An integrated urban transit service in Bucharest City

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ABSTRACT: The paper studies a solution to improve urban public transport in Bucharest taking into account opportunity for more efficient usage of the two transit modes with the exclusive way that operate at the moment in Bucharest city: metro and light rail transit (LRT). We study the integrated urban transit services by the correlation of metro and LRT schedules and frequencies. Every trip with origin and destination nodes along the integrated transit path will have the minimum trip duration without any inference from traffic road congestion and so, the certainty of trip duration and arrive time. The paper takes into consideration also the main conditions to implement such a public transit, and the effect on car users in favor of the sustainability.

RÉSUMÉ : La communication étudie une solution pour améliorer le transport public urbain à Bucarest en tenant compte de l'opportunité d'une utilisation plus efficace des deux modes de transport avec la voie exclusive qui fonctionne à l'heure actuelle dans la ville de Bucarest : métro et transport ferroviaire léger (TFL). Nous étudions les services de transport urbain intégrés par la corrélation des horaires et des fréquences du métro et du TFL. Chaque trajet avec les points nodaux d'origine et de destination le long de l'itinéraire de transport intégré aura une durée de voyage minimum sans aucune inférence des encombrements sur la route et ainsi, la certitude quant à la durée du voyage et l'heure d'arrivée. La communication prend également en considération les conditions principales pour mettre en oeuvre un tel transport public et l'effet sur des utilisateurs de voiture en faveur du caractère durable.

1 A SHORT REVIEW OF BUCHAREST TRANSPORT ENVIRONMENT

The main issues of the urban public transport in Bucharest City are the following:

1 a relative dense and diversified network of the public transport services (tramway, trolley bus, bus, subway and for a short time a LRT line) (JICA 2000);
2 the motorization is increasing and almost entire road network is congested during the major two peaks of the working days;
3 the uncertainty of the arriving time is increasing for the trips by transport mode which use the domestic street network (bus, trolley bus, tramway);
4 there is a relative low quality of public transport services in terms of:
   - ♦ vehicle frequency in rush hours
   - ♦ the level of vehicle occupancy
   - ♦ the transport lines segmentation
   - ♦ long waiting time in transfer points
   - ♦ lack of the integrated pricing system

5 the personal car is more and more becoming a "status good" which satisfies the relative needs that means it's usage is seen like a social indicia;
6 the lack of coherent educational program in school in favor of sustainable transport;
7 the lack of public information in terms of different public transport opportunities;
8 the two urban transit modes with dedicated infrastructure (LRT and subway) do not use their entire transit capacity.

In Figure 1 there is the scheme of the subway network and the first line of LRT in Bucharest City. Nowadays, the subway network is constituted of four main lines with 62.95 km operational length and 45 stations opened for regular service. The operation of this underground network is insured daily by an average fleet of 50 trains (39 in weekend) transporting about 350000 - 400000 passengers each working day. In 2001, the first light rail transit line was opened. It makes the connection between two dense residential zone from west to north-east of the city, along the second ring of the metropolitan area (LRT is with double line in Figure 1).

The scarcity of space and finances to invest in the new infrastructure capacities and all above issues indicate that there is requirements to urban public transport coordination (to make public transport modes complementary not competitive ones).

The attraction of public transport in Bucharest City can increase and a part of the car users will be tempted to try it only if the public transport quality will increase. This paper will show some solutions for that.

