EVALUATION OF PUBLIC SERVICE NETWORKS EFFICIENCY AND ACCESSIBILITY LEVELS IN URBAN AREAS.

FOTINI ATHANASIOU[1], YORGOS N. PHOTIS[2]

[1]PhD Candidate, Department of Urban Planning and Regional Development, University of Thessaly, Greece

[2] Assistant Professor, Department of Urban Planning and Regional Development, University of Thessaly, Greece

Abstract

Trips in urban areas from residence to different activities constitute a large amount of daily transportations. The study of these trips and especially those towards public sector services and by public transportation means is essential in order to evaluate the effectiveness of public networks planning. In this paper, both public services and public buses networks are studied in a joint framework in order to evaluate their spatial allocation association which reflects effective service of citizens' daily trips. The proposed methodology utilizes GIS technology and spatial analysis methods and is applied to the city of Volos (Greece). In this framework, population of each building block is assigned to the closest bus stop (destination) while each bus stop (origin) is assigned to its closest public facility. Different service areas are defined for each station and public service and the proximity of all building blocks is calculated. Further processing of the resulting information leads to the quantification of the spatial relationship between demand (population) and supply (public services and bus stops) and therefore, to the evaluation of the efficiency and effectiveness levels of public networks in urban areas.

Keywords: public services, public bus network, service area, demand-supply

INTRODUCTION

Social prosperity largely depends on spatial structure, a relation which becomes stronger in urban areas where the quality of life is menaced by several factors. Traffic, over-building, lack of open space and deficient location of services come to the fore. The latter reflects access inequality and is one of the main reasons for everyday movement difficulties of citizens. Particularly, public services, as part of the public sector, are considered to be driven by the principle of social well-fare. The location of these services and the provision of an adequate transportation infrastructure, is the essence of urban planning. More specifically, the transportation system has a great influence and impact on regional patterns of development, economic viability, environmental impacts, and on maintaining socially acceptable levels of quality of life (Murray, 1998).

Interest increases in the case of public service systems which should be designed aiming to social well-fare. Accessibility has been discussed in geographic contexts from a number of perspectives (Kwan 1998). According to Tallen (2002) access "defined as the quality of having interaction with, or passage to, a particular good service or facility" (Talen, 2002: 259) emerges as a central priority in the planning process by improving citizen's daily mobility and providing equity in access. Daily trips from residence to various services inside urban areas constitute a large amount of movement realized in cities. These trips include several means like private means but also public means as a part of organized networks. In this paper public transportation networks (buses) are studied through its efficiency in relation with citizens' daily trips. Since a public buses network is a part of public sector its efficiency is analyzed in relation with public services network.

As a response to the above the main aim of the proposed methodological framework is the evaluation of the locational effectiveness of public services networks by analyzing the conceptual triangle people – transport system- facilities. The study area is the city of Volos (Greece) and the proposed methodology consists of two main phases of procedures implemented on a GIS. In the first phase an aspect of the efficiency of bus stops network results by the creation of service areas in different walking distances where a part of population and public services fall inside. Percentage of populated points (junctions) and percentage of public services intersecting service areas are a measure of public bus network evaluation and an important element of the final evaluation image. In the second phase, population and public services locations are assigned to their closest bus stops (according to walking distance) and a clustering of results is created in order to group bus stops according to services and population percentages assigned to each one. The final step includes the creation of a triangle for each bus stop formed by the centroid of its assigned services, the spatial mean of its assigned populated junctions and the location of bus station. The area of this triangle as well as a quotient of its sides is studied in combination in order to lead in useful conclusions for buses network evaluation.

1. PUBLIC SERVICE PLANNING

Services and facilities location is a primary issue in every initiative of human-centered planning. Especially when this issue concerns exclusively the public sector and the location of its services, the locational planning is called to choose the best solution having as principle a positive impact in the society. Furthermore, suitable location of public services and sufficient accessibility constitutes one of the fundamental parts of the environment (in the sense of the surroundings) which determine the quality of life (Van Kamp et al., 2003:13). In this respect, spatial accessibility is a crucial consideration in the provision of services, both public and private.

In a similar manner, transportation planning can be considered as a key element in the evolution and growth of metropolitan regions. Such planning must take into consideration trip purpose, temporal and spatial distributions of trips, modal splits of travel, and costs (Meyer and Miller, 1984). In public transit planning, accessibility is comprised of access and geographic coverage. Access is important because it is the process associated with getting to and departing from the service. Such access is typically perceived of in spatial terms as the physical proximity to transit stops or stations (Murray and Wu, 2003).

In a locational planning framework of services, the critical problem parameters are **geographical proximity**, **spatial coverage** and **diachronic**

efficiency. The term geographical proximity refers to the distance between services and served population. Since access can be conceived as the opportunity for system use based upon proximity to the service and its cost, if the distances or barriers to access a service are too great at either the trip origin or destination, then it is unlikely to be utilized as a mode of travel. Accessibility in this respect, is the suitability of the public transport network to get individuals from their system entry point to their system exit location in a reasonable amount of time.

