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NETWORK OF DEDICATED BUS LANES: A SOLUTION TO INCREASE THE ACCESSIBILITY OF THE URBAN INTERMODAL TRANSPORT

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Rezumat

Sistemul de transport public are un rol esențial în asigurarea dezvoltării durabile a orașelor. Accesibilitatea este una dintre funcțiile importante pentru creșterea eficienței transportului public. În acest cadru, lucrarea propune o metodologie pentru ameliorarea accesibilității rețelei de transport public. Metodologia se referă la configurarea unei rețele de linii de autobuz cu cale dedicată, proiectate în zone cu accesibilitate scăzută, cu scopul de a ameliora accesul la linii de metrou și tramvai, adică la servicii rapide și de capacitate mare.

Cuvinte cheie: Mobilitate durabilă, transport public, accesibilitate, configurarea rețelelor, linii de autobuz cu benzi dedicate.

Abstract

The public transport system has an essential role in the sustainability of the urban environment. The accessibility is one of the critical functions for the increase of public transport efficiency. In this framework, the paper presents a methodology to enhance the accessibility of the public transport network. The methodology aims to design a network of dedicated bus lanes to operate in areas with low accessibility and improve the connections to metro and tram lines that provide rapid and high-capacity services.

Keywords: Sustainable mobility, public transport, accessibility, network design, dedicated bus lanes.

1. INTRODUCTION

In the last decade, changes in urban structures and lifestyles have influenced mobility habits (especially marked by the broadening of the travel demands). The standard of living, the urban pattern differentiate the individual capacities to access the daily activities. Also, each social category appreciates different temporal dysfunctions in the chain of daily activities. Despite the objectives of sustainable development, which aim to reduce pollution and energy consumption, many urban agglomerations face issues caused by traffic congestion and inadequate public transport services.

In Bucharest (the capital of Romania, with 1.885 mills. of inhabitants - about 10% of the country population), the last decades have been characterised by the continuous intensification of car use. The effects of this trend have negatively influenced the quality of urban life: high level of space occupancy by road infrastructure and parking, significant financial costs for traffic infrastructure investment and maintenance, negative external effects of the excessive use of cars (congestion, noise, pollution). Also, the excessive use of cars for daily commuting has led to a decreased demand for many public transport services and, consequently, to negative consequences for the efficiency and effectiveness of the urban public transport system.

However, public transport systems can be developed in such a way as to become an attractive alternative, leading to the reduction of the share of daily travel by personal cars [1]. The development of public transport systems must be correlated with the measures applied in urban planning. Changes in the relationship between daily mobility needs and urban planning can create, reduce, or amplify inequalities in the accessibility of the activities. Providing a network of rapid services can improve public transport's commercial and operating efficiency [2-4].

In this framework, this paper aims to identify how the topology of the rapid and semi-rapid service network can be extended to increase the attractiveness of public transport. The goal mainly consists of designing a network of dedicated bus lanes (DBL) to serve the areas with low accessibility and provide connections to the urban rapid and semi-rapid services (by metro and tram).

The paper is structured as follows. The first part describes the methodology developed for designing the DBL network that complements the existing topology of the rapid and semi-rapid service network (by metro and tram). The second part presents the results of the first stage of the methodology. The Geographic Information System (GIS) procedures are applied to assess the accessibility of Bucharest's high-capacity public transport network. The areas identified as having

low accessibility are selected as input databases in the following research stage. Then, a multicriteria decision model will be applied to determine the recommended routes for DBL.

2. INCREASING THE ACCESSIBILITY OF PUBLIC TRANSPORT THROUGH THE EXTENDING OF THE DBL NETWORK

Urban public transport and non-motorised travel are increasingly assimilated with the mandatory components of sustainable development of cities. In a congested urban environment, where there are multimodal travel options, travel offers must be designed and dimensioned to ensure the judicious use of space and high performance of the operating of transport systems [5].

Solutions to improve the share of public transport use for daily commuting are targeted towards public transport grade-separated or exclusive right-of-way (e.g., subways, which can offer rapid services and high transport capacities for commuters during peak hours) [6]. By providing a network of rapid services, accessibility functions can be improved and, consequently, the indicators of commercial and operating efficiency of public transport.