2 GENERALIZED COST OF THE PUBLIC TRANSPORT TRAVEL

The components of the generalized cost of the public transport travel or the usage (or perceived) cost are (Ortuzar&Willumsen 1994):

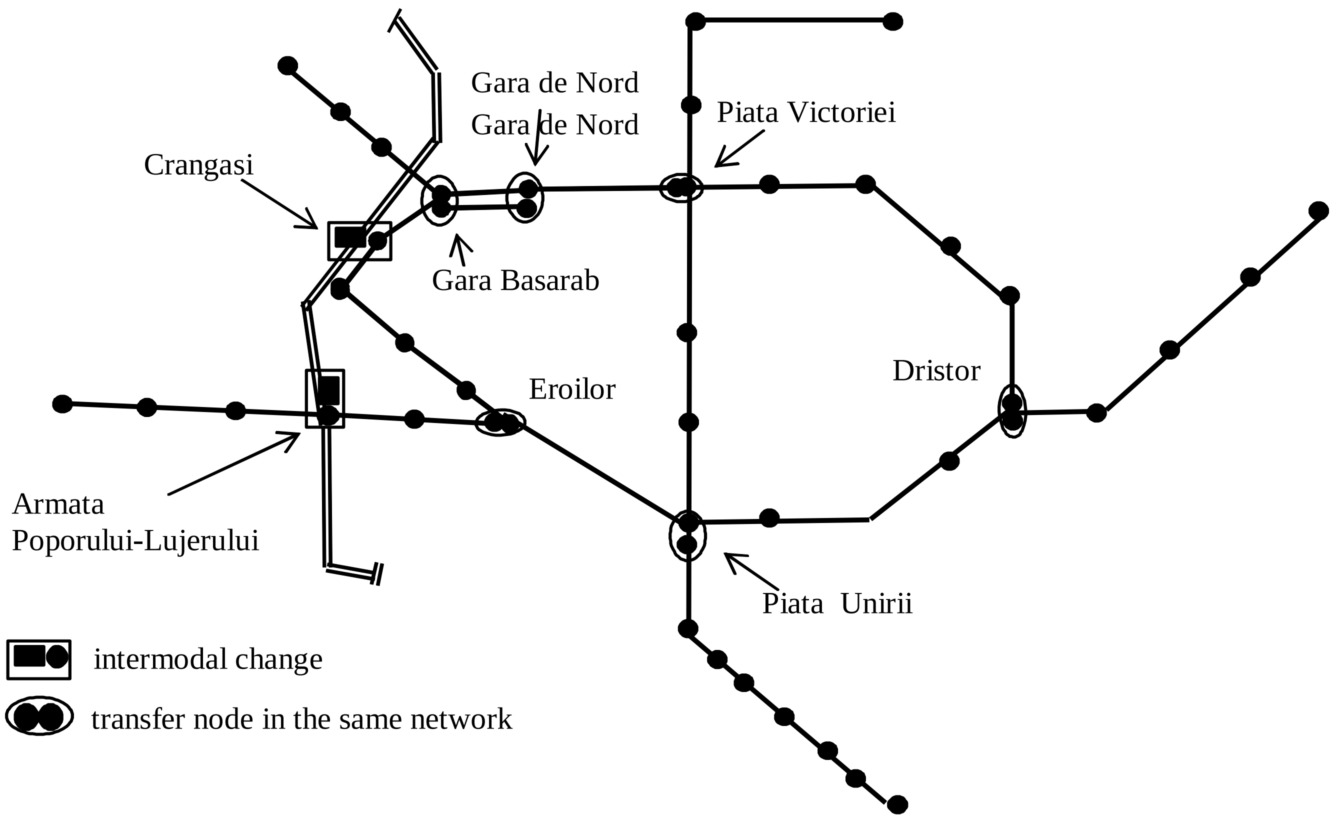

Figure 1. The subway network and the LRT line in Bucharest City

1 a monetary component, derived from the transport operator cost (in Bucharest City this is about 0,2 EUR);
2 the access to the departure station and respectively, the access to the destination station of public transport line;
3 the waiting times in departure and respectively, in destination stations;
4 the line change or/and the change of transport mode;
5 the in-vehicle-time.

The second component has a significant importance to modal split, but it will be perceive like an advantage only if the citizen of the city will receive a school education in favor of sustainable education (the urban environment is the sedentary one). After all, this component is less than the equivalent of about 300-400 m walking.

