

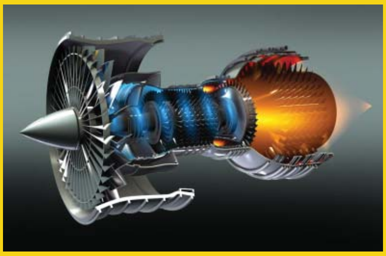




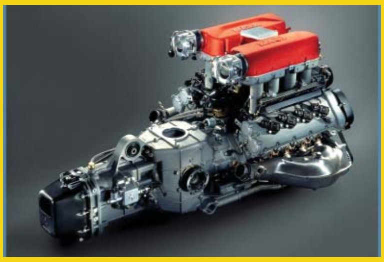

Technical University of Sofia

50 Years Faculty of Transport

ANNIVERSARY SCIENTIFIC CONFERENCE on Aeronautics, Automotive and Railway Engineering and Technologies

BulTrans-2013

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INVESTIGATION OF THE ORGANIZATION OF METRO LINES IN ISTANBUL

SVETLA STOILOVA
Faculty of Transport, Technical University,
Sofia, Bulgaria
stoilova@tu-sofia.bg

VESELIN STOEV
Faculty of Transport, Technical University,
Sofia, Bulgaria
veselin.v.stoev@gmail.com

MUSTAFA SISMAN
Faculty of Transport, Technical University,
Sofia, Bulgaria

Abstract:
In the study has been done the research on urban railway transport in Istanbul. The interaction between metro line Ataturk Airport – Aksaray and tram lines in Istanbul are studied. Is used a linear mathematical model to optimize the time of contact in the contact points of the metro line and tram lines. Criterion for optimization is the reduction to a minimal level of the transport vehicles stay from different destinations, permitting to establish connection in the transport junctions of the transport network. In carrying out the optimization is taken into account the intervals. For the implementation of the optimal solution are proposed the changes in the schedule of the surveyed metro line and routes and the trams.

Keywords: *urban railway transport, metro line, tram, time connection, linear optimization.*

1. Introduction

Public transport in Istanbul comprises a bus network, various rail systems, funiculars, and maritime services to serve the more than 13 million inhabitants of the city spread over an area of 5712 km². The most efficient and cheap way to get from A to B in Istanbul by public transportation is undoubtedly by metro, tram, funicular and ferry. These means of public transportation are very efficient, quick and punctual.

To reduction of time during needed to travel is very important the links between transport lines in the contact points to be synchronized.

In this article is made a research of connections between metro lines and tram lines in Istanbul. The tasks are: to analyze the connections between the metro line M1 and tram lines; to optimize the time connection; to offer a scheme of organization with synchronized links in contact points.

2. Istanbul transportation: an overview

Transportation in Istanbul mainly relies on road-based transportation (92,3%), followed by rail (5.5%) and water (2.2%), as [1], [2] and [4]. Overall, 53 percent of the population use one or more forms of public transportation, including commuter rail, metro, light rail, and extensive networks of bus and minibus services. In Istanbul are 17 different ways of transportation, more than 57,000 private operator, 3 local administration operator (there is operator for metro and tram system) and 1 Government operator (TCDD – railway transport), as [8]. Ulasim is the operator of the Istanbul metro, light rail, tram and aerial cable car and covers all disciplines, from planning design and consultancy, [9].

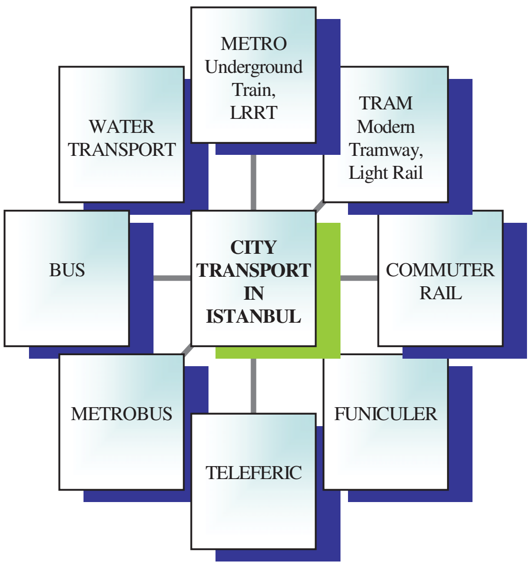

Fig. 1. Type of public transport in Istanbul

In fig. 1 is shown the different types of Istanbul's public transport.

Istanbul has a metro (8,5 km), a light metro (19,3 km), three tramways (32 km), two funiculars (1,2 km) two "historic" tramways (4,2 km), suburban railways (72 km), and two cable car lines (0,2) km with a total rail network of 138 km, as [4]. A series of major investments are now planned to extend the urban rail network to 265 km by 2013.