Accordingly, the issue of spatial coverage is particularly important in the case of public sector services which are supposed to function beyond profit and have equity as their central network design principle. The terms of geographical proximity and spatial coverage are two of the basic parameters forming the concept of accessibility since "accessibility is determined by the spatial distribution of potential destinations, the ease of reaching each destination…" (Handy et al., 1997: 1175). The diachronic efficiency of proposed solutions remains a key point to the process since it is often translated to the spatial restructuring of the system.

1.1. SPATIAL ANALYSIS

Spatial analysis focuses on the study of spatial phenomena and processes seeking the cause-effect relation behind every change or stagnancy in space. In this respect, the main issues studied in spatial analysis are **Location** and **Spatial Organization.** Location is basically related with the existing geographical distribution of phenomena, activities, facilities or populations while spatial organization constitutes the relational study of more than one objects seeking the explanation of spatial structure. Thus "Spatial Analysis focuses on the phenomena location and distribution, the relations between humans and goods, the supply-function between regions, the spatial arrangements, the spatial structure and organization as well as the evolution of space" (Koutsopoulos, 1990:7).

Different spatial analysis methods are focusing in different stages of the process. One of these is the exploitation of information from a set of statistical characteristics by multivariable methods such as **factor** and **cluster analysis**. Their basic difference lays on the fact "whereas factor analysis works by searching for similar *variables*, cluster analysis has as its objective the grouping together of similar *observations*" (Rogerson, 2001:197).

Cluster analysis comprises methods attempting to group observations in order to create groups with minimum within-group variance and maximum between-group variation. These methods are furthermore discriminated in agglomerative or hierarchical and nonagglomerative or nonhierarchical (Rogerson, 2001:200). In this paper, **K-Means cluster analysis,** a nonhierarchical method, is used to group observations on accessibility. This method is also known as "nearest centroid sorting pass" or "reassignment pass" (Aldenderfer et al, 1984:47).

1.4. GEOGRAPHIC INFORMATION SYSTEMS

The possibilities provided by Geographic Information Systems (GIS) are henceforth recognized in the majority of scientific sectors and particular in the frame of locational planning where the whole process has radically changed. The combination of a rich descriptive database with objects completely determined respecting their spatial attributes constitutes one from the basic advantages of GIS. Particularly interesting is in deed the possibility provided with regard to the "representation of certain aspects of the 'real' world by digital means… where it provides an environment for queries and experimentation which would be expensive or impractical to perform in reality" (Martin, 1991: 161).

Moreover, it is possible to realize complex searches of objects according to logical functions that combine more than one criterion. Also, very important is the possibility for the placement of facilities or activities on the map with the method of **Geocoding**. Basically it is a "process of connection of databases containing conventional location elements (address, kilometric place, etc) with map elements (points, arcs, polygons)" (Pappas, 1998: B-41). In the end of this process a digital background is produced with points representing the geocoded facilities providing thus a complete picture of space.

Finally, it should be pointed out the catalytic role of GIS in the **mapping** of space. The possibility provided by GIS for mapping of results produced by complex searches, creations of links between files that increase the size of information included in a database and abundance of other processes has changed the frame in which cartography is moving. Despite that, the introduction of GIS in the sciences of space "does not necessarily eclipse the role of cartography in the visualization of spatial knowledge but, as a means of storing, managing and analyzing that knowledge, a GIS provides immense benefits when compared to the analogue technology of conventional maps" (Jones, 1997:4). Indeed, the production of thematic maps with GIS constitutes a useful tool in the territorial analysis providing plenty of elements and correlations between them that help in the deeper analysis and finally knowledge of processes formulating space. The suggested methodological framework of this paper benefits from the GIS advantages and is fully described in the next chapter.

2. METHODOLOGY

The proposed methodology in this paper comprises two major phases of analyzing procedures. In the first phase, service areas within different walking distances from bus stops were created resulting in the calculation of services and population percentages inside these areas. The second phase deals with the procedures applied to find the closest bus stop for each service and junction of the street network. The centroid of these services, the spatial mean of junctions and the location of the corresponding bus stop are forming a triangle which is studied regarding its area and sides leading in useful conclusions.

2.1. SERVICE AREAS OF BUS STOPS

The first phase of the methodological framework includes three stages. The first includes the database creation where public services, population data and bus stops should be registered as point features over a street network with network junctions. The next stage includes the procedures implemented on a GIS like the creation of service areas around bus stops for different service distances. The clustering procedure using K-Means cluster analysis and the creation of pivot tables for the results of the previous stage are the elements of the third stage.

