Berceni	1	1	13	28	10	8	8
37		Dimitrie Leonida	2	1	13	28	20	11	11
38		Apărătorii Patriei	2	1	13	28	20	14	14
39		Piaţa Sudului	2	1	13	28	20	18	17
40		C. Brâncoveanu	2	1	13	28	20	24	22
41		Eroii Revoluţiei	2	1	13	28	20	31	27
42		Mihai Bravu	2	2	28	14	40	36	32
		Total	**13**	**8**	**106**	**182**	**150**	**142**	**131**
43	East zone	Anghel Saligny	1	1	14	26	10	15	0
44		Nicolae Teclu	2	1	14	26	20	19	0
45		1_Dec_1918	2	1	14	26	20	23	0
46		N. Grigorescu	3	2	28	14	40	28	22
47		Dristor	3	2	28	14	50	34	28
48		Piaţa Muncii	2	1	20	22	20	31	25
49		Piaţa Iancului	2	1	20	22	20	31	28
50		Obor	2	1	20	22	20	31	27
51		Pantelimon	1	1	20	22	10	13	10
52		Republica	2	1	20	22	20	15	12
53		C. Georgian	2	1	20	22	20	19	15
54		Titan	2	1	20	22	20	23	18
		Total	**24**	**14**	**238**	**260**	**270**	**282**	**185**

For every pole of the network six comparison indexes were considered:

- NA represents the number of links with the origin in the considered pole;
- NL – number of transport lines that traverse the pole;
- PDA – number of direct accessible poles;
- PIA – number of poles accessible with one interchange;
- FRV – circulation frequency;
- PA– number of accessible nodes in 30 minutes.

For determining specified indexes the known values used in the exploitation activity of the metro network were considered:

- I – headway - 6 min;
- t_{st} – time lost per stopping at one station - 30 sec;
- t_m – station to station average travel time - 3 min;
- t_{tr} – transfer time – 6 min.

Travel time maximum accepted limit might have a vast range of answers in relation to trip motivation, context, transport mode service quality, time stability, income, age and some other factors, many being choice subjective. Speciality literature considers a time "budget" daily associated to transportation (Mokhtarian and Chen, 2004; O'Sullivan and Morrall, 1996; Zahavi and Ryan, 1980), restriction an individual can stand (an average of one hour and a half a day, but with a considerable variability). Figure 4 illustrates the accessibility of every pole of the network and figure 5 illustrates the accessibility of every zone at the two analysed moments.

From figure 4 we can conclude that Politehnica station gained the most in accessibility (9 stations), followed by Universitate (8 stations) and Lujerului (7 stations). The least in accessibility gained 9 poles, representing 16,4% from the total number of metro network poles (Gara de Nord, Grozăveşti, Petrache Poenaru, Crângaşi, Piaţa Victoriei, Berceni, Dimitrie Leonida, Apărătorii Patriei, Pipera).

Figure 5 illustrates that the East zone of Bucharest gained the most in accessibility (52,43%) in comparison with 2005 year, while North and South zones gained the least (8,78% and 8,40%). The central zone, that has the biggest population density, only gained 11,17% in accessibility, value situated under the average. North zone, having the biggest surface and the biggest population only gained 8,78% in accessibility. In conclusion, the development of the network must be oriented towards the zones with big population preferably towards the North zone where the congestion on DN 1 is well known.

Figure 6 illustrates the number of links and lines in the five studied zones.

From Figure 6 it can be seen that the most links and lines are in the Central zone (NA=43. NL=28) and the least are in the South zone (NA=13, NL=8).