The Istanbul LRRT (Light Metro), which consists of the M1 and T4 lines, is a light metro system. Light rail is typically an urban form of public transport using steel-tracked fixed guide ways that operate primarily along exclusive rights of way and have vehicles capable of operating as a single train or as multiple units coupled together. The modern tram T1 of Istanbul is a modern tramway system on the European side. In fig. 2 is shown scheme of Istanbul's railway public transport, as [8].

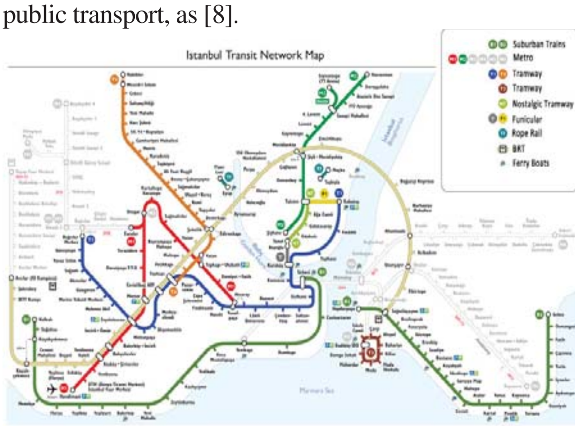

Fig. 2. Scheme of Istanbul's railway public transport

Table 1. Operational data

Line	M1	T1	T4
Destination	Aksaray-Ataturk Airopart	Kabatas - Bagcılar	Topkapi-Habibler
Mode	LRRT*	Modern Tramway	Light Rail
Operational data			
Line Length	19,6	18,5	15,3
Number of stations	18	31	22
Number of cars	85	92	78
Trip Duration, min.	32	65	42
Operational hours	06:00-00:00	06:00-00:00	06:00-00:00
Daily ridership, passengers / day	220 000	320 000	95 000
Number of Daily Trips per direction	180	295	165
Frequency, minutes during peak hours	5	2	5
Average Speed, m/h	36,7	29,2	21,9

The first line of LRRT M1 began service on 1989 between Aksaray and Kartaltepe. The line was further developed step-by-step and reached Ataturk Airport on 2002. Other line of LRRT T4 was opened in 2007. Service is operated with LRT vehicles built by ABB (a multinational corporation headquartered in Zurich, Switzerland). A fast tram T1 was put in service in 1992 on standard gauge track with modern cars, connecting Sirkeci with Topkapi .

Table 1 show operational data for studied lines according to the information given in [2], [7] and [9].

In table 2 is shown the parameters for periods per day for studied lines, as [9].

Table 2. Parameters for line M1

№	Period	Duration, min	Interval, min	Number of vehicules
Line M1				
1	6:00-6:30	30	10	3
2	6:30-7:30	60	7	8
3	7:30-8:30	60	5	12
4	8:30-16:00	480	6	75
5	16:00-20:00	240	5	48
6	20:00-21:30	90	6	15
7	21:30-23:00	120	7	12
8	23:00-00:00	60	10	7
Line T1				
1	6:00-6:30	30	10	3
2	6:30-19:15	765	5	153
3	19:15-20:30	75	7	10
4	20:30-23:12	162	10	17
Line T4				
1	6:00-7:00	30	10	3
2	7:00-7:30	30	7	8
3	7:30-8:00	30	5	12
4	8:00-9:00	60	6	75
5	9:00-16:30	450	7	48
6	16:30-20:15	225	5	15
7	20:15--21:15	60	7	12
8	21:15-00:05	170	10	7

3. Method for optimization the time connections in junctions

The optimal interaction of the vehicles in the transport junctions is defined by the minimum duration of the passengers stay for realizing connection between the transport vehicles.

"Connection" means the time interval from the arrival of the vehicle from a direction to the moment of departure of the vehicle from the same point to another direction.

The transport system is represented as one connected junction's structure, as [6]. For every part between two junctions is stated transport servicing, for which we can determine the minute of departure X_i. The minute of arrival X_j in the next junction is fixed depending on the minute of departure from the previous junction and the time travel between both transport junctions t_i, i.e. $X_j = X_i + t_i$, min.

For the big urban agglomerations with metropolitan railway, the optimal interaction is important between the route lines of the underground and the other types of urban transport. The places for connection realization, i.e. the points with equal time intervals of traffic, in this case are the subway stations. The basic unknown are the minutes of departure of the subway trains from the initial to the final station X_m and the minutes of vehicles departure from an initial to a final station X_i of the corresponding type of urban transport which makes contact with the metropolitan railway.