The analysis of the performances for a public transport line is necessary to highlight its attractiveness. However, public transport lines must also be examined in terms of network access points. This analysis allows emphasising the role of correspondences in structuring the network. I.e., how the overall logic of the network corresponds to the mobility needs of the territory [7]. Even for lower-performance lines, positive effects can be identified: ensuring an adequate cover of the service area, attracting passenger volumes that feed high-capacity lines, and improving overall performance.

Given these features, this research aims to develop a methodology for designing a network of DBL to supplement the network of rapid and high-capacity services provided by the metro and tram networks. The results will lead to increased accessibility and, implicitly, to increased attractiveness of public transport.

The priority of the bus lines can be spatial (dedicated lanes) and temporal (traffic signal priority). This paper refers only to the first category. Several studies have investigated the impact of lines dedicated exclusively to buses [2,3,5,8,9,10]. But further research is still needed to comprehensively address the issue of setting up networks of DBL to ensure high performance of the entire urban mobility system.

Some studies have developed a macroscopic approach for designing a DBL network by allocating road infrastructure in a bi-modal system - cars and buses.

Currie *et al*. [11] applied traffic flow simulation and multicriteria model to assess the impacts of transit priority measures on traffic queues and travel time reliability. Bagloee *et al*. [8] developed a model for designing a network of priority lines in congested zones. To configure the network, the roads were selected according to transit ridership and congestion level, for which a nonlinear programming problem with binary decision variables was formulated. Braess Paradox was applied to minimise the side effects of introducing priority lanes.

Hadas & Nahum [10] developed a multi-objective and multicriteria combined approach to recommend a scheme for a network of DBL. The objectives were to minimise the travel time for passengers, maintain balanced connectivity between the selected nodes, and minimise the budget allocation for the construction of priority lanes. A multicriteria approach was applied to select a preferred solution function of the preferences of different groups of stakeholders.

Zheng & Geroliminis [5] proposed a macroscopic model which aimed to minimise the total passenger hours travelled for different pricing strategies. Further, Geroliminis et al. [12] developed a model to evaluate the effects of scheduled stops on public transport operations.

The methodology proposed in this paper aims to design the spatial scheme of the DBL network, with exclusively reserved lanes but with interaction with other traffic flow in intersections. The novelty of this methodology consists of the integrated approach of the public transport network. Isolated examined, the public transport network lines have wide-ranging performances (depending on the served area and the characteristics of the services). But at the network level, they all can significantly contribute to the global performance of the network. Concerning the accessibility currently offered by the networks of exclusive lines (metro and tram), the areas with reduced accessibility will be determined. Then the necessary routes will be determined to connect low- accessibility areas to rapid and semi-rapid services (metro and tram). The routes for DBL will be established in function of the existing road infrastructure and potential passenger volumes.

The methodology is based on a comprehensive approach that includes multicriteria and traffic simulation models at macroscopic and microscopic levels to select an optimal solution for the DBL network. The following section presents the main steps of the methodology.

4. METHODOLOGY FOR DESIGN A DBL NETWORK

The methodology developed to design a network of DBL (Figure 1) aims to increase the overall performance of the public transport system in Bucharest. But it can be applied in any city with intermodal public transport. The main objectives are:

- Increasing the accessibility of the public transport network;
- Minimising costs for DBL implementation (such as marking, pavement, separation facilities, etc.);
- Minimising the effects of reducing the road traffic capacity through reserving a set of road lanes exclusively to buses.

In the first phase of the methodology, the accessibility offered by the metro and tram networks is evaluated, i.e., by the networks that allow services with high capacity and speed (services with attractiveness in a densely populated urban space such as Bucharest). The following paragraph presents the procedures applied in this phase.

Then, the zones with attractiveness (evaluated relative to the number of residents and the number of employees in each area) and low accessibility will be identified. For the selected zones, the next features will be analysed:

- The existing public transport services covering the zones (including bus lines, not only metro and tram lines included in the first step of the analysis)
- The significant flows originating from and/or having destinations in each zone (based on data on traffic flow in existing studies and passenger flow in the statistics of public transport companies)
- Ongoing or planned urban planning measures (e.g., new residential, commercial centres, etc.).

