Connections between Bucharest underground and rail networks*

CRISTINA STEFANICA, VASILE DRAGU, STEFAN BURCIU, ANAMARIA ILIE
Department Transport, Traffic and Logistics
University Politehnica of Bucharest
Spl. Independenței, No.313, Bucharest, 060042
ROMANIA
cristina_stefanica@yahoo.co.uk, http://www.ingtrans.pub.ro

Abstract: The impetuous growth of the mobility needs and thus the road traffic proliferation led to concerns for a more attractive public urban transport. Public transport attractiveness might grow by improving the quality indicators of the transport offer (travel time, safety, comfort, convenience, regularity) .
Attractiveness of public urban transport in concern to private car use is conditioned, especially, by travel time and by the certainty of the announced arrivals and departures moments from the transport schedules.
A case study is realised for the existing suburban rail network and for the underground network designed for 2030 in Bucharest. From the superposition of the two networks by analyzing the degree of coincidence of the nodes, resulted the integrated network. For the integrated network, a structure of the transport schedules that assures favourable connections for the train and metro lines in the transfer stations (Gara Băneasa, 1 Mai and Gara de Nord) was designed.
By correlating the transport schedules, the travel time for Pantelimon – Gara de Nord – Gara Băneasa – Otopeni itinerary can be diminished up to 29 minutes for one transfer and up to 36 minutes for 2 transfers.

Key-Words: public transport, terminal, schedule, travel, rail, metro

1 Introduction

The competition between transport modes led to a segmented transport system instead of an integrated one, especially in the urban areas. In fact, every transport mode tried to use its own advantages regarding the growth of attractiveness on a highly competitive market. The transporters tend to maintain the intensity of the activity by using the routes that they operate to their maximum capacity. The lack of modal integration was made much worse, on international level, by the government policies that prohibit the companies to operate in other ways that their own and by placing a transport mode under state authorities control, maintaining the monopoly [19].

In the last forty years important efforts have been made for integrating transport systems that functioned separately, from the intermodality point of view. This concept implies the use of at least two transport modes for a travel between origin and destination.

The intermodality phenomenon was possible due to the advanced technologies of information processing and transmission.

So, the main characteristic of intermodality is providing a service for one unique ticket (for passengers) or for one unique transport document (for fright), but also other measures that reduce the transfer times from one transport mode to another.

Public power intervenes to mitigate the dominance of road transport in modal competition, but also, to diminish congestion, to increase traffic safety and to prevent environment degradation. In Europe, public policies led to decongest the major freight and passengers corridors. Intermodal transport is perceived as the most viable solution from this point of view.

In a continuous space all the connections are theoretical possible, but the various constrains of time, cost or space limit this continuity and the ubiquity character of transport [13][16].

Strategically, the management of intermodality can be realised taking into consideration the need of mobility generated by land use strategies, residential and recreation areas etc. These mobility needs of the entire system of socio-economic activities (transport demands) are directly related to land use decisions (including the urban space) and lead successively to transport flows and to traffic flows on the transport infrastructure network [14].

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In an urban area, it is not possible to cover all the land with infrastructure for all transport modes. Though, the mobility can be satisfied by cooperation and by integrating the transport modes.

The points where the transfer from one mode to another takes place represent sensitive points that can encourage or discourage intermodality. The existing amenities in these places, regarding the reduction of transfer time and especially the commodity and comfort of the transfer (escalators and moving walkways, minimum walking distances, transport schedules correlations, guidance signs and commercial and social facilities etc.) lead to an increased intensity of use of such facilities with major implications in enhancing intermodality that is so necessary in urban environment [2].

2 The role of nodality in land structure

The transport nodes are considered to be points of incidence of two or more traffic paths [13].

S/N (system/network) matrix shows that the nodality is determinant for the most spatial-functional attributes: interfaces, diffusions (distributions), mobility, concentrations (consolidations), hierarchies [13].

In terms of planning, the node can't be considered a neuter and inconsistent point because it is, in fact, a complex system that receives, delivers and transforms flows more or less varied. Because of that, a meticulous service is required, a microscopic analyse, a histology, to emphasize the internal structure of the node. From the structure of this node's histology derives the node philosophy that emphasize four fundamental principles [2]:

- there are six spatial-functional nodal functions;
- every node must have one of this functions;
- every node gives a combination of a certain number of functions;
- some of nodal functions requires mandatory presence of one or more functions.