Criterion function of the urban transport looks as follows:

$$\sum_{m=1}^{M}\sum_{k=0}^{K}\sum_{i=M+1}^{I}\left(X_m+\sum_{k=0}^{K-1}t_{k,k+1}+\sum_{k=0}^{K}t_{s,k}\right)- \left(X_i+t_{i,k}+t_{p,ik}\right)]+\sum_{v=I+1}^{V}X_v \rightarrow min, \qquad (1)$$

where: k is the serial number of a subway station; $k = 0,...,K$; X_m is the minute of departure of the subway train from an initial/final/ station of the subway; $m = 1,...,M$; X_i is the minute of vehicle departure from the initial station of the corresponding type of urban transport /tramway, trolleybus, autobus/ which make contact with the metropolitan railway, min; $i = M+1,...,I$ is the serial route number of the urban transport. $\sum_{k=0}^{k-1}t_{k,k+1}$ - is the time travel of the subway train, between two neighbor stations of the subway, min; $t_{i,k}$ is the time travel from an initial/final/ station of the urban transport to the contact station with the subway, min.; $t_{p,ik}$ is the duration of the passenger movement from the contact station of the urban transport to k subway station, min; X_v is additional unknown, introduced in order to limit the negative values taking and values exceeding the fixed value of X_i; $v = I+1,...,V$ is the number of the connections between the routes of the urban transport and the metropolitan railway, min.

On fig.1 is shown a contact point for realization of connection, for which are indicated the unknowns and the connection between the route of the metropolitan railway and the urban transport route.

The task may be resolved under the following restricting conditions:

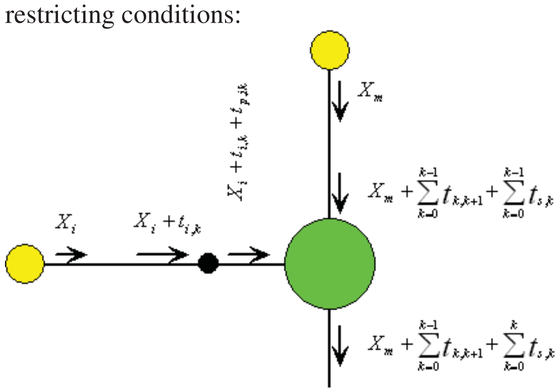

Fig.3. Contact point for realization of the connection with the urban transport

1. For the basic unknown

As the basic unknowns represent the minute of departure, they may take values from 0 to 59 minutes. To facilitate the task, the minutes shall be transformed in hour hundredths. All basic unknowns must meet the following conditions:

$$0 \le X_i < 1 \qquad 2)$$

2. For the duration of the connection

$$t_{\min,k} \le X_m + \sum_{k=0}^{k-1}t_{k,k+1} + \sum_{k=0}^{k}t_{s,k} - (X_i + t_{i,k} + t_{p,ik}) + X_v \le t_{\max,k} \qquad (3)$$

where: $t_{\min,k}$, $t_{\max,k}$ are the minimal and the maximal time for connection.

The minimal time for connection $t_{\min,k}$ is stated depending on the minimal time required for the passengers to change the vehicle. The maximal time for connection $t_{\max,k}$ depends on the value of the passenger stream, realizing connection.

3. For the subsidiary whole number round variable quantities:

For the variable quantities X_v are stated upper and lower limits, i.e.:

$$X_{v,\max} \ge X_v \ge X_{v,\min} \qquad (4)$$

Maximum value of the time for connection is 1, when:

$$X_m + \sum_{k=0}^{k-1}t_{k,k+1} + \sum_{k=0}^{k}t_{s,k} = 1, \quad X_i + t_{i,k} + t_{p,ik} = 0 \qquad (5)$$

The minimum value of the time for connection has the value of –1, when:

$$X_m + \sum_{k=0}^{k-1}t_{k,k+1} + \sum_{k=0}^{k}t_{s,k} = 0, \quad X_i + t_{i,k} + t_{p,ik} = 1 \qquad 6)$$

If is indicated the maximum and the minimum value of the time for connection with M=1 and m=-1 in the equations which characterize the connections, is shall received:

$$t_{\min,k} - M \geq X_v \geq t_{\max,k} - M,$$
$$t_{\min,k} - m \geq X_v \geq t_{\max,k} - m \quad (7)$$

In order not to exclude any possible resolution of the above formulas, are fixed $X_{v,\max}$, $X_{v,\min}$, i.e.

$$X_{v,\min} \leq t_{\min,k} - m = t_{\min,k} + 1,$$
$$X_{v,\max,k} \geq t_{\max,k} - M = t_{\max,k} - 1 \quad (8)$$

4. Determination of the starting hour and minute of the departure of the vehicle for each route line

After receiving the optimal results are made corrections according to the time period per day and interval of movement of vehicles. The periods per day are formed depending on number of passenger and interval of movement of vehicles.