These examinations will lead to a set of potential origin-destination relationships for the introduction of DBL. To establish the route for each origin-destination relationship, a preliminary step will be performed to select features of the road network by appropriate constructive attributes for ceding a lane exclusively for bus traffic. The selection procedures will be applied for the entire urban road network, and the results will consist of a set of road features that can be used as candidate sections for the DBL network.

Then, for each origin-destination pair, an algorithm will be developed to determine a set of candidate routes based on a composite weighted index function of the attributes of the road features, the existing bus lines, the congestion level. The alternative routes will be generated up to a limit of the development route coefficient (relative to the shortest origin-destination route).

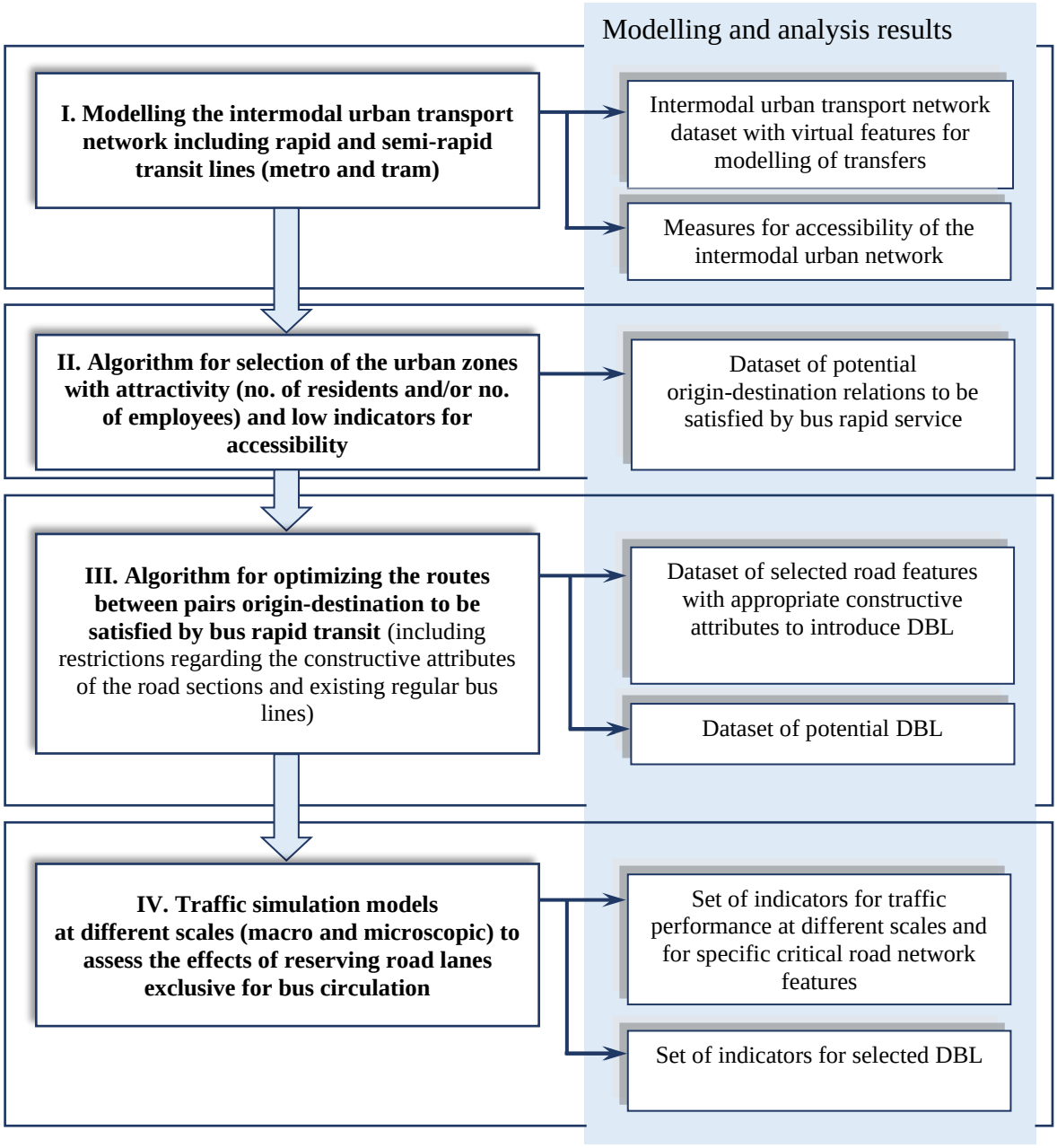


Figure 1. Flowchart of the methodology applied to identify the recommended DBL network

The connection problems for certain relationships or routes will be solved, and the optimal route will be selected function of the time, the potential passenger volume, the attributes of the road features. The results of this step will consist of a set of recommended routes for DBL.