The six spatial-functional nodal functions are:

a) *Connection function* - that ensures a continuous movement between two or more links of the network;

b) *Shelter/refuge function* for transport means, travellers or goods, that is so obvious in the antiquity harbours developed in closed road steads, bays protected from the weather;

c) *Service/halt function*, staggered between origin and destination points and realized by introducing intermediate stops that carry out technical operations on the infrastructure (pipeline pumping stations, connections between railways with different gauge), or on the transport means (garages, workshops, supply ports) or that carry passenger (recovery, recreation) and goods (storage, conditioning, marketing) services. Technical and economical changes have affected the distribution of the points that carry out this function along a route (the points for water and coal supply of locomotives, for example, disappeared by introducing the electrical and diesel traction);

d) *"Rupture of charge" function* that consists in loading, unloading, transhipment of the goods, passengers getting in and out from one transport mean to another and that represents the expression of transport discontinuity;

e) *Transfer function from one mode to another*, extremely frequent and trivial - from the traveller that got off a bus and is getting into a train, to the oil that is pumped from a pipeline network to a ship. Transport modes cooperation represents a solution for increasing the transport efficiency and for reducing the negative externalities of traffic;

f) *Function for changing the functional space spreading*, that consists in the fact that transport makes connections between networks that cover different territories.

All nodal functions mentioned above present different levels that rank the nodes compared to their relational capacities with the served territory, number, structure and performances of the equipments and with the traffic intensity.

The criteria used to rank the importance of nodes can be grouped into two categories, as follows:

1. the first category aims the node's attraction power, expressed by accessibility as a result of some spatial (connectivity, node position in relation to the served territory) and economical (quantity and quality of the offered services) particularities;

2. the second category concerns the level of nodal activity expressed through the size and structure of traffic, traffic flows origin and destination, area of the served territory, degree of multimodality, relationship between incident transport modes, level of offered services.

3 Transport modes interaction in transfer stations

The most complex interaction between transport modes takes place within junction points [15].

In a transfer station where more transport modes interact, when the transport schedules are designed, it is necessary to take into consideration the capacity of the involved transport means for assuring the transfer of all travellers.

In a transfer station the following conditions must be met:

1. The continuity of the transport process must be assured - transport schedules correlation;

2. The consistency of transport and traffic capacity for all the facilities must me assured - transport capacities correlation.

The transport schedules must be designed:

- to provide the needed transport capacity;
- to ensure a minimum service frequency needed from the level of service point of view (table 1);
- to ensure the continuity of passengers' travel in case they transfer from one transport mean to another.

Table 1 Level of service (LOS) for transport means frequency (Source: [20])

LOS	Average headway [min]	Frequency [veh./h]	Comments
A	< 10	> 6	A traffic plan (schedule) is not needed
B	10 – 14	5 – 6	The frequency of the service is high but the passengers need to consult a transport schedule
C	15 – 20	3 – 4	Maximum accepted waiting time
D	21 – 30	2	Unattractive service for the passengers that have alternatives
E	31 – 60	1	Services available at hourly intervals
F	> 60	< 1	Unattractive services for all travellers

The transport schedules are based on determining the headways between transport means [1] [3] [4] [9] [10] [11]. If passengers` arrivals are random, headways between vehicles must be equals. If those equal headways are higher than the minimum possible technological intervals for a given technical equipment, then it is possible to reduce the probability of delays` propagation.

The traffic plan is defined by routes and by transport schedules (presented either as a graph or as a timetable).

The traffic plan must be established for each of the h=1, 2, 3, ..., H distinctive lines. For one of these lines, the traffic plan is defined if the following elements are known: - the number of vehicles assigned to the transport line; - the routes; - the transport schedule.

The transport schedule for each transport line must ensure the needed transport capacity and a minimum frequency of service (for the maximum headway) needed from the level of service point of view.

The needed information for designing a schedule for a transport line is given by the estimated passengers volume and by their time and space distribution.

4 Transport schedule correlation for Bucharest metro - rail integrated network

The case study is realised on Bucharest suburban rail network (fig.1) and underground network expected in 2030 (fig.2) [18].

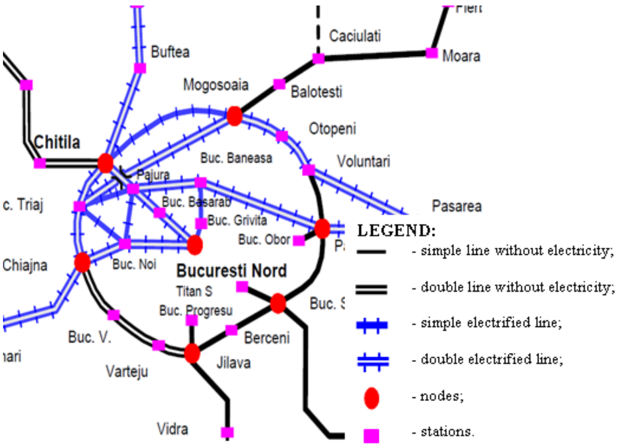

Fig.1 Bucharest suburban rail network [17]

Fig.2 Bucharest underground network in 2030 [6]

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By comparing the two networks [17] and by analyzing and retaining the common nodes, the integrated network from figure 3 can be formed.