The component (5) has a high uncertainty in case of those public modes which use the common road infrastructure during peak hours. But, it is a short duration in case of transit modes with dedicated infrastructure like LRT and subway.

The unit cost is a relative low because of the direct subsidies and the social founds to support people with low-income. In Bucharest City, the amount of these subsidies is different for the two main public transport operators (METROREX and RATB).

An integrated public transport will improve the (4) component of the perceived cost.

The solution for the correlation of the schedules in the interchange nodes has practical implications to improve the quality of travel, in the special case of to-work travels. Every trip with origin and destination nodes along the integrated transit path will have the minimum trip duration without any inference from traffic road congestion.

3 THE MODEL CORE OF THE SCHEDULES CORRELATION IN THE INTERCHANGE NODE

There are the follows main types of changes node in transit network (Fig.1):

- simple line change nodes
- transfer nodes in the same mode network
- modern-built interchange facility
- no interchange facility

The scheme of such last node is in Figure 2. The model has a wide generality for any type of interchange.

The model uses the follows notations and abbreviations:

- I_M, I_T=the locations of stations for subway and respectively, for LRT, wich make the interchange node;
- m_i = the arriving time in node from i direction, with i={N,S,E,V};
- N,S = the direction indices for the subway line;
- E,V = the direction indices for LRT line;

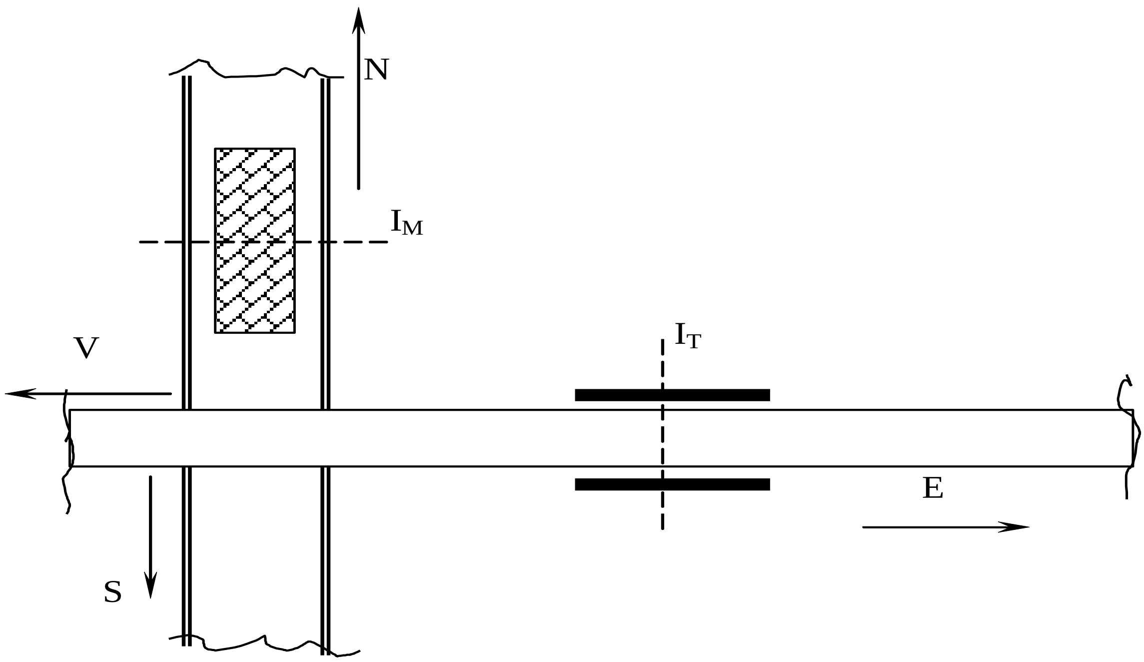

Figure 2. The scheme of change node in transport public network

- Δi_M, Δi_T= headway between vehicles, fixed from the endogenous modal considerations, in case of subway and respectively, LRT;
- θ_{ij} = the waiting time in the node to change i to j direction, i≠j;
- τ_{ij} = the needed time to walk from I_T to I_M (Fig. 2) in each direction change, i≠j.