The last step aims to assess the effects of the insertion of DBL. Reserving lanes for buses and reducing the road traffic capacity for cars may negatively affect the congestion level. The dynamics of flows on bimodal networks (with infrastructures used by cars and buses) is more complex due to the operating characteristics of buses and the interactions between the road vehicles (interactions which are not completely eliminated) [12]. It is necessary to determine the influences of each mode in the dynamics and performance of traffic, to correctly assess the measures for resizing the traffic capacity for each travel mode.

Traffic simulation models will be developed at the macroscopic level to assess the implementation of the network of DBL. Then, for critical areas, simulations will be performed at a microscopic level for certain intersections and roads identified as being significantly influenced by the network of DBL.

The indicators resulting from the simulation models will be used to evaluate the effects of the network of DBL and to select those that are recommended. Obviously, for each selected line a peculiar study will have to be developed, especially to examine supplementary measures for:

- operating efficiency, computed as the ratio between the results obtained (vehicles-km, places offered-km) and the consumed resources (financial, material, human, energy);
- commercial efficiency computed based on the utilisation of the offered capacity (measured in benefit, passenger-km);
- used as the ratio between the results obtained defined in function of the degree of use of the offer (measured by revenue, passengers km).

In this phase of the research, the procedures from the first step of the methodology are applied to Bucharest.

The following section presents the assessment results of the accessibility at the level of the network of rapid and semi-rapid services (metro and tram). Further research aims to develop models for the next steps of the methodology.

5. ACCESSIBILITY FOR THE PUBLIC TRANSPORT NETWORK IN BUCHAREST

5.1. Background

The accessibility of the traffic network and the accessibility of the public transport service network influences the travel demand and land use [13,14]. Therefore, assessing the accessibility is an important step to characterise the performances of the public transport system and to identify measures that can increase performance.

Accessibility, as an intrinsic attribute of the physical network, expresses the easiness, high or reduce, of reaching a point from another area covered by a connected network. There are different methods and indicators for the assessment of the accessibility [13-18]. At this stage of our research, we refer only to the accessibility of the network of public transport services by metro and tram from Bucharest (Figure 2).