The adjustments to the resulting optimal values of the moments of departure allows keeping the number of vehicles in the relevant time period.

For each route line should be known the information given in the table 3.

Table 3. Parameters of periods

Line q				
№	Period	Duration, min	Interval, min	Number of vehicules
1	$P_{11} = P^{*}_{11} \div P^{**}_{11}$	T_{11}	I_{11}	N_{11}
…	…	…	…	…
z	$P_{zq} = P^{*}_{zq} \div P^{**}_{zq}$	T_{zq}	I_{zq}	N_{zq}
…	…	…	…	…
Z	$P_{ZI} = P^{*}_{ZI} \div P^{**}_{ZI}$	T_{ZI}	I_{ZI}	N_{ZI}

$z = 1,\dots,Z$ are the number of time period; * is the start of the time period; ** is the finish of the time period; $q = m, i = 1,\dots,M, M+1,\dots,I$ is the number of line of transport (subway and another that are a link in the contact points of the metro).

For the periods per day is effective the following relation:

$$T_{zq} \geq I_{zq}, \text{ min} \quad (9)$$

The number of vehicles for line q and period z is:

$$N_{zq} = \text{int}\left[T_{zq} / I_{zq}\right]_{\max}, \text{ number} \quad (10)$$

Determination of the starting hour and minute of the departure of the vehicle for each route line is made taking account the formulas below:

$$X_{zq}^{*} = X_{zq} - I_{zq}.k, \quad (11)$$
$$k = -N_{zq},\dots,0,\dots,(N_{zq} - 1)$$

X_{zq} is the value of the optimal solution for line q received by the model, X_{zq}^{*} is the corrected value taking account for intervals, P^{*}_{zq} is the initial minute of the interval.

There are two cases:

- First case: $X_{zq} \geq P^{*}_{zq}$

If $X_{zq} \in \left[P^{*}_{zq} \div [P^{*}_{zq} + (I_{zq} - 1)]\right] \Rightarrow k = 0$;

$$X_{zq}^{*} = X_{zq} \quad (12)$$

If $X_{zq} \in \left[(P^{*}_{zq} + I_{zq}) \div [P^{*}_{zq} + (2I_{zq} - 1)]\right] \Rightarrow k = 1$;

$$X_{zq}^{*} = X_{zq} - I \quad (13)$$

If $X_{zq} \in \left[(P^{*}_{zq} + 2I_{zq}) \div [P^{*}_{zq} + (3I_{zq} - 1)]\right] \Rightarrow k = 2$;

$$X_{zq}^{*} = X_{zq} - 2.I_{zq} \quad (14)$$

If $X_{zq} \in \left[[P^{*}_{zq} + (N_{zq} - 1)I_{zq}] \div [P^{*}_{zq} + (N_{zq}I_{zq} - 1)]\right]$

$$\Rightarrow k = N_{zq} - 1; \quad X_{zq}^{*} = X_{zq} - (N_{zq} - 1).I_{zq} \quad (15)$$

Another case to determine the corrected value of unknown is using the number of interval periods in time period. The number of interval periods in time period is equal to number of vehicles in time period.

Let $n = 1,\dots,N_{zq}$ is the sequence number of the interval in time period. Taking into account the formulas above can be written:

$$k = n - 1 \quad (16)$$

Given the formula 11 is should:

$$X_{zq}^{*} = X_{zq} - (n - 1).I_{zq} \quad (17)$$

- Second case: $X_{zq} < P^{*}_{zq}$

If $X_{zq} \in \left[(P^{*}_{zq} - I_{zq}) \div (P^{*}_{zq} - 1)\right] \Rightarrow k = -1$;

$$X_{zq}^{*} = X_{zq} + I_{zq} \quad (12)$$

If $X_{zq} \in \left[(P^{*}_{zq} - 2I_{zq}) \div [P^{*}_{zq} - (I_{zq} + 1)]\right] \Rightarrow k = -2$;

$$X_{zq}^{*} = X_{zq} + 2I_{zq} \quad (13)$$

If $X_{zq} \in \left[(P^{*}_{zq} - 3I_{zq}) \div [P^{*}_{zq} - (2I_{zq} + 1)]\right] \Rightarrow k = -3$;

$$X_{zq}^{*} = X_{zq} + 3.I_{zq} \quad (14)$$

If $X_{zq} \in \left[(P^{*}_{zq} - N_{zq}I_{zq}) \div [P^{*}_{zq} - [(N_{zq} - 1)I_{zq} + 1)]]\right]$

$$\Rightarrow k = -N_{zq}; \quad X_{zq}^{*} = X_{zq} + N_{zq}.I_{zq} \quad (15)$$

Taking into accout the sequence number of the interval in time period can be written:

$$k = 1 - n \quad (16)$$

Given the formula 11 is should:

$$X_{zq}^{*} = X_{zq} - (1 - n).I_{zq} \quad (17)$$

The table 4 shows the interval periods in one time period and the values of k and n.