In case of interchange node (I_T,I_M), based on a real one (Lujerului-Armata Poporului), we consider the follows hypothesis:

$$\tau_{ES} = \tau_{EN} = \tau_{SE} = \tau_{NE} = \tau_1 \qquad (1)$$

$$\tau_{VS} = \tau_{VN} = \tau_{SV} = \tau_{NV} = \tau_2 \qquad (2)$$

From real streets configuration, we have $\tau_1<\tau_2$.

We can reveal the following relations:

$$\theta_{SV} = m_E - m_S - \tau_1 \qquad (3)$$

$$\theta_{SE} = m_V - m_S - \tau_2 \qquad (4)$$

$$\theta_{NV} = m_E - m_N - \tau_1 \qquad (5)$$

$$\theta_{NE} = m_V - m_N - \tau_2 \qquad (6)$$

$$\theta_{VS} = m_N - m_V - \tau_2 \qquad (7)$$

$$\theta_{ES} = m_N - m_E - \tau_1 \qquad (8)$$

$$\theta_{VN} = m_S - m_V - \tau_2 \qquad (9)$$

$$\theta_{EN} = m_S - m_E - \tau_1 \qquad (10)$$

The arriving times in node from i direction - m_i , depending on Δi_M or Δi_T. We consider the congruence relations modulo Δi_M on integer set *Z*, defined by:

$$x \Re y \Leftrightarrow \exists k \in Z \text{ with } x - y = k\Delta i_M$$

and the conventional notation $x \equiv y(\text{mod}\Delta i_M)$. Similarly, for Δi_T, we have a congruence relations modulo Δi_T, $x \equiv y(\text{mod } \Delta i_T)$.

With some convenient summations to eliminate the arriving times in equations system (3)÷(10), we obtain the following relations (or a rectangular equivalent matrix) (Potthoff 1980):

$$\theta_{VS} + \theta_{SE} + \theta_{EN} + \theta_{NV} = -2\tau_1 - 2\tau_2 \quad (11)$$

$$\theta_{NE} + \theta_{VN} + \theta_{SV} + \theta_{ES} = -2\tau_1 - 2\tau_2 \quad (12)$$

These two relations set the reciprocity conditions between waiting times and mode changing times.

The equations system (3)÷(10) has eight unknown variables, which are the θ_{ij} – the waiting time in the node to change i to j direction, with $i \neq j$.

One can determine the needed time to walk from I_T to I_M (or mode changing time) in various congestion conditions, taking into account the real situation. In real case of Lujerului-Armata Poporului interchange, there are two crossings of the main roads with fixed duration of signalized control. From observations in congestion morning peak conditions results τ_1=3 min and τ_2=4 min.

We consider in this analysis the unit passenger flows (i.e. 1000 passengers per hour), from equity reasons for passengers of all eight directions.

Let be these passengers flows Φ_{ij} from i to j directions (and $i \neq j$).

The objective function to improve modal interchange condition is:

$$\sum_{i,j} \Phi_{ij}\theta_{ij} \rightarrow \min \quad (13)$$

and for $\Phi_{ij} = F = ct.$, the objective function is:

$$\sum_{i,j} \theta_{ij} \rightarrow \min, \text{ with } i \neq j.$$

But, the waiting times for modal interchange depend on the arriving times of vehicles and the walking times of passengers. That means the walking conditions, τ_1 and τ_2, are the main variables in case of uncorrelated technical conditions of exploitation (m_i and Δi_M, Δi_T are independent fixed).

The minimizing of the total interchange time requests investments to improve the walking access.