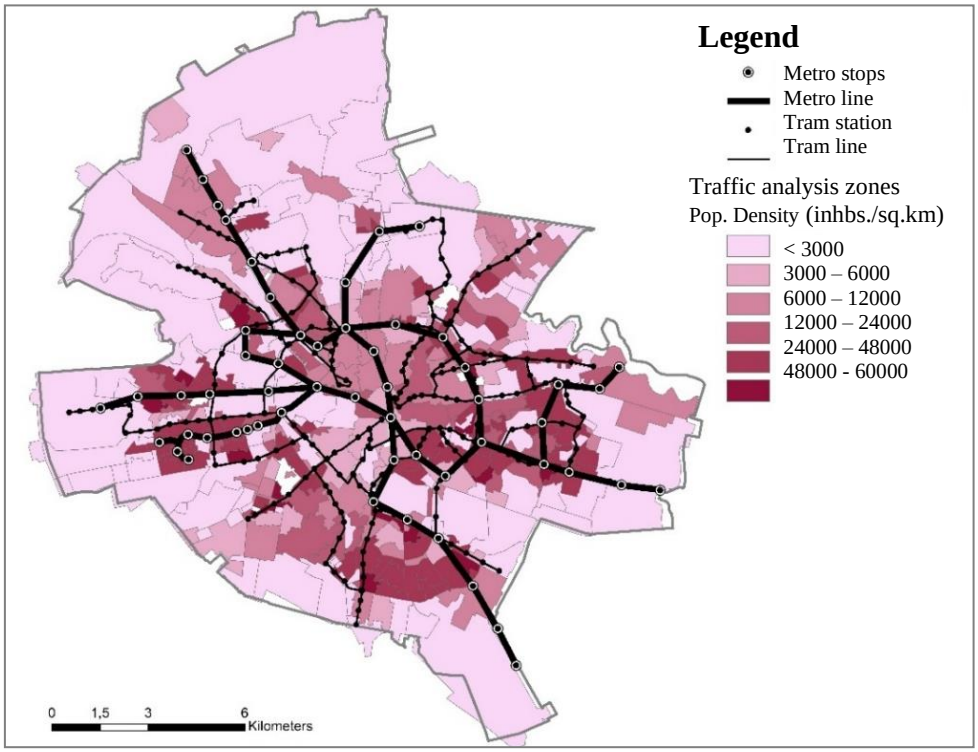


Figure 2. The analysed networks of public transport services by metro and tram in Bucharest

The accessibility of these networks was analysed from two viewpoints:

- The service coverage area, which includes places serviced by public transport at the minimum service standard [17];
- The spatial accessibility at the network level, based on the shortest paths between locations [19].

5.2. Service coverage area

The network coverage indicators measure the percentage of residents and jobs located within satisfactory walking time (10 minutes around metro stations, 7 minutes around tram stations) of at least one public transport service that meets these standards (Figure 3).

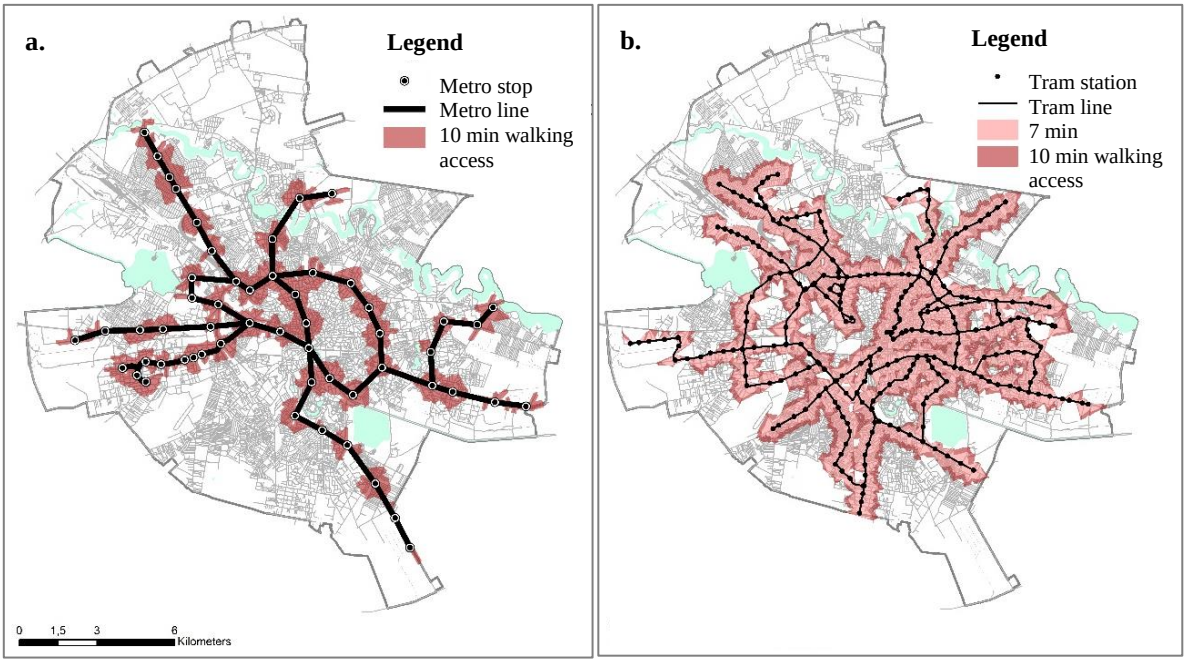


Figure 3. Service area coverage for the metro network (a) and tram network (b)

The indicators of the service coverage area (for the stations of the metro and tram networks) were determined using GIS procedures (Table 1).