In figure 4 is shown a scheme for determination the corrected values of the unknown.

Table 4. Dimension of interval periods

	n	Period	k
$X_{zq} < P^*_{zq}$	$N_{zq}-1$	$X_{zq} \in \lfloor(P^*_{zq} - N_{zq}I_{zq}) \div [P^*_{zq} - [(N_{zq}-1)I_{zq}+1)]]\rfloor$	$-N_{zq}$
	-	…	…
	3	$X_{zq} \in \lfloor(P^*_{zq} - 2I_{zq}) \div [P^*_{zq} - (I_{zq}+1)]\rfloor$	-2
	2	$X_{zq} \in \lfloor(P^*_{zq} - I_{zq}) \div (P^*_{zq} - 1)\rfloor$	-1
$X_{zq} >= P^*_{zq}$	1	$X_{zq} \in \lfloor P^*_{zq} \div [P^*_{zq} + (I_{zq}-1)]\rfloor$	0
	2	$X_{zq} \in \lfloor(P^*_{zq} + I_{zq}) \div [P^*_{zq} + (2I_{zq}-1)]\rfloor$	1
	3	$X_{zq} \in \lfloor(P^*_{zq} + 2I_{zq}) \div [P^*_{zq} + (3I_{zq}-1)]\rfloor$	2
	…	…	…
	N_{zq}	$X_{zq} \in \lfloor[P^*_{zq} + (N_{zq}-1)I_{zq}] \div [P^*_{zq} + (N_{zq}I_{zq}-1)]\rfloor$	$N_{zq}-1$

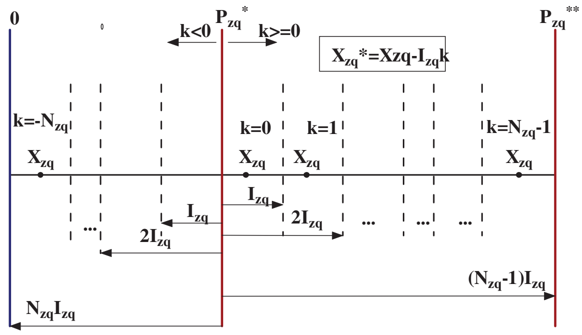

Fig. 4. Determination the corrected values of the unknown

Example for determination a value of start minute of departure

Let the first time period is 6:20-7:20, I=7 min, $\Rightarrow$ P*=20; T=60 min.

The number of vehicles is:

$$N = \text{int}\left[{T}/{I}\right]_{\max} = {60}/{7} = 9$$

In table 5 is shown the duration of interval periods in time period.

Table 5. Duration of interval periods

№	n	Interval Period	k
-	4	5:59-6:05	-3
-	3	6:06-6:12	-2
-	2	6:13-6:19	-1
1	1	6:20-6:26	0
2	2	6:27-6:33	1
3	3	6:34-6:40	2
4	4	6:41-6:47	3
5	5	6:48-6:54	4
6	6	6:55-7:01	5
7	7	7:02-7:08	6
8	8	7:09-7:15	7
9	9	7:16-7:23	8

Let the value of unknown is X=37 $\Rightarrow$ X>P*.

According to table 3 and table 5 $\Rightarrow$ k=2; n=3.

According to formulas (11) and (17):

$X^* = X - I.k = 37 - 7.2 = 23$

$X^* = X - I.(n-1) = 37 - 7.(3-1) = 23$

This means that the start time of departure according to the optimal solution is 6:23.

Let X=8 $\Rightarrow$ X<P*.

According to table 3 and 5 $\Rightarrow$ k=-2; n=3.

According to formulas (11) and (17):

$X^* = X - I.k = 8 - 7.(-2) = 22$

$X^* = X - I.(1-n) = 8 - 7.(1-3) = 22$

This means that the start time of departure according to the optimal solution is 6:22.

5. Determination of the duration the time for connection

The duration of time for the connection depend on the duration of the intervals between the vehicles for each lines of transport.

Let the intervals of movement for lines of transport i and j which connections will be synchronized in time period z are I_{zi} and I_{zq}. For the first line $q = i$, for the second line $q = j$.