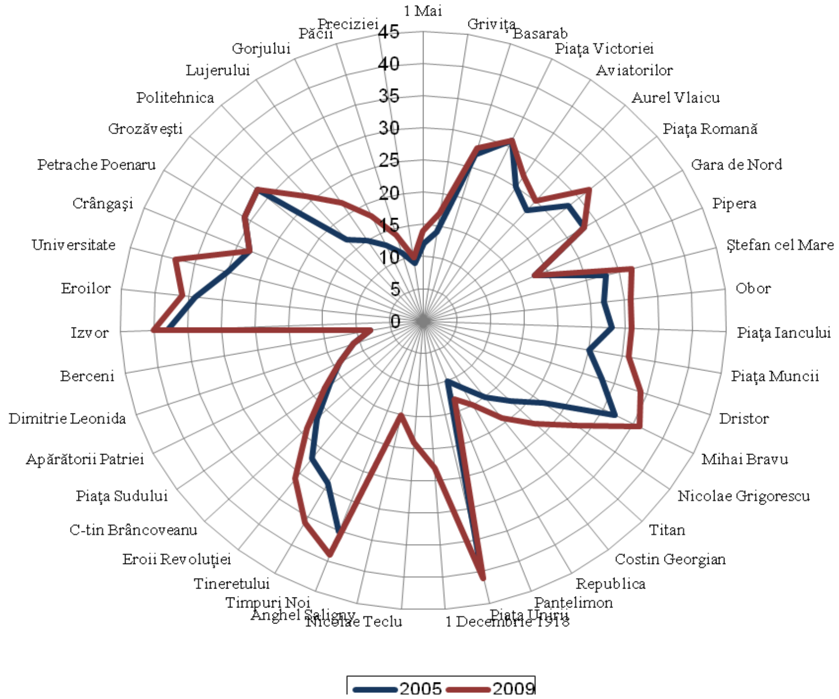

FIGURE 4 - METRO POLES CLASSIFICATION ACCORDING TO ACCESSIBILITY (2005 AND 2009)

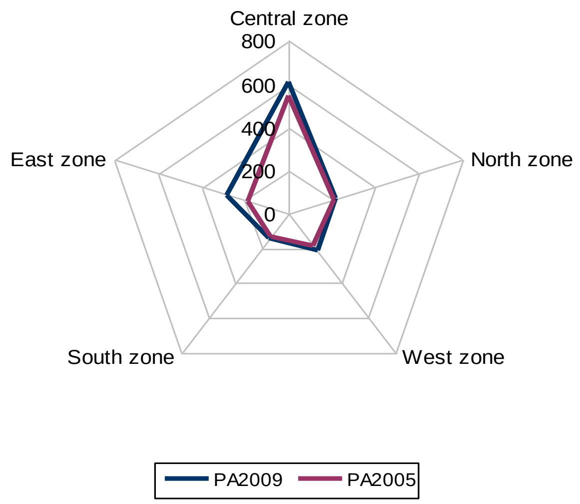

FIGURE 5 - STUDIED ZONES ACCESSIBILITY (2005 AND 2009)

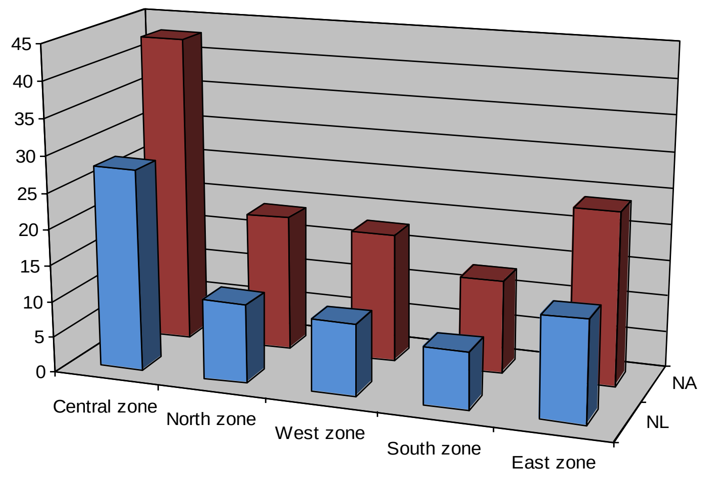

FIGURE 6 - NA AND NL IN THE STUDIED ZONES

Figure 7 illustrates the number of direct accessible poles and the number of poles accessible with one interchange for the studied zones.