2.2. CLOSEST BUS STOP TO FEATURES

This methodological phase constitutes of two major stages. The first stage comprises the procedures leading to the detection of the closest bus stop from each service and population junction by the use of GIS capabilities. In the second stage, the results of these procedures are aggregated and the spatial mean of population junctions and the centroid of services having the same closest station are calculated. These points along with the location of the corresponding bus stop are forming a triangle for each bus stop which by the calculation of its area constitutes a definitive element for the evaluation of bus stop location. In order to proceed in a complete analysis of studied networks, a quotient of triangle sides is created and along with triangle area results in useful conclusions regarding the evaluation of the current public bus and services network.

3. APPLICATION

The proposed methodology is applied in the major part of Volos municipality. The municipality of Nea Ionia as well as the settlements of Alykes and Agios Stefanos were excluded.

3.1.1 DATABASE

Public services, street network, building blocks and bus stops digital maps were obtained from the *Laboratory of Spatial Analysis, GIS and Thematic Cartography*. Public services comprise services from sectors like education, healthcare – provision (including squares and public playgrounds), athletics and general services. The services studied in this paper are shown in Table 1:

Education	Heathcare Provision	Athletics	General Services
Nursery school	Hospital	National & Municipal Stadiums	Police Department
Primary school	Municipal health centers	Gymnasium	Fire Department
Lower secondary school	Public day nurseries	Swimming pools & relative	Courts
Upper secondary school	Centers of elderly restitution	Athletic Centers	Public Economic Service
University	Youth centers	Fields	Forest authorities
	Squares		Post offices
	Public Playgrounds		

Table 1. Public services by sector

The street network digital map is converted, using ArcGIS Network Analyst, in a Network Dataset with a network topology necessary for two basic actions: a. the drawing of routes between points in the case of service area and closest facility procedure and b. the creation of network junctions where the population per building block should be assigned. Since different distances calculated in this application are walking distances between bus stops and residence (populated junctions around building blocks) or public services, the directions of circulation have not been taken into account.

The population data are included in the building blocks digital map (population per building block) and accrues from the 1991 census. The need to produce the demand (population) points on the street network leads to the application of a freeware (Polynet 1.0) created in the *Laboratory of Spatial Analysis, GIS and Thematic Cartography* which uses an algorithm to assign the population of building blocks to its surrounding junctions of the street network.

Finally bus stops digital map results from the initial map which illustrates bus stops on the edges of building blocks. After the projection of initial points on the street network, a number of bus stops are excluded. In especial bus stops which have over against another bus stop in the opposite direction of circulation are excluded since both their projection on the street network would finally resulted in one single point.

Study points as resulted from the procedures above are illustrated in Fig. 1:

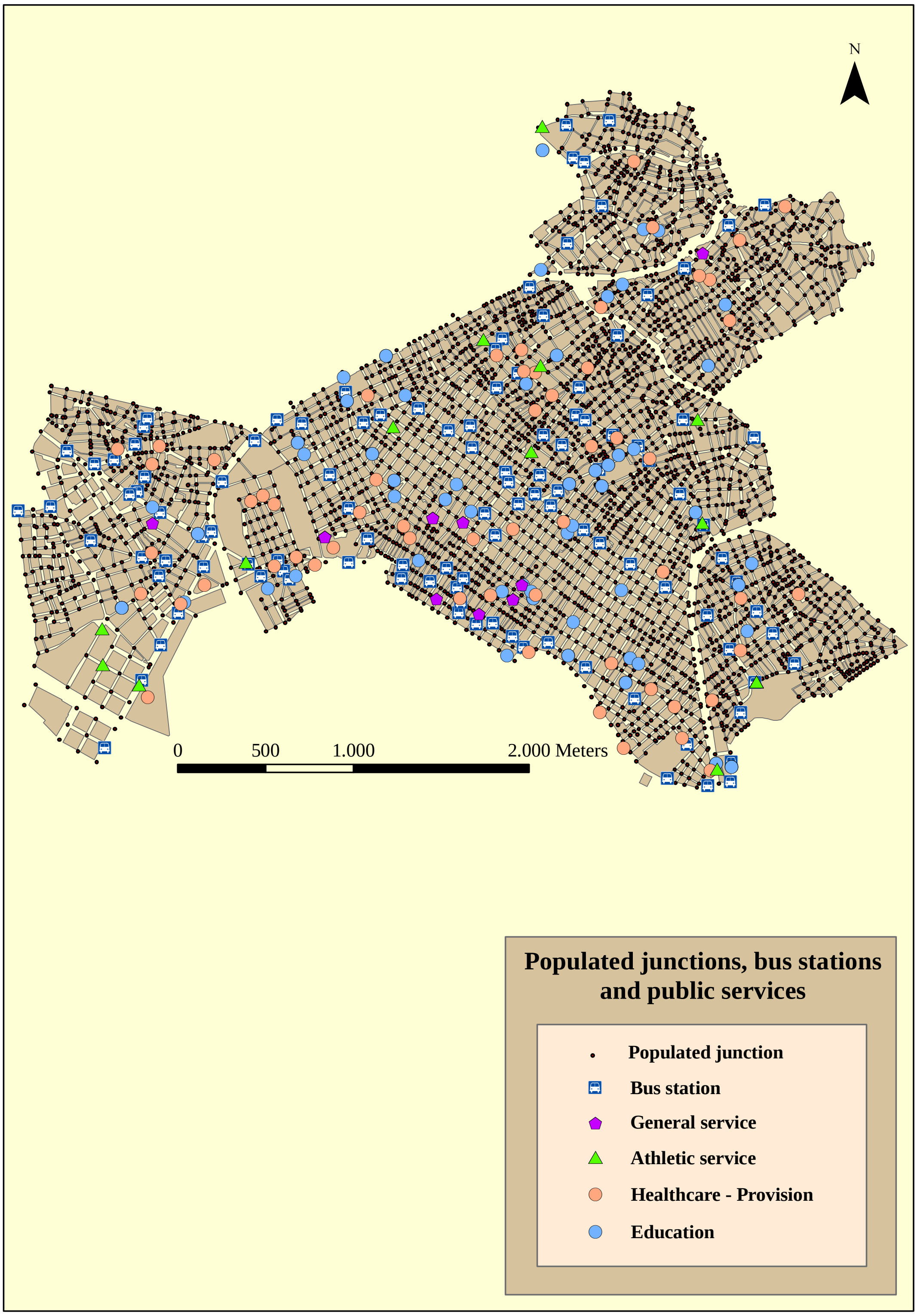

Figure 1. Populated junctions, bus stops and public services in the study area

3.1.2. SERVICE AREAS FOR BUS STOPS

The starting point to gain a first image of the efficiency of bus stops network is to create service areas in different walking distances where a part of population and public services fall inside. In this way the percentage of population and public services intersecting service areas can be a measure of public bus network evaluation.

Different distances for service areas are selected according to the standard accepted walking distance in urban areas which is 400 meters. To find out how the deflection from this standard distance influence the features intersecting the corresponding service areas two more distances, 300 m. and 500 m., are used to produce two additional service areas.

The procedure to create service areas is applied using ArcGIS Network Analyst extension where three service areas result for every bus station: a. service area A within 300 m., b. service area B within 400 m. and c. service area C within 500 m. By taking advantage of GIS potentials, the count of public services and populated junctions falling inside the service areas are calculated for each bus stop as well as percentages of public services and population. Different groups of these percentages are created applying the method of Natural breaks (Jenks) in Arc GIS for each service area and percentages of bus stops belonging to these groups are calculated. Bus stops percentages for each group in service areas A are shown in Table 2:

Percentages of bus stations	Percentages of population			
Percentages of public services	0 - 1,4%	1,5% - 2,7%	2,8% - 4,2%	Total
0 - 1,6%	29%	10%	15%	53%
1,7% - 3,8%	15%	14%	13%	42%
3,9% - 8,2%	0%	3%	3%	5%
Total	43%	26%	30%	100%

Table 2. Bus stops percentages for service area A by population and public services percentage groups

The majority of bus stops presents low percentages both of population and services (29%, 53% and 43% as aggregated percentages) inside service area within 300 m. in the same time that minority has the highest aggregated percentage of public services (5%). Since the distance of

300 m. applied in service areas A is lower than the standard maximum walking distance (400 m.), service areas B within 400 m. are created and the aggregated results are shown in Table 3:

Percentages of bus stations	Percentages of population			
Percentages of public services	**0 - 2,5%**	**2,6% - 4,7%**	**4,8% - 7,1%**	**Total**
0 - 2,2%	21%	7%	8%	36%
2,3% - 5,4%	21%	18%	12%	51%
5,5% - 10,3%	1%	6%	6%	13%
Total	43%	31%	26%	100%

Table 3. Bus stops percentages for service area B by population and public services percentage groups

In Table 3 the highest proportion of bus stops presents low population percentage and low and medium percentages of services (21%) while the highest aggregated percentages of bus stops (51% and 43%) have correspondingly medium percentages of public services and still low population. A comparison between the results of Tables 2 and 3 reveals an augmentation of services percentages around the majority of bus stops (53% and 51% correspondingly) from low percentages (1,7% - 3,8%) to medium percentages (2,3% - 5,4%) while population percentages remain always the lowest (0 – 1,4% and 0 – 2,5%). This fact calls for the creation of another service area within a highest distance like 500 m. in order to follow up mainly the change in the population percentages around the majority of bus stops. The results from the creation of service areas C around bus stops are illustrated in Table 4:

Percentages of bus stations	Percentages of population			
Percentages of public services	**0 - 3,4%**	**3,5% - 6,9%**	**7% - 11,1%**	**Total**
0 - 3,8%	18%	11%	6%	36%
3,9% - 7,1%	12%	14%	9%	35%
7,2% - 12%	4%	12%	13%	30%
Total	35%	37%	28%	100%

Table 4. Bus stops percentages for service area C by population and public services percentage groups

As shown in Table 4, the highest bus stops percentage (18%) presents low population and services percentages as in Tables 2 and 3. At the same time the highest aggregated percentage of bus stops (37%) belongs for the first time to the medium population percentages group (3,5% - 6,9%).

