Motion Control in Mechanical Transport Systems with Fuzzy Given Distance and Time

Marina Savelyeva[1], Marina Belyakova[1]

[1]Southern Federal University, Taganrog, Russia
marina.n.savelyeva@gmail.com,beliacov@yandex.ru

Abstract. We investigate traffic management in the mechanical transport system. A major factor in the management of the MTS is search of the optimal route. Therefore, this article is described the routing in the MTS taking into account the inaccuracies and uncertainties of transportation options. We have developed a routing algorithm that takes into account the temporal fuzzy nature of the variables. We have illustrated the example of the developed routing algorithm.

Keywords. Routing algorithm, mechanical transport systems, fuzzy temporal graph

1.   Introduction

Mechanical transport system (MTS) is a class of transport systems using conveyors for moving cargo [1]. Conveyors form a network, where nodes are switches direction. The switch is a mechanical device that directs the load unit from one conveyor output to one input of the adjacent conveyors [2]. Example of such systems is the MTS delivery of luggage at airports. The total number of conveyors and switches in these systems can be quite large, which suggests several options for each cargo transport unit. The main element in the management of MTS is a routing, which enables us to construct the optimal path taking into account various parameters.

2.   Formulation of the problem

We have following problem taking into account the changing reality and inaccuracies of incoming information. It is necessary to build a set of optimal routes for each of the MTS units. Information about received routes is stored in each node of MTS. And for determination of optimal route is used as a time parameter, and the parameter range. These parameters are presented in fuzzy form. The initial data are given on the MTS by expert to analyze the system.

$$L^* = \min_{\tilde{t}} \min_{w(\tilde{t})} \{ (\widetilde{w}(\tilde{t}) < s_m, x_i >), (\widetilde{w}(\tilde{t}) < x_i, x_j >), (\widetilde{w}(\tilde{t}) < x_j, r_m >) \} \qquad (1)$$

3. Routing Algorithm in MTS under fuzzy given distance and time

There are various ways to implement the routing of mechanical transport systems taking into account only the distance parameter, such as Ford's algorithm, Floyd' algorithm and etc [3]. We consider the algorithm that contains both parameters. The parameters are presented in fuzzy form. For the decision of problem, it is advisable to use the apparatus of the theory of graphs, namely based on fuzzy temporal graph.

Fuzzy temporal graph is a triple $\tilde{G} = (X, \tilde{U}_t, T)$, where X is set of vertices of the number of vertices c $|X| = n, T = \{1, 2, \dots, N\}$ is the set of natural numbers, determining (discrete) time; $U_t = \{< \mu_t(x_i, x_j) | (x_i, x_j) >\}$ is fuzzy set of edges, where $x_i, x_j \in X, \mu_t(x_i, x_j) \in [0,1]$ is the value of the membership function μ_t for the edge (x_i, x_j) at time $t \in T$, and at different times for the same edge (x_i, x_j) values of the membership function (in general) different. Vertex x_j is fuzzy adjacent vertex x_i on the moment of time $t \in T$, if the condition $\mu_t(x_i, x_j) > 0$ [4].

Step 1. To form the matrix $\tilde{D}^0$ (dimension N×N, where N is number of vertices in the graph). Each element i, j of the matrix $\tilde{d}_{ij}^0(\tilde{t})$ determines the length of the shortest arc leading from vertex i to vertex j. In the absence of such an arc put in $\tilde{d}_{ij}^0(\tilde{t}) = \infty$.

Step 2. Here $\tilde{D}^m$ denotes the dimension of the matrix $m \times m$ with $\tilde{d}_{ij}^m(\tilde{t}), m = \overline{1, m-1}$. To determine successively the elements of the matrix $\tilde{D}^m$ from elements of the matrix of $\tilde{D}^{m-1}$ for m, taking values $1, 2, \dots, N$:

$$\tilde{d}_{mj}^m(\tilde{t}) = \min_{i=1,m-1}\{\tilde{d}_{mi}^0(\tilde{t}) + \tilde{d}_{ij}^{m-1}(\tilde{t})\}\, (j = \overline{1, m-1}) \tag{2}$$

$$\tilde{d}_{im}^m(\tilde{t}) = \min_{j=1,m-1}\{\tilde{d}_{ij}^{m-1}(\tilde{t}) + \tilde{d}_{jm}^0(\tilde{t})\}\, (i = \overline{1, m-1}) \tag{3}$$

$$\tilde{d}_{ij}^m(\tilde{t}) = \min\{\tilde{d}_{im}^m(\tilde{t}) + \tilde{d}_{mj}^m(\tilde{t}), \tilde{d}_{ij}^{m-1}(\tilde{t})\}\, (i, j = \overline{1, m-1}) \tag{4}$$

Moreover, for all i and put m

$$\tilde{d}_{ii}^m(\tilde{t}) = 0 \tag{5}$$

As a result of the algorithm in the beginning is searched for the minimum distance, and then made to minimize the time.