If these improvements are already made (or there is no technical or financial conditions to make improvements), and $\tau_1$and τ_2 are fixed, then it is necessary to improve exploitation conditions in an integrated way.

In that case, the passengers' flows determine the referential mode to start the analysis.

Let's consider the M mode with a higher transit capacity and again Δi_M, Δi_T= headway between vehicles, fixed from the technological modal considerations, in case of subway and respectively LRT (Fig.3).

Then, we consider a time horizontal axe, with 0 time – the vehicle arrival time from N direction (subway line) as a reference point.

Let's also consider the following new notions:

- Δs_M = the intervals between the vehicles arriving from the two direction of the M mode, in I_M.;
- Δs_T = the intervals between the vehicles arriving from the two direction of the T mode, in I_T.;
- Δs_{MT}= the intervals between two vehicles arriving from the two modes, in I_M and I_T like the Figure 3 shows (any other combination is possible, and passengers flows study is decisive for that).

These three intervals derive taking into account the starting service time from starting node, for each of the studied lines.

Obvious, there is some uncertainty about the fullfil the Δs_T and Δs_{MT}, because of the same level intersection with some roads. This implication need to be study in a further researches.

We can reveal the following relations:

$$m_N = 0(\text{mod}\,\Delta i_M) \quad (14)$$

$$m_S = m_N + \Delta s_M = 0(\text{mod}\,\Delta i_M) + \Delta s_M = \\ = \Delta s_M (\text{mod}\,\Delta i_M) \quad (15)$$

$$m_E = m_N + \Delta s_{MT} = 0 + \Delta s_{MT} (\text{mod}\,\Delta i_T) = \\ = \Delta s_{MT} (\text{mod}\,\Delta i_T) \quad (16)$$

$$m_V = m_E + \Delta s_T = \Delta s_{MT} (\text{mod}\,\Delta i_T) + \\ + \Delta s_T (\text{mod}\,\Delta i_T) = (\Delta s_{MT} + \Delta s_T)(\text{mod}\,\Delta i_T) \quad (17)$$

There are also the following conditions:

$$\Delta s_{MT} \geq 0, \Delta s_M \geq 0, \ \Delta s_T \geq 0 \quad (18)$$

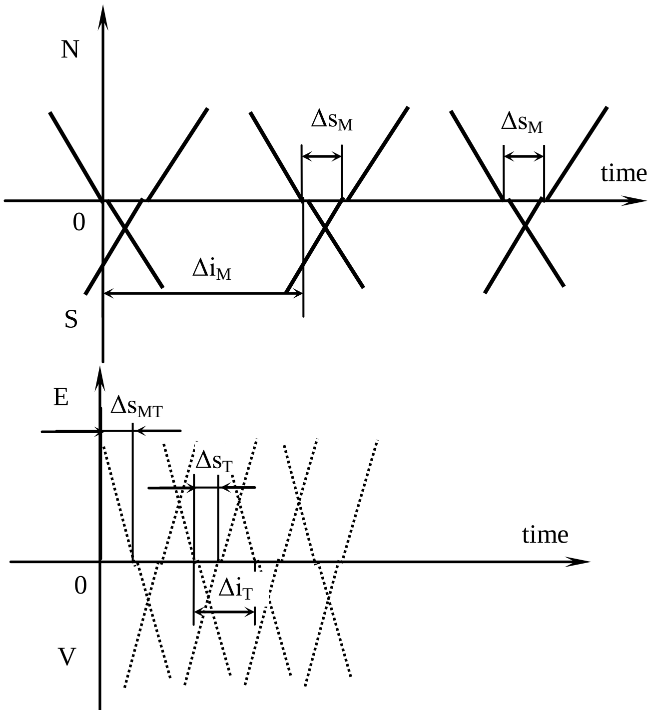

Figure 3. Correlated arrivals in modal node

We determine the passengers flows in peak hours from the O-D matrix using various sources of date, surveys (stated-preferences and revealed-preferences surveys), taking into account the new economic and social settlements and the changes in travel pattern and motorization increasing too.