3.1.3. CLUSTERING FOR SERVICE AREAS AROUND BUS STOPS

The need to gain a more concise image of the results presented in Tables 2, 3 and 4, a clustering procedure using K-Means method is applied for the two variables (population percentage and services percentage) in each service area (A, B and C). The number of clusters (three clusters) is predetermined and clusters centers for each variable as well as the aggregated cluster membership of bus stops are presented in Table 5:

		Clusters centers		
		1	2	3
service area A	population percentage	**0,8%**	**2,5%**	**2,8%**
	services percentage	**0,9%**	**2,2%**	**5,5%**
	bus stations percentage	36%	59%	5%
service area B	population percentage	**1,6%**	**4,6%**	**5,3%**
	services percentage	**2,3%**	**7,0%**	**3,1%**
	bus stations percentage	50%	18%	32%
service area C	population percentage	**2,7%**	**6,2%**	**9,5%**
	services percentage	**3,5%**	**8,5%**	**5,8%**
	bus stations percentage	50%	29%	21%

Table 5. Clusters centers and bus stops cluster membership (in percentage) for each service area

The clustering procedure for service area A results in three clusters where clusters centers follow a common gradation regarding the variables values. In cluster 1 low percentages (for both variables) are grouped while in cluster 2 medium percentages show up and finally in cluster 3 high percentages for both variables are gathered. This values sequence change for the clustering for the two other service areas B and C. Indeed the centers of cluster 1 for service areas B and C gather still low percentages for both variables while in cluster 2 medium population percentage show up together with high services percentage and in cluster 3 high population percentages are grouped with medium services percentages.

3.2.1. CLOSEST BUS STOP TO JUNCTIONS AND SERVICES

The results of Table 5 indicate that percentages of population and services segregate concerning their evolution in the case of service areas within a distance ascending far from 300 m. In order to study further this evolution, the closest bus stop to each junction and public service by walking along the street network was detected. This procedure was realized by the use of Network Analyst which finds the closest facility from a number of points by taking into account network distances. By the end of this procedure each public service and populated junction are assigned to their closest bus station. Consequently each bus stop shows up with a number of exclusively served junctions and public services.

In case that a bus stop serves no service or not populated junctions the services and junctions served by the closest bus stop to this one in question were assigned.

Percentages of bus stations	Percentages of population			
Percentages of public services	**0 - 0,7%**	**0,8% - 1,7%**	**1,8% - 5%**	**Total**
0,5% - 1,1%	36%	23%	10%	69%
1,2% - 2,7%	16%	5%	2%	23%
2,8% - 5,4%	2%	5%	2%	9%
Total	53%	34%	13%	100%

Table 6. Bus stops percentages by closest served population and public services (percentage groups)

A low proportion of public services (0,5% - 1,1%) is served by the majority of bus stops (69%) from which 36% serves low population percentages (0 - 0,7%). The lowest bus stops percentage (2%) has high population percentages (1,8% - 5%) but also low population and high services percentages (2,8% - 5,4%). These results constitute another more element together with service areas to use in order to analyze and evaluate the efficiency of services and buses networks. None the less, distance between bus stops and their closest features remains a determinate of the evaluation procedure. The question arising here is how distance from these closest features can be taken into account along with a term involving them. In the next stage the creation of a triangle for each bus stop answers the question.

3.2.2. TRIANGLES AND Q_S QUOTIENT FOR BUS STOPS

In this stage the main action is to create a triangle formed by the location of each bus station, the centroid of its closest services and the spatial mean of its closest populated junctions. After the formation of these triangles, the next step comprises the calculation of their area as a measure of bus stops efficient location. The smaller the area is, the better the bus stop location is in relation with services and population. Area values of bus stops triangles are illustrated in Fig. 2:

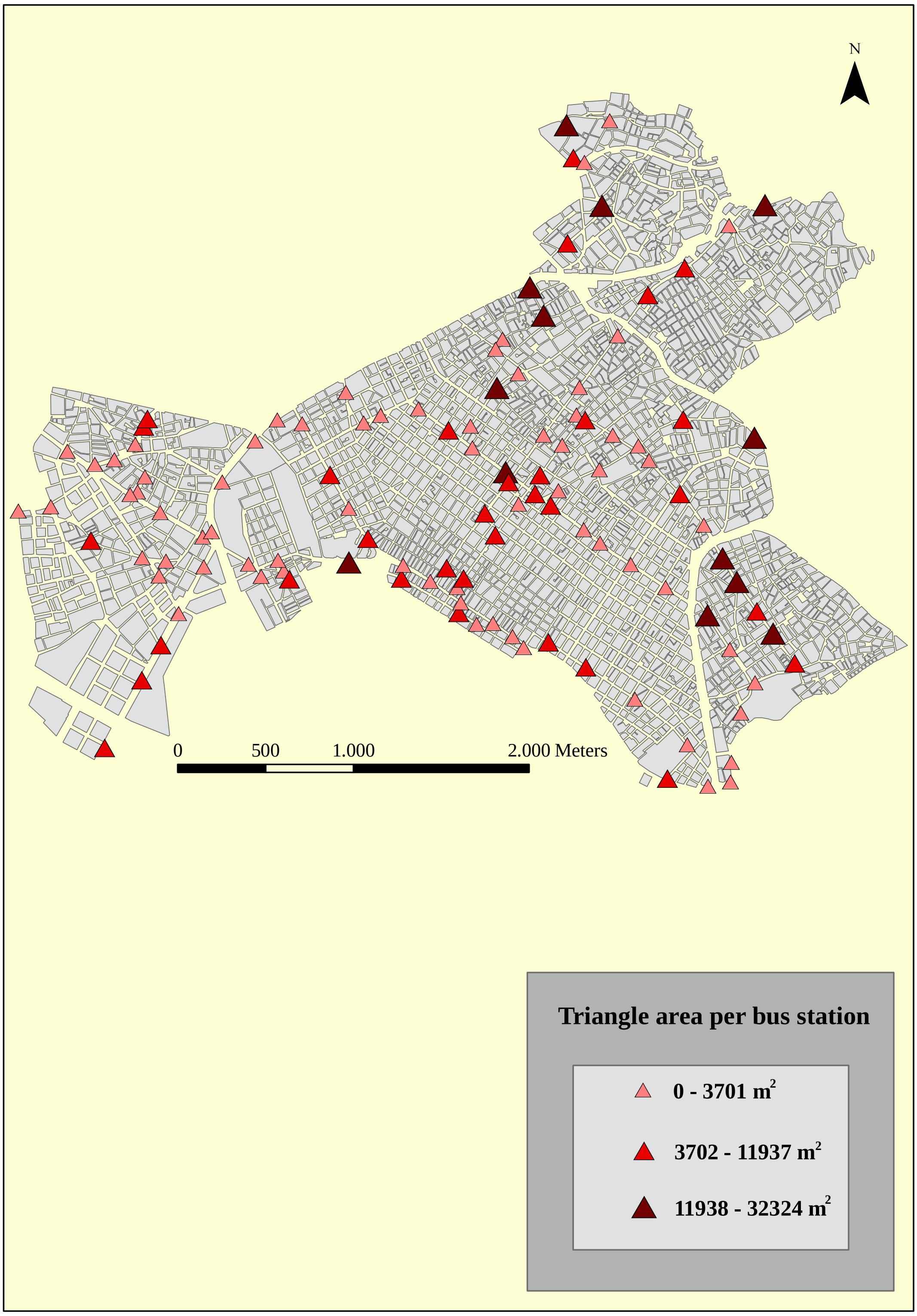

Figure 2. Triangle area per bus station

The classes of triangle area illustrated in Fig. 2 are created by using the Natural breaks method in Arc GIS. The bus stop percentage for each area class is: 61% with 0 – 3701 m^2 area, 28% with 3702 – 11937 m^2 and finally 11%

with 11938 – 32324 m^2 triangle area. These results show that the majority of bus stops forms triangles with relatively small area, a fact proclaiming the efficient relative position of bus stops regarding its closest features.

In spite that, since two triangles having equal area can vary far regarding the size of their sides, that is distances between bus stops, population and services, another more measure is studied: a quotient of these sides. In the case of a triangle (B, S,P) where B is the bus stop location, S the centroid of closest services and P the spatial mean of closest populated junctions, the sides quotient (Q_S) is given by the following formula:

$$Q_S = \frac{BS + BP}{SP}$$

This quotient is studied in parallel with area in order to gain a full aspect of networks efficiency. When Q_S values are close to 1 and area is small the distances BS and BP remain short a fact confirming the efficient location of the corresponding bus station. In Table 7, area and Q_S values are combined resulting in bus stops groups with specific characteristics:

Percentages of bus stations	Q_S values			
Triangle area (m^2)	1 - 5,2	5,3 - 17,9	18 - 51	Total
0 - 3701	47%	9%	5%	61%
3702 - 11937	20%	8%	0%	28%
11938 - 32324	11%	0%	0%	11%
Total	78%	17%	5%	100%

Table 7. Bus stops percentages by Q_S values and triangles areas (percentage groups)

The area and Q_S values classes in Table 7 are formed using the Natural breaks (Jenks) method in Arc GIS. The majority of bus stops (47%) has low triangle area and low Q_S value and thus is effectively located in relation with its served population and public services. In the same time extreme values of Q_S and area do not coexist (0% of bus stops), a positive fact for the studied networks efficiency. The two variables of Table 7 are illustrated in combination in Fig. 3:

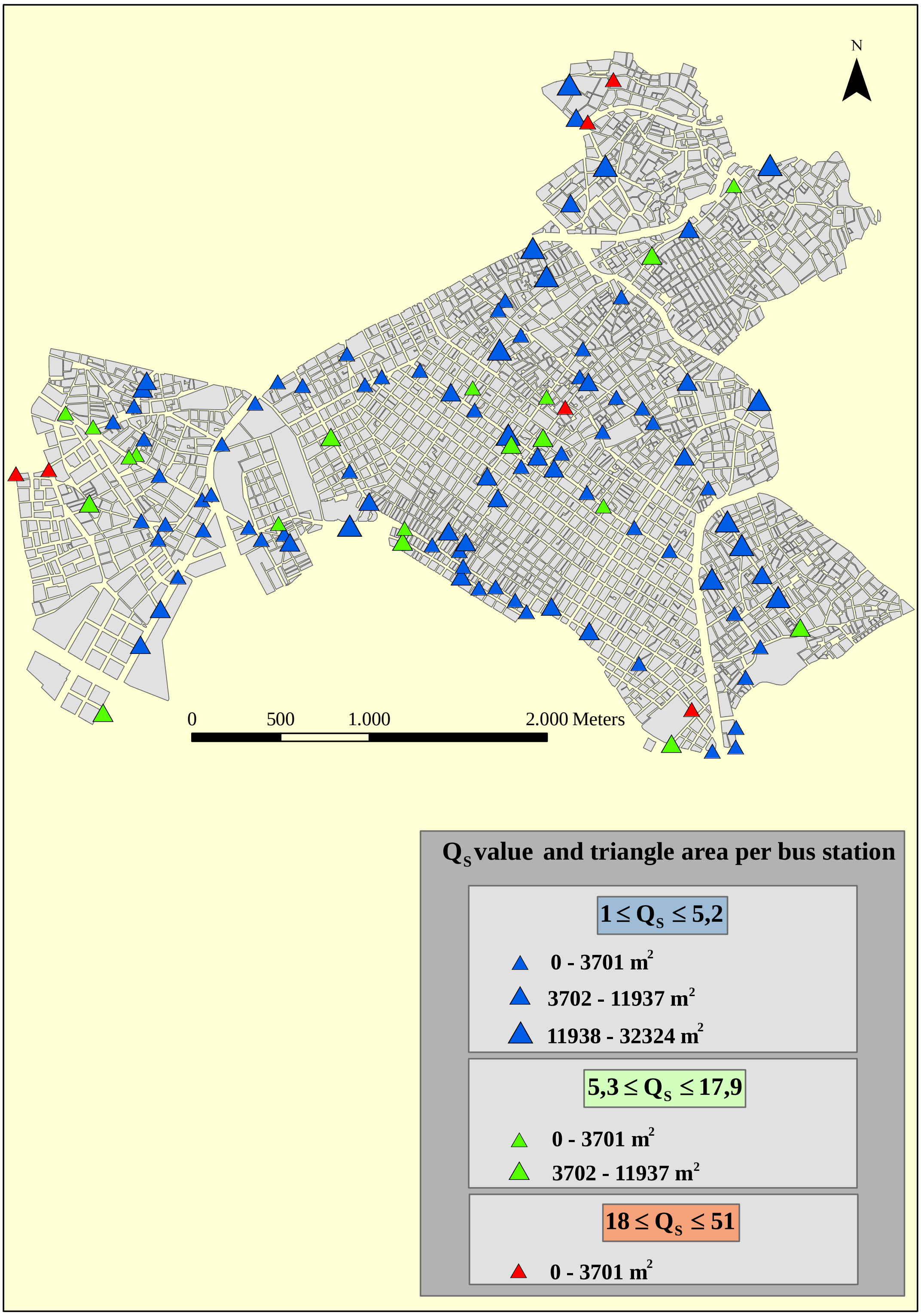

Figure 3. Q_S value and triangle area per bus station

Bus stops with low Q_S and low triangle area (47%) are expanding as expected in the central study area where also CBD is located but also in peripheral parts of the city where buses network efficiency seems to be in a sufficient level. In spite that a considerable number of bus stops remain inefficiently located even in the central study area. This situation might be strengthened by the fact that bus stops in the central area extend only in four streets (two horizontal and two vertical), due mainly to the absence of wide streets, leaving in this way large uncovered areas.

4. CONCLUSION

The main aim of the suggested methodological framework was the evaluation of public buses network efficiency with respect to passenger and public services locations and their spatial convergence. Utilising advanced GIS capabilities, several concepts like closest features to one point and service area of a point along with statistical classification methods are performed. In addition, a triangle formed by the centroid of closest services, the spatial mean of closest populated points and the location of corresponding bus stop is studied by its area and the analogy of its sides. The smaller the area and the analogy the better the bus stop is located. The results of the above procedures are forming an overall image of the studied networks status in terms of effectiveness and efficiency.