Step 3. After the algorithm to produce defuzzification [5].

4. Example of illustration the routing algorithm in MTS with fuzzy given parameters and temporal dependence

You need to find the shortest routes to all nodes. Data are presented in fuzzy form. In round brackets is the distance, in square brackets indicates the time. Figure 1 shows example of MTS.

The initial matrix of distance and time as follows (equation (6)):

$$\tilde{D}^0(\tilde{t}) = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} \begin{array}{ccc} 1 & 2 & 3 \\ (0,0,0)[0,0,0] & (3,4,6)[1,3,5] & (4,5,6)[2,3,4] \\ - & (0,0,0)[0,0,0] & - \\ - & - & (0,0,0)[0,0,0] \\ (2,4,5)[3,4,5] & - & - \\ - & (2,5,7)[3,5,6] & - \\ - & - & - \end{array}$$

$$\begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} \begin{array}{ccc} 4 & 5 & 6 \\ - & - & - \\ - & (2,5,7)[3,5,6] & - \\ - & - & (5,6,7)[2,3,5] \\ (0,0,0)[0,0,0] & - & - \\ - & (0,0,0)[0,0,0] & (4,6,8)[2,3,4] \\ (3,4,7)[1,3,4] & (4,6,8)[2,3,4] & (0,0,0)[0,0,0] \end{array}$$
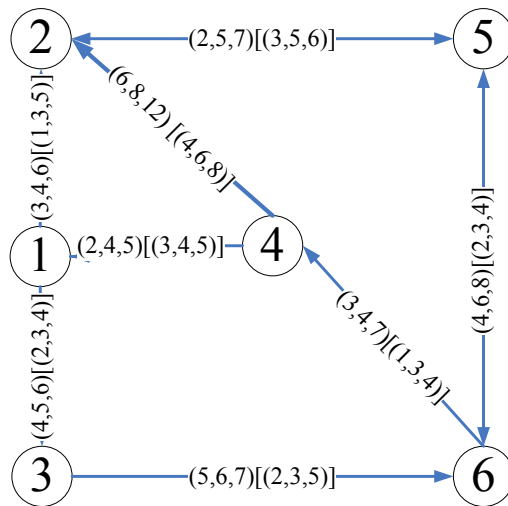
(6)

Fig. 1 – Illustration example of MTS scheme

Using the formula (5) of the algorithm we get equation (7).

$$\tilde{d}_{11}^1(\tilde{t}) = 0 \tag{7}$$

So we get the matrix $\tilde{D}^1(\tilde{t})$ below

$$\tilde{D}^1(\tilde{t}) = \begin{array}{c} \\ 1 \end{array} \begin{array}{c} 1 \\ (0,0,0)[0,0,0] \end{array} \tag{8}$$

Then the next phase for the elements use the formula (2) at the beginning, we obtain

$$\tilde{d}_{21}^2(\tilde{t}) = \min\{\tilde{d}_{21}^0(\tilde{t}) + \tilde{d}_{11}^1(\tilde{t})\} = \min\{\infty + (0,0,0)[0,0,0]\} = \infty \tag{9}$$

Consequently, instead of element $\tilde{d}_{21}^2(\tilde{t})$ in the matrix $\tilde{D}^2(\tilde{t})$ we have element "–". The next step we use the formula (3):

$$\tilde{d}_{12}^2(\tilde{t}) = \min\{\tilde{d}_{11}^1(\tilde{t}) + \tilde{d}_{12}^0(\tilde{t})\} = \min\{(0,0,0)[0,0,0] + (3,4,6)[1,3,5]\}$$
$$= (3,4,6)[1,3,5](route\ from\ 1\ to\ 2) \tag{10}$$

Then we use formula (5)

$$\tilde{d}_{11}^2(\tilde{t}) = 0, \tilde{d}_{22}^2(\tilde{t}) = 0 \tag{11}$$

Fill matrix $\tilde{D}^2(\tilde{t})$

$$\tilde{D}^2(\tilde{t}) = \begin{array}{c|cc} & 1 & 2 \\ \hline 1 & (0,0,0)[0,0,0] & (3,4,6)[1,3,5] \\ 2 & - & (0,0,0)[0,0,0] \end{array} \tag{12}$$