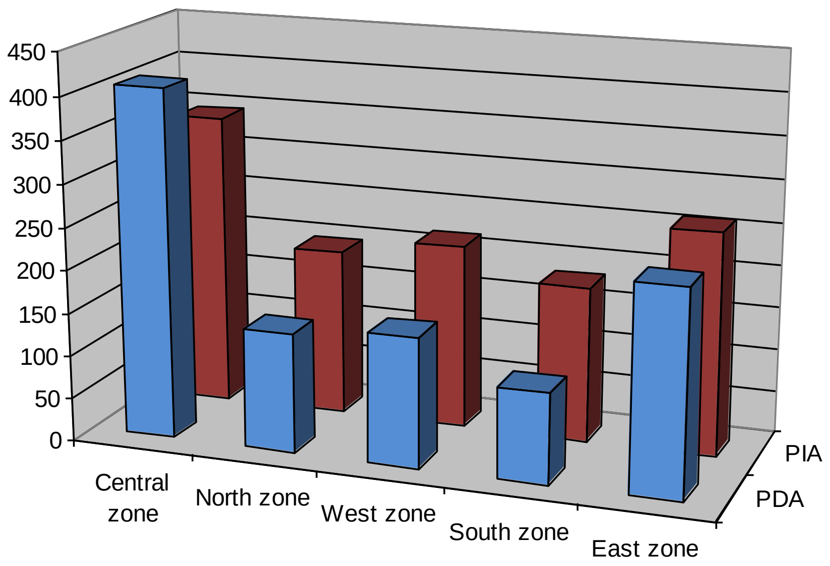

FIGURE 7 - PDA AND PIA IN THE STUDIED ZONES

From Figure 7 it can be seen that the first and the last place are occupied by the same zones from Figure 6, the third place being occupied by the West zone (in Figure 6 the West zone was on forth place).

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In Table 4 demographic characteristics and metro network characteristics are presented for Bucharest studied zones.

TABLE 4 - DEMOGRAPHIC CHARACTERISTICS AND METRO NETWORK CHARACTERISTICS FOR BUCHAREST STUDIED ZONES

Zone	Surface [km²]	Population [loc.]	Population density [loc/km²]	Network density [km/km²]	Accessibility		Relative variation [%]
					2005	2009	
Central	24,40	253861	10404	1,02	546	607	11,17
North	69,38	672213	9689	0,16	205	223	8,78
West	55,90	423178	7570	0,26	183	209	14,21
South	43,36	276349	6373	0,20	131	142	8,40
East	39,76	319743	8042	0,42	185	282	52,43
Total (Bucharest)	232,80	1945343	8356	0,29	1250	1463	17,04

Table 5 illustrates the variation of the accessibility at the two moments of time in comparison with the entire network accessibility.

TABLE 5 - METRO LINES ACCESSIBILITY VARIATION

No.	Line	Length [km]	Number of stations	Accessibility		Relative growth [%]
				PA 2005	PA 2009	
1.	M 1	29,10	22	596	661	10,90
2.	M 2	18,90	14	322	354	9,93
3.	M 3	15,25	15	293	401	36,86
4.	M 4	3,70	4	81	87	7,41
5.	Total	66,95	55	1292	1503	16,33

From Table 5 it can be seen that only one metro line had a growth beyond the average of the network (M3 – Preciziei-Anghel Saligny). The network development in 2009 consisted in the opening of three stations on this metro line. The other metro lines registered accessibility growth between 7 and almost 11%.

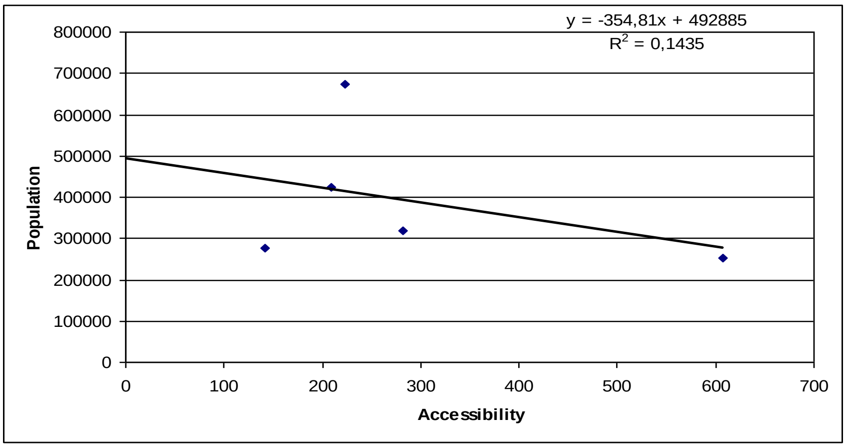

FIGURE 7 - THE CORRELATIONS BETWEEN THE POPULATION AND THE ACCESSIBILITY OF THE FIVE ZONES (2009)