The results show low percentages for access to rapid transit by metro at an acceptable standard (only 28% of the urban population and 30% of employees with job locations in the urban area).

Higher percentages for access to semi-rapid transit by tram were obtained (obviously, due to the higher density of the tram network). The coverage values are still reduced for 7 minutes walking time to tram stations (which is considered

an acceptable standard to access semi-rapid services). The procedures were applied also for 10 minutes walking time to tram stations, which is a less acceptable standard. But the calculation is made to verify if at this lower standard, the coverage values are more satisfactory for a city with such a high population density as Bucharest (around 7800 inhbs./sq.km).

Table 1. Indicators of service area coverage of metro and tram networks in Bucharest

Class	Measure	Value
Demographic data [20]	Population	1.885 mill. inhbs.
	Density of the population	7800 inhbs./sq.km
	Employees	1.002 mill. empls.
	Density of the employees	4140 empls./ sq.km
Overall data on metro and tram networks	No. of metro stops	56
	Metro network length	80 km
	Metro network density	0.33 km/sq.km
	No. of tram stations	270
	Tram network length	132 km
	Tram network density	0.55 km/sq.km
Service coverage of the metro network	Residents with access to metro stops in 10 minutes walking	535493 inhbs. 28% of the overall urban population
	Employees with access to metro stops in 10 minutes walking	304019 empls. 30% of the overall urban employees
Service coverage of tram network	Residents with access to tram stations in 7 minutes walking	916322 inhbs. 49% of the overall urban population
	Employees with access to tram stations in 7 minutes walking	402913 empls. 40% of the overall urban employees
	Residents with access to tram stations in 10 minutes walking	1124596 inhbs. 60% of the overall urban population
	Employees with access to tram stations in 10 minutes walking	541527 empls. 54% of the overall urban employees

The unsatisfactory values of service coverage for rapid and semi-rapid services [17] emphasise the need for measures to enhance accessibility. One of the feasible measures is to design a DBL network that can improve semi-rapid

services. Also, the DBL network can improve the connections of low-accessibility zones to existing rapid and semi-rapid services by metro and tram.

5.3. Spatial accessibility at the network level

The travel time was used to assess the accessibility provided by metro and tram networks in Bucharest. For each station, the accessibility was expressed as easiness to access all other stations of the public transport network. The accessibility vector was computed function of the minimum travel time for each pair of stations.

Denote R the set of nodes corresponding to the stations of the public transport network,

$$R = \{k, k = 1,\ldots, N\} \quad (1)$$

where N is the number of stations.

The measure of the most preferred itinerary from node i to node j, defined by the sequence of the nodes ($i = k_1, k_2, ..., k_s, ..., k_I = j$), is

$$T_{ij} = min\sum_{s=1}^{I-1} t(k_s, k_{(s+1)}) \quad (2)$$

where $t(k_s, k_{(s+1)})$ is the average travel time on the link $(k_s, k_{(s+1)})$ of the public transport network.

Then, the average spatial accessibility for node i (origin) relative to all other nodes (destinations) of the network is

$$\overline{A_i} = \frac{1}{N-1}\sum_{\substack{j=1 \\ j\neq i}}^{N} T_{ij} \quad (3)$$

The value $\overline{A_i}$ represents the measure of the accessibility of all interest points (stations) from a given origin i.

The average accessibility of metro stations and tram stations were determined in function of travel time (Figure 4). The circle symbol represented in Figure 4 for a station is proportional to the average travel time to all other stations. The larger its circle radius, the less a station is accessible. The smaller its circle radius, the more a station is accessible. Obviously, the terminus stations have high values of average spatial accessibility due to the peripheral position on the network. The station with the lowest value of the average spatial accessibility represents the pole of the network, i.e., the most accessible location at the network level.