For brevity let:

$I_{zi} = I_i$; $I_{zj} = I_j$, min (18)

There are two cases:

- The first is $I_i = I_j$, min; (19)
- The second is $I_i \neq I_j$,min. (20)

When $I_i = I_j$, the connections between the lines of transport are equal. In this case is realized the maximum number of connection with optimal duration.

When $I_i \neq I_j$ there is the snooze time for times for connections.

The value of snooze time depends of intervals. When the intervals are multiples the snooze time of the duration of the links in time period z is:

$I_p = \max(I_i, I_j)$, min (21)

In this case the duration of connections is equals.

Otherwise the snooze time of the duration of the links in time period z is:

$I_p = I_i.I_j$, min (22)

The number of connections in the snooze time when the intervals are multiples is

$B = \min({I_i}/{k}, {I_j}/{k})$, (23)

where k is the common divisor of the intervals.

The number of connections in the snooze time when the intervals are not multiples is

$B = \min(I_i, I_j)$ (24)

The duration of the connection depending on the interval is:

$$W_r = r.I_j - s.I_i \text{ , min} \quad (25)$$

$$r = 1,\dots,I_i \text{ ; } s = 0,\dots,(I_j - 1)$$

If $W_{r-1} \geq t_{\min} \Rightarrow W_r = r.I_j - s.I_i$, min (26)

If $W_{r-1} < t_{\min} \Rightarrow W_r = r.I_j - (s-1).I_i$, min (27)

where $t_{\min}$ is the minimal time of connection, min.

When $W_{r-1} < t_{\min}$ there are two cases:

- The first case is when
- $W_r = r.I_j - (s-1).I_i \geq t_{\min}$, min (28)

$\Rightarrow W_{r+1} = (r+1).I_j - s.I_i$, min (29)

- The second case is when

$W_r = r.I_j - (s-1).I_i < t_{\min}$, min (30)

$\Rightarrow W_{r+1} = (r+1).I_j - (s-2).I_i$, min (31)

The general form of the formula is:

$W_{r+1} = (r+1).I_j - (s-h).I_i$, min, (32)

where h is the serial number of case when the condition (31) is not satisfied.

The determination of time connections should be determined for each time period.

Example

Let route line 1 and route line 2 witch connections will be synchronized have intervals respectively $I_1 = 5$ min; $I_2 = 4$ min. In figure 4 is shown a scheme of intervals.

The snooze time according to formula (22) is $I_p = I_1.I_2 = 20$ min.

The number of connections in the snooze time according to formula (24) is $B = \min(I_1, I_2) = 4$.

The duration of connections according to formulas (24) is:

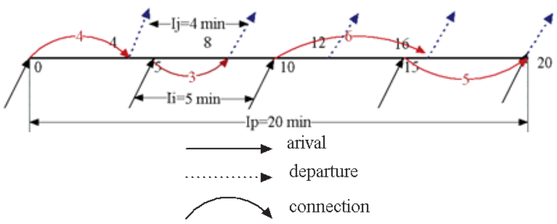

Fig. 4. Scheme of intervals

$W_1 = 1.I_2 - 0.I_1 = 4$ min

$W_2 = 2.I_2 - 1.I_1 = 3$ min

$W_3 = 3.I_2 - 2.I_1 = 2 < t_{\min}$

According to formulas (25), (26), (27):

$W_4 = 4.I_2 - (3-1).I_1 = 6$ min

$W_5 = 5.I_2 - 3.I_1 = 5$ min

6. Approbation of the methodology

For each node the equations define the relations representing the difference between the time of departure and arrival time of vehicles contacting the node. According to the methodology for each equation is introduced an additional unknown. Equations are made in the direction.