Fig.3 The integrated network

To analyze the connections between the two networks (underground and rail network), the integrated network from figure 3 was formalized in figure 4. The intermediate stations on the four transport lines were not represented. Line I (metro line - Dristor – Gara de Nord – Pantelimon) is represented by the unidirectional links 1 and 11; line II (rail - Gara de Nord – Gara Băneasa - Obor) is represented by the unidirectional links 2, 3 and 5; line III (metro line - 1 Mai – Gara Băneasa – Otopeni) is represented by the unidirectional links 6, 4 and 7; line IV (metro line - Gara de Nord – 1 Mai – Lac Străuleşti) is represented by the unidirectional links 9, 8 and 10. The values in the middle of the links represent travel times between transfer stations.

The travel times and the transfer times are known [7] [8]; the transfer times are between 3 an 6 minutes and depend on the distance between the platforms; the headways for the two transport modes are: T_{train}=30min; T_{metro}=10 min.

For the network from figure 4 the transport schedule was designed (fig.5).

Using the linear programming with integer numbers model developed by Potthoff [12], a structure of transport schedules was developed, that provides favourable connections between metro and train lines in the three transfer stations: Gara Băneasa, 1 Mai, Gara de Nord (fig.5). The schedule correlation was elaborated considering the routes characterized by the highest passengers flows.

We note:

Δs_M - the intervals between two vehicles arriving from opposite directions for metro line (it has to be at least equal with the minimum walking time from one platform to another)

Δs_T - the intervals between two vehicles arriving from opposite directions for train line (it has to be at least equal with the minimum walking time from one platform to another)

Δs_{MT}, Δs_{TM} - the intervals between two vehicles corresponding to the two transport modes (it has to be at least equal with the minimum walking time from one platform to another)

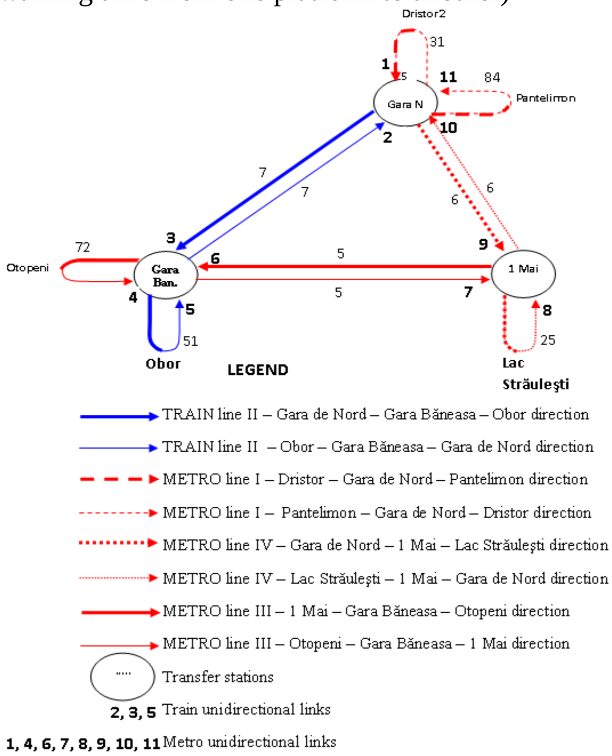

Fig.4 Formalized integrated network

In tables 2.a., 2.b. and 2.c. the timetables for the three transfer stations are presented.

Table 2.a Gara Băneasa timetable

		Headway, T_{train}=30 min		**Headway, T_{metro}=10 min**	
Line		**II** (2, 3, 5)		**III** (4, 6, 7)	
Station \ **Station**		Gara de Nord	Obor	1 Mai	Otopeni
Gara Băneasa	**arrivals**	7	0	3	6
	departures	8	9	7	4

Table 2.b 1 Mai timetable

		Headway, T_{metro}=10 min		
Line		**III** (4, 6, 7)	**IV** (8, 9, 10)	
Station \ **Station**		Gara Băneasa	Gara de Nord	Lac Străuleşti
1 Mai	**arrivals**	1	5	1
	departures	8	8	6