The correlations between the population and respectively the population density and the accessibility of the five zones are presented in Figures 7 and 8.

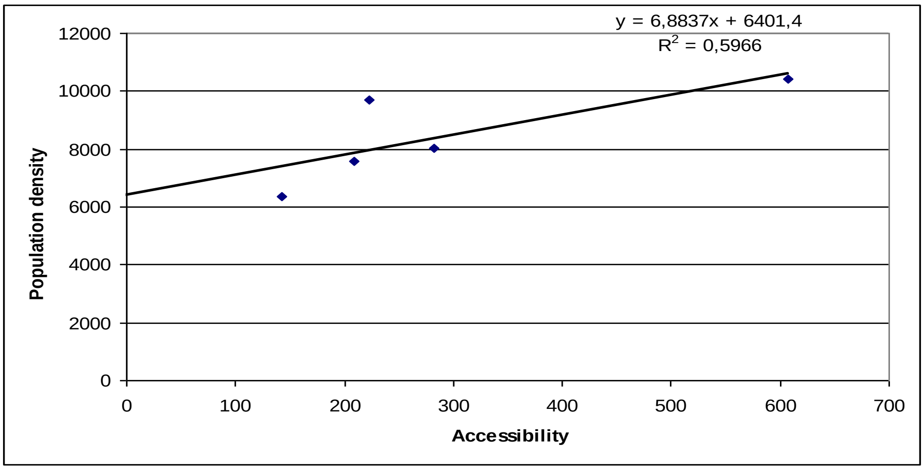

FIGURE 8 - THE CORRELATIONS BETWEEN THE POPULATION DENSITY AND THE ACCESSIBILITY OF THE FIVE ZONES (2009)

3. CONCLUSIONS

By analyzing the H(R) index, that characterizes the homogeneity of the metro lines and of the metro network, it can be concluded that the homogeneity is quite low (values between 7,18 and 12,35), three metro lines (M1, M2 and M3) having H(R) index bigger than the average of the entire network.

The heterogeneity of the network represents a barrier in achieving correlated transport time tables for the four metro lines, so that the transfer time would be minimum.

The first metro line development didn't have as primer goal the satisfaction of the demand, but the easiness of the construction works. Let's remember that the first metro line was made on the Dambovita's right bank using at sight paths. After the excessive industrialization and taking into consideration the development of construction techniques and population growth, the problem of satisfying the demand appeared and the metro lines were designed to connect the periphery with the centre of the city.

From accessibility point of view it can be observed that the development of the metro network in 2009 didn't modify the hierarchy of the nodes, the first places being occupied by Piaţa Unirii, Izvor and Timpuri Noi but the hierarchy of the zones modified. In 2005 the Central zone and the North zone were on the first two places, while in 2009 the Central zone and the East zone occupy the first two places (the stations developed in 2005-2009 are in the East zone).

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The new line was finalized only because the project and work had been already started and had to be brought to an end. There is no real transport demand in that zone. Further more, the heavy industry (Pharmacy Plant, Glass Plant, Policolor, Chemical Plant, RATB dockyard and garage) reduced its activity.

Analyzing accessibility – population correlation (Figure 7) the reduced value of R^2 shows that there is no correlation. Analyzing accessibility – population density correlation (Figure 8) with R^2= 0.596 shows that there is a good correlation those two.

In conclusion, according to the accessibility values, the metro network must be developed in particular in the South zone, and after that in the West and North zones for facilitating the access to the new developed residential areas, to the airports and especially for respecting the assertion that the city must be developed only if the high-capacity public transport is developed.

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