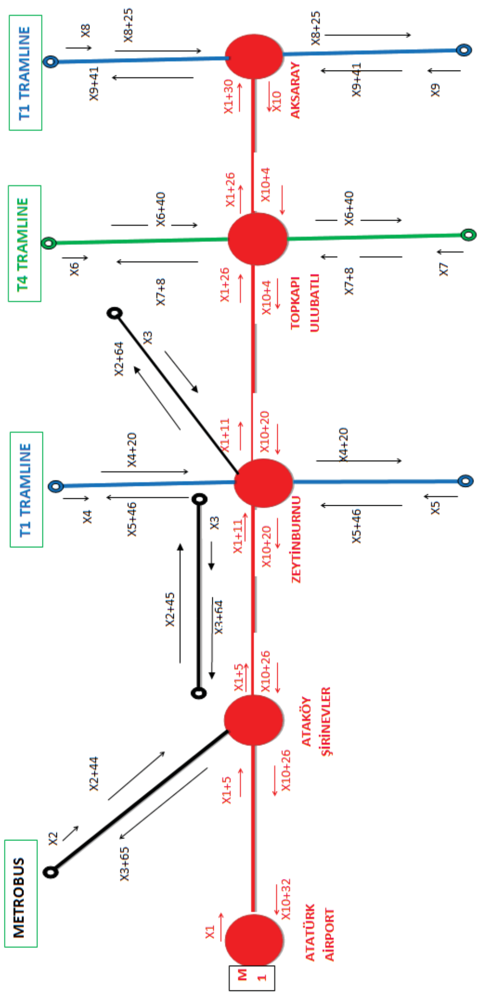

Fig. 5. Scheme for connections

Fig. 6. Maps of lines and junctions for connection

In figures 5 and 6 is shown the scheme of unknowns and the maps of studied lines.

The task is with the following dimensions:

- 10 basic unknown;
- 24 additional unknown;
- Number of equations links = 48;

- Number of equations for the upper and lower limits of the additional unknowns - 48.
- Total number of equations = 96.

In fig.7 is shown the scheme of connections in junction Topkapi.

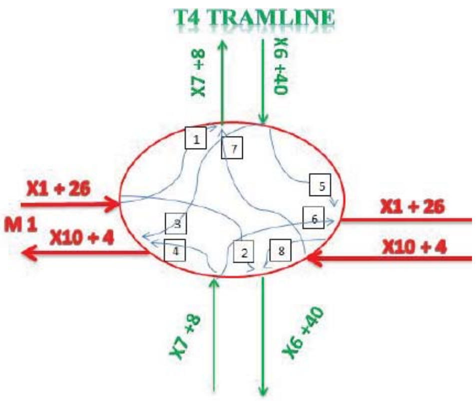

Fig. 7. Scheme of connection in Topkapi.

The formulas (33) present the equations for connections for junction Topkapi. The unknowns X1 ÷ X10 are basic; the unknowns X23 ÷ X30 are additional.

For solving linear optimization model is used MS Excel – Solver.

$$\begin{aligned}
&1)\ (X_7+8)-(X_1+26)+X_{23} \geq 5\\
&\ \ \ (X_7+8)-(X_1+26)+X_{23} \leq 10\\
&2)\ (X_6+40)-(X_1+26)+X_{24} \geq 5\\
&\ \ \ (X_6+40)-(X_1+26)+X_{24} \leq 10\\
&3)\ (X_{10}+4)-(X_6+40)+X_{25} \geq 5\\
&\ \ \ (X_{10}+4)-(X_6+40)+X_{25} \leq 10\\
&4)\ (X_{10}+4)-(X_7+8)+X_{26} \geq 5\\
&\ \ \ (X_{10}+4)-(X_7+8)+X_{26} \leq 10\\
&5)\ (X_1+26)-(X_6+40)+X_{27} \geq 5 \qquad (33)\\
&\ \ \ (X_1+26)-(X_6+40)+X_{27} \leq 10\\
&6)\ (X_1+26)-(X_7+8)+X_{28} \geq 5\\
&\ \ \ (X_1+26)-(X_7+8)+X_{28} \leq 10\\
&7)\ (X_7+8)-(X_{10}+4)+X_{29} \geq 5\\
&\ \ \ (X_7+8)-(X_{10}+4)+X_{29} \leq 10\\
&8)\ (X_6+40)-(X_{10}+4)+X_{30} \geq 5\\
&\ \ \ (X_6+40)-(X_{10}+4)+X_{30} \leq 10
\end{aligned}$$

An advantage of linear programming is that one can obtain several optimal solutions. In this study, are obtained ten optimal solutions. For practical realization a results is chosen this solution, which has good minutes of departure for passengers.

In table 6 is presented the results of research. According to the model the value of the unknowns is obtained in hour hundredths. After that they are transformed into minutes, as is shown in the table.

After obtaining the values of unknowns, they are corrected according to the intervals periods. Thus are received the initial minutes of departure of the studied route lines from the starting station. In table 7 is shown the corrected value of unknown.

Table 6. Results

Unknown	**X1**	**X2**	**X3**	**X4**	**X5**
Result	0,5	0,9	0,0	0,5	0,0
min	30	53	0	28	2
Unknown	**X6**	**X7**	**X8**	**X9**	**X10**
Result	0,3	0,4	0,0	0,5	0,4
min	21	26	0	31	25

Table 7. Corrected value of unknown

For tram line T1:	
Unknown value	Corrected value
X_4=28	X^*_4=58
X_5=2	X^*_5=02
For tram line T4:	
X_6=21	X^*_6=59
X_7=26	X^*_7=04
For metro line M1:	
X_1=30	X^*_1=00
X_{10}=25	X^*_{10}=55