The amount of passenger.minute has to be a minimum one (rel.(13)). Using the mathematical programming we determine the relative positions in time for the vehicles arriving and also the waiting times for each direction change (in an integrated way).

The major passengers' flows (using or non-using these two public transport modes) derived from O-D matrix suggest the "set of the integrated transport services" to be promoted in an aggressive-commercial manner.

The problem is more complex (but even more incentive one) in case of schedules correlation in two passenger transfer nodes (Fig. 4).

There are three different transport service lines. In this case the velocity of the LRT vehicle between I_{T1} and I_{T2} is the key issue of correlation.

We use also the mathematical programming to solve the system of adequate correlation equations from real situation.

4 THE MAIN ISSUES TO IMPLEMENT AN INTEGRATED PUBLIC TRANSPORT

The quality increase of public transport services requests the correlated schedules of the transit modes (which use the dedicated infrastructure), but into a systematic vision (Fig. 5), which implies:

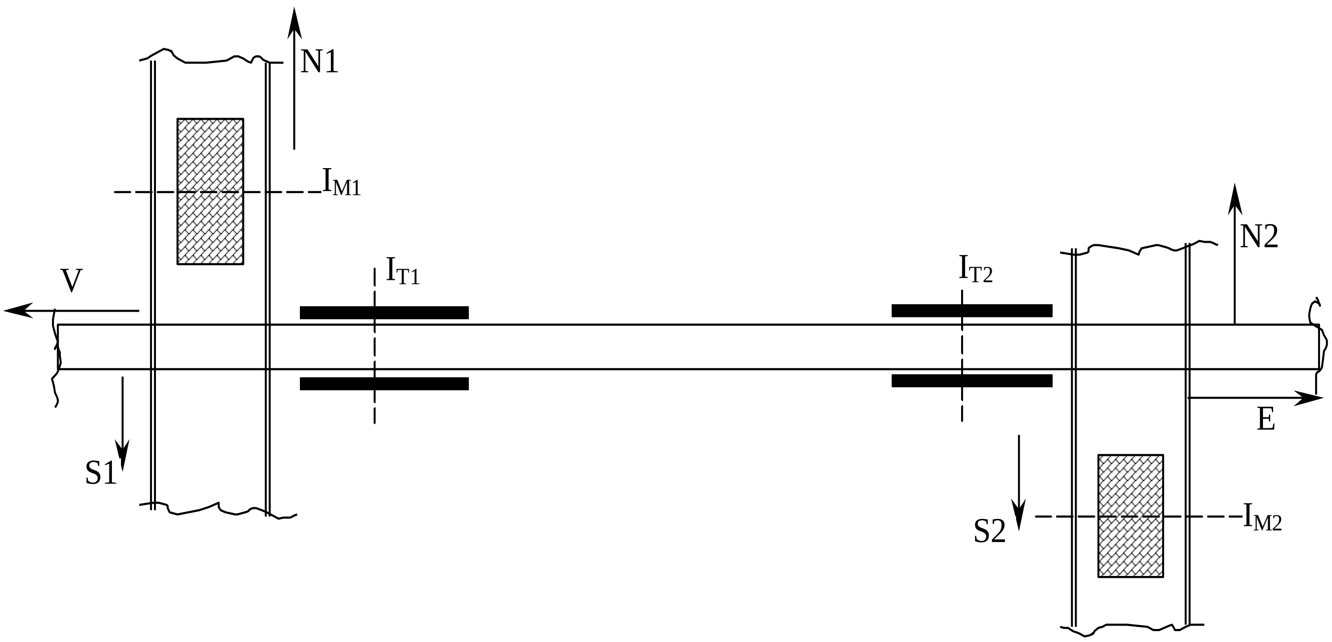

Figure 4. Correlation of schedules in two interchange nodes

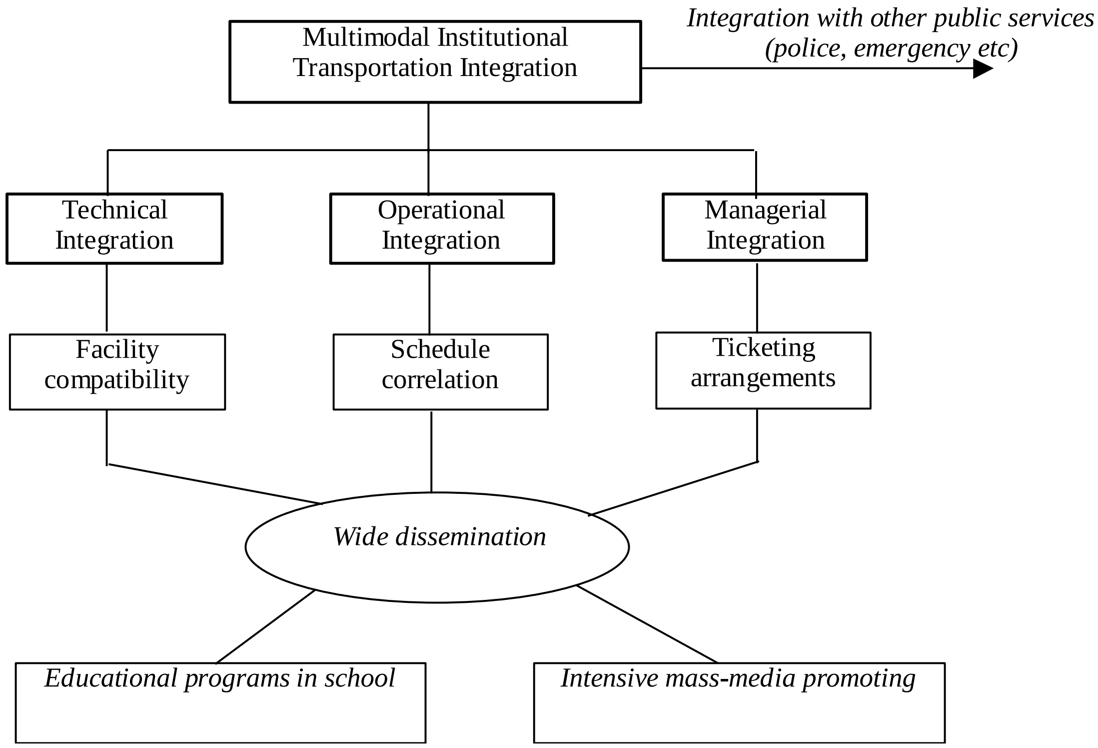

Figure 5. Systematic approach to the integrated public transport services

♦ an institutional integration by a new department with coordination function (to avoid the competition between public modes and to facilitate complementarity of them);
♦ an integration between public and private operators from regional decision level (a higher level);
♦ a technical and commercial integration (with the main component – schedules correlation and the other important parts: common ticketing, information, large promoting, facility improvements etc.) (Hine 2000).

5 CONCLUSIONS

We proposed the integrated urban transit services by the correlation of metro and LRT schedules and frequencies. An integrated service with linked schedules and frequencies is a transit service composed from several modal or/and multimodal segments of transit line, with the property: the generalized cost of trip is minimum one. The schedule of each transit segment is correlated with each other in junction nodes. Every trip with origin and destination nodes along the integrated transit path will have the minimum trip duration without any inference from traffic road congestion.

This integrated service may become a competitive alternative to the car trip, due to its reduced travel time and the certainty of trip duration and arrive moment; these are the relevant issues in the modal split for almost all the users in rough hours.

A technical and commercial integration (with the main component – schedules correlation and the other important parts: common ticketing, information, large promoting, facility improvements etc.) is a first stage of the needed wide future correlation between transport and urban land use in Bucharest City.

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