It should be pointed that the results of this work can appear particularly useful in planning or re-designing of studied networks which by benefiting from GIS capabilities can be further analyzed providing even richer conclusions when time series data are available. Furthermore individual-based data regarding daily trips in urban areas collected from individual interviews realized at services locations can enrich the proposed methodology and provide even more realistic results for networks evaluation. Questions dealing with preferable transportation means for daily trips towards public services, frequency of services utilization or walking distance from bus stop or parking area to a specific public service could be some of the interview issues. Finally the incorporation of procedures referred to above in an integrated spatial decision support system as well as the quantification of corresponding results is one of the most interesting perspectives.

BIBLIOGRAPHY

Aldenderfer, M.S., Blashfield, R.K. (επ.) (1984/1991) *Cluster Analysis (Series: Quantitative Applications in the Social Sciences)*, California: SAGE Publications

Aronoff, S. (επ.) (1989/1991/1993) *Geographic Information Systems: A Management Perspective*, Ottawa: WDL Publications

Bailey, T., Gatrell, A. (επ.) (1995/1996) *Interactive Spatial Data Analysis,* Essex: Longman

Birkin, M., Clarke, G., Clarke, M, Wilson, A. (1996) *Intelligent GIS: Location decisions and strategic planning*, Glasgow: Pearson Professional

Dimitriadis, E. (2002) *Descriptive Statistics*, Athens: Kritiki publications (in Greek)

Dueker, K., McDonald Jampoler, S. (2002) 'Global Urban Quality: An Analysis of Urban Indicators Using Geographic Information Science', Final Report To U.S. Department of Housing and Urban Development Office of Policy Development and Research HUD Project H-21260CA (http://www.cobblestoneconcepts.com/ucgis2hud/FinalHUDRpt/ken-ver2.pdf)

Fotheringham, S., Rogerson, P. (1994) *Spatial Analysis and GIS*, London: Taylor & Francis

Ghosh, A., Rushton, G. (1987) *Spatial Analysis and Location – Allocation Models*, New York: Van Nostrand Reinhold Company

Handy, S., Niemeier, D. (1997) Measuring accessibility: an exploration of issues and alternatives, *Environment and Planning A,* 29, 1175-1194

Ikporukpo, C. O. (1987) 'An analysis of the accessibility of public facilities in Nigeria', *Socio-Economic Planning Sciences,* 21 (**1**), 61-69

Jahan, S., Oda, T. (1999) 'Distribution of Public Facilities in Dhaka, Bangladesh: A Spatial Analysis' (http://www2.kobe-u.ac.jp/~oda/Jahan&Oda.pdf)

Jones, C. (1997) *Geographical Information Systems and Computer Cartography*, Essex: Longman

Koutsopoulos, K. (1990) *Geography: Methodology and Spatial Analysis Methods*, Athens: Symmetria publications (in Greek)

Kwan MP (1998). Space-time and integral measures of individual accessibility: A comparative analysis using a point-based framework. *Geographical Analysis*, 30:191–216

Martin, D. (1991) *Geographic Information Systems and their Socioeconomic applications*, New York: Routledge

Meadows, D. (1998) 'Indicators and Information Systems for Sustainable Development: A report to the Balaton Group', Hartland Four Corners: The Sustainability Institute

Meyer, M. and Miller, E. (1984). *Urban Transportation Planning*. McGraw-Hill, New York.

Murray, A. T. (1998) Public transport access, *Transportation Research D*, , Vol. 3, No. 5, pp. 319-328

Murray, A. T. and Wu X (2003). Accessibility tradeoffs in public transit planning, *Journal of Geographical Systems*, 5:93–107.

Pappas, V. (1998) 'Introduction to GIS (Lecture notes in the Department of Urban Planning and Regional Development)', Volos: University Publications of Thessaly (in Greek)

Pizzolato, N., Barcelos, F., Lorena, L. (2002) 'School Location Methodology in Urban Areas of Developing Countries', *International Transactions in Operational Research*

Rogerson, P. (2001) *Statistical Methods for Geography*, London: SAGE Publications

Talen, E. (1998) Visualising fairness: equity maps for planners, *Journal of American Planning Association*, 63 (1), 22-38

Talen, E. (2002) Pedestrian Access as a Measure of Urban Quality, *Planning Practice & Research,* 17(**3**), 257-278

Talen, E., Anselin, L. (1998) Assessing spatial equity: an evaluation of measures of accessibility to public playgrounds, *Environment and Planning A*, 30, 595-613

Van Kamp, I., Leidelmeijer, K., Marsman, G., De Hollander, A. (2003) 'Urban environmental quality and human well-being: towards a conceptual framework and demarcation of concepts; a literature study', *Landscape and Urban Planning*, **65**, 5-18

Worrall, L. (1991) *Spatial Analysis ans Spatial Policy using Geographic Information Systems*, London: Belhaven Press