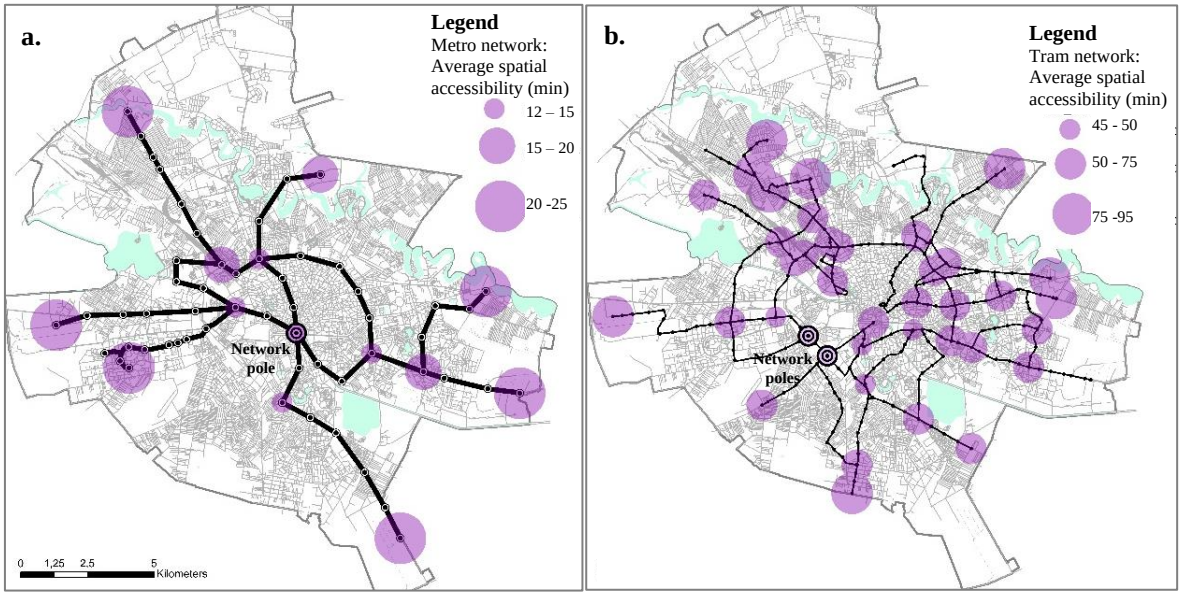


Figure 4. Average spatial accessibility function of travel time for the metro (a) and tram (b) networks

For the metro network, even for stations with reduced accessibility, the values of the average spatial accessibility are satisfactory (20 - 25 min). The values reflect the advantages of operating in systems with separated grade lines on which any conflicts with other categories of flows are eliminated.

On the tram network, the range of the average spatial accessibility is much lower, mainly due to lower operating speed caused by mixed usage of road infrastructure components and the high density of station (which, on the other hand, brings advantages for service coverage). However, due to the increased connectivity of the network, a significant number of stations have good accessibility. Two adjacent tram stops were considered poles because they have very close values of the average spatial accessibility.

The accessibility ranges obtained through both perspectives (service coverage and spatial accessibility) allow further evaluation of the level of service for the origin-destination relations with significant travel volumes. The origin-destination relations with no satisfactory accessibility will be input data in the next stage for the multicriteria evaluation of the solutions for the design of DBL.

5. CONCLUSIONS

Mandatory components of sustainable development of cities increasingly integrate urban public transport and non-motorised travel. The urban public transport system must be constantly adapted to the new requirements to ensure the social, environmental, and urban planning missions. The solutions for improving the share of the use of public transport for daily commutes are oriented towards high-capacity public transport (e.g., by metro, which can provide high transport capacities for commuters during peak hours). But more attention must also be given to the DBL network, which can significantly increase the public transport system's efficacity and efficiency. The first part of the paper emphasises these statements by presenting the main functions of public transport and the criteria for assessing these functions.

The paper proposes a methodology for designing a DBL aimed to increase the overall accessibility of the public transport network and increasing the attractiveness of public transport services.

In addition to other studies on priority bus lines, the presented methodology is not limited to assessing the dynamics of flows on the mixed usage of the road network (cars and buses). It starts from a broader approach, with an analysis of the topology and accessibility of the rapid and semi-rapid services networks. The identified low accessibility zones and the characteristics of the road network will form the basis for determining the candidate itineraries for DBL.

Further, research will be carried out for a multicriteria model and traffic simulation models to select an optimal solution for the configuration of a DBL network.

The proposed methodology is developed for the mobility system in Bucharest but can be applied for cities with high population density and intermodal urban transport systems (metro, tram, bus).

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