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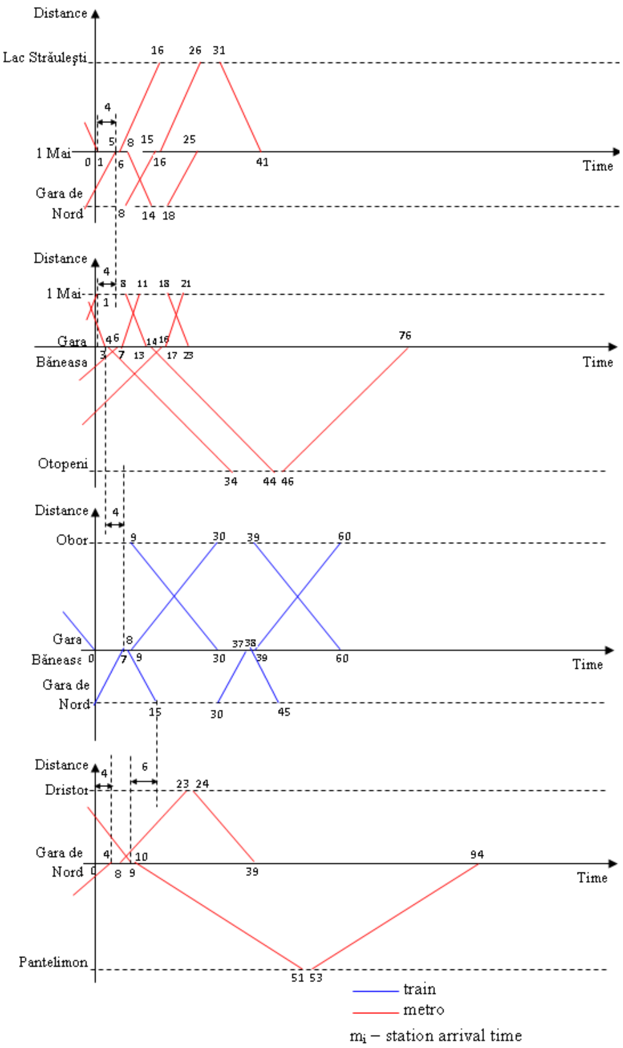
Table 2.c Gara de Nord timetable

		Headway T_{train}=30 min	Headway, T_{metro}=10 min		
Line		II (2, 3, 5)	I (1, 11)		IV (8, 9, 10)
Station \ Station		Gara Băneasa	Pantelimon	Dristor	1 Mai
Gara de Nord	arrivals	15	4	9	4
	departures	0	10	8	8



1 Mai	Gara Băneasa	Gara de Nord
$m_{LacStraulesti} = 1(\bmod T_{metrou}) = 1$ $m_{GaraNord} \equiv m_{LacStraulesti} + \Delta s_M = 5$ $m_{GaraBaneasa} \equiv m_{GaraNord} - \Delta s_M = 1$	$m_{Obor}=0$ $m_{1\ Mai}=3$ $m_{Gara\ de\ Nord}=7$ $m_{Otopeni}=6$	$m_{Gara\ Baneasa}=15$ $m_{Dristor}=9$ $m_{1\ Mai}=4$ $m_{Pantelimon}=4$

Fig.5 Transport schedule correlation in the three transfer stations

5 Conclusions

To emphasize the need of having correlated schedules for providing a continuous travel, the minimum and maximum travel times for a trip with one transfer and for one with two transfers will be determined.

We consider that the trip's itinerary is: Pantelimon – Gara de Nord – Gara Băneasa – Otopeni.

The travel times are presented in table 3.

Table 3 Travel times on Pantelimon – Gara de Nord – Gara Băneasa – Otopeni itinerary

From \ To	Gara de Nord	Gara Băneasa	Otopeni
Pantelimon	41		
Gara de Nord		7	
Gara Băneasa			30

Minimum transfer times in Gara de Nord and Gara Baneasa are 6 minutes.

The travel time for a trip with one transfer (Pantelimon – Gara de Nord – Gara Băneasa) is

Minimum: 41+6+7=54 minutes

Maximum: 41+5+30+7=83 minute

The travel time for a trip with two transfers (Pantelimon – Gara de Nord – Gara Băneasa – Otopeni) is:

Minimum: 41+6+7+6+30=90 minutes

Maximum:41+5+30+7+5+10+30=128 minute

From the designed schedules for the integrated network, the travel times for the two considered trips (with one transfer and with two transfers) are:

I. Pantelimon – Gara de Nord – Gara Băneasa: 41+6+7=54 minutes

II. Pantelimon – Gara de Nord – Gara Băneasa – Otopeni: 41+6+7+6+30=90 minutes

Observe that this coincides with the minimum travel times.

So, by correlating the transport schedules, the travel time for the considered itinerary can be diminished up to 29 minutes for a trim with one transfer and up to 36 minutes for a trip with two transfers.

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