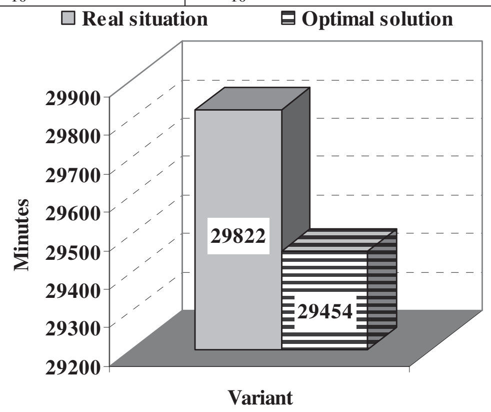

Fig. 8. Total time of connections

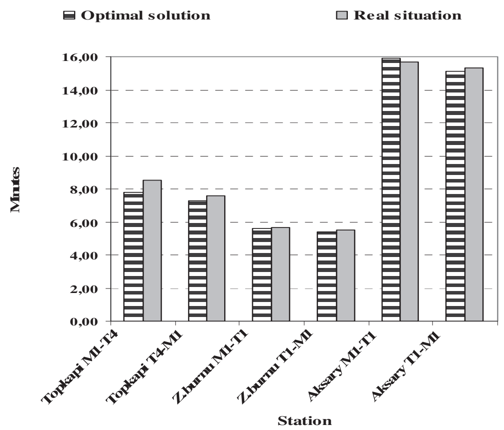

Fig. 9. Average time of connection, min

Taking into account the input received minutes of departure and intervals in the periods per day is obtained the schedule of movement of vehicles. Thus ensure optimum times of connection in the junctions.

Fig.8 show total time of connections for all stations per day. Fig. 9 shows a comparison of average time of connections between real situation and the results of optimal solution by model. The total time for interaction for optimal solution is reduced with 1 minute for one connection. For all day the reduction is about 370 minutes.

The maximum connection time for the proposed organization reduces the average of six minutes compared to the present situation of connections.

7. Conclusions

The new in this study is:

- The method of linear optimization is applied to synchronization the connections of vehicles in transport junctions.
- Formulas for calculation the times of connections according to intervals between the vehicles for each lines of transport are determined.
- In the paper are determined the relations to calculate the start time of departure of vehicles for each line of transport, depending on the interval of movement and optimal results on the model.

The performed research offers the reason to make the following conclusions:

- The study results suggest the potential ability of using presented metodology for optimal synchronization the connections between transport lines in junctions.
- For the implementation of the optimal solution are proposed the changes in the schedule of the surveyed metro line and trams lines.
- Now the organization of metro and tram transport is elaborated using expert method. At present the start time of departure of vehicles from the base station is 6 o'clock. The proposal to change the starting hours of the departure from the base station is:

For tram line T1:

- Station Bagcilar: The start hour is: 5:58
- Station Kabatas: The start hour is: 6:02

For tram line T4:

- Station Habibler: The start hour is: 5:59
- Station Topkapı: The start hour is: 6.04

For metro line M1:

- Station Ataturk Airport: The start hour is: 6:00.
- Station Aksaray: The start hour is: 5:55

For the urban conditions, the optimization model provides synchronization and rhythm in the organization of the different types of urban transport.

This method is elaborated concerning the optimization of the interaction of the vehicles in the transport junctions. It's applicable for the highway transport systems and mixed interurban - urban transport.

The method can be aplayed for synchronization the connections between vehicules in juctions for all day period or for each time period during the day.

The transport organization with synchronized connection in the transport junctions is a base for elaboration a table time with optimal intervals for vehicles traffic.

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Svetla Stoilova is Assoc. Prof. PhD, Department of Rail Engineering, Faculty of Transport

Veselin Stoev is Mas. Eng. PhD student, Department of Rail Engineering, Faculty of Transport

Mustafa Sisman is from Turkey, Bac.Eng. Information Technology of Transport, Technical University of Sofia

ИЗСЛЕДВАНЕ НА ОРГАНИЗАЦИЯТА НА МЕТРО ЛИНИИТЕ В ИСТАНБУЛ

доц. д-р Светла Стоилова, докт. Веселин Стоев и инж. Мустафа Сисман,
Катедра "Железопътна техника", Технически университет, София

Резюме: В доклада се изследва градския железопътен транспорт в Истанбул. Използва се линеен математически модел, за минимизиране на престоя на транспортните средства от различни дестинации, позволяващи да се установи връзка с възлите на транспортната мрежа. За прилагането на оптималното решение са предложени промени в графика на изследваните линии и маршрути на метрото.

Ключови думи: градски жп транспорт, метро линия, трамвай, време на свързване, линейно оптимиране