We turn to the calculation of the matrix $\tilde{D}^3(\tilde{t})$. Similarly, the use early in the formula (2):

$$\tilde{d}_{31}^3(\tilde{t}) = \min\{\tilde{d}_{31}^0(\tilde{t}) + \tilde{d}_{11}^2(\tilde{t}); \tilde{d}_{32}^0(\tilde{t}) + \tilde{d}_{21}^2(\tilde{t})\}$$
$$= \min\{\infty + (0,0,0)[0,0,0]; \infty + \infty\} = \infty \tag{13}$$

$$\tilde{d}_{32}^3(\tilde{t}) = \min\{\tilde{d}_{31}^0(\tilde{t}) + \tilde{d}_{12}^2(\tilde{t}); \tilde{d}_{32}^0(\tilde{t}) + \tilde{d}_{22}^2(\tilde{t})\}$$
$$= \min\{\infty + (3,4,6)[1,3,5]; \infty + (0,0,0)[0,0,0]\} = \infty \tag{14}$$

Using equation (3) we obtain the following values of the elements of the matrix:

$$\tilde{d}_{13}^3(\tilde{t}) = \min\{\tilde{d}_{11}^2(\tilde{t}) + \tilde{d}_{13}^0(\tilde{t}); \tilde{d}_{12}^2(\tilde{t}) + \tilde{d}_{23}^0(\tilde{t})\}$$
$$= \min\{(0,0,0)[0,0,0] + \infty; (3,4,6)[1,3,5] + \infty\} = \infty \tag{15}$$

$$\tilde{d}_{23}^3(\tilde{t}) = \min\{\tilde{d}_{21}^2(\tilde{t}) + \tilde{d}_{13}^0(\tilde{t}); \tilde{d}_{22}^2(\tilde{t}) + \tilde{d}_{23}^0(\tilde{t})\}$$
$$= \min\{\infty + \infty; (0,0,0)[0,0,0] + \infty\} = \infty \tag{16}$$

We recalculate values of the matrix by the formula (4) with the new values obtained in the previous step.

$$\tilde{d}_{12}^3(\tilde{t}) = \min\{\tilde{d}_{12}^2(\tilde{t}); \tilde{d}_{13}^3(\tilde{t}) + \tilde{d}_{32}^3(\tilde{t})\} = \min\{(3,4,6)[1,3,5]; \infty + \infty\}$$
$$= (3,4,6)[1,3,5](route\ (1,2)) \tag{17}$$

$$\tilde{d}_{21}^3(\tilde{t}) = \min\{\tilde{d}_{21}^2(\tilde{t}); \tilde{d}_{23}^3(\tilde{t}) + \tilde{d}_{31}^3(\tilde{t})\} = \min\{\infty; \infty + \infty\} = \infty \tag{18}$$

For further calculation of matrix elements we use the formula (5):

$$\tilde{d}_{11}^3(\tilde{t}) = 0, \tilde{d}_{22}^3(\tilde{t}) = 0, \tilde{d}_{33}^3(\tilde{t}) = 0 \tag{19}$$

Fill the matrix $\widetilde{D}^3(\tilde{t})$

$$\widetilde{D}^3(\tilde{t}) = \begin{matrix} & \begin{matrix} 1 & \quad\quad 2 & \quad\quad 3 \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} & \begin{matrix} (0,0,0)[0,0,0] & (3,4,6)[1,3,5] & (4,5,6)[2,3,4] \\ - & (0,0,0)[0,0,0] & - \\ - & - & (0,0,0)[0,0,0] \end{matrix} \end{matrix} \tag{20}$$

We repeat similar iterations for the calculation of the matrix $\widetilde{D}^4(\tilde{t})$. Similarly, we use early in the formula (2):

$$\tilde{d}_{41}^4(\tilde{t}) = \min\{\tilde{d}_{41}^0(\tilde{t}) + \tilde{d}_{11}^3(\tilde{t}); \tilde{d}_{42}^0(\tilde{t}) + \tilde{d}_{21}^3(\tilde{t}); \tilde{d}_{43}^0(\tilde{t}) + \tilde{d}_{31}^3(\tilde{t})\}$$
$$= \min\{(2,4,5)[3,4,5] + (0,0,0)[0,0,0]; \infty + \infty; \infty + \infty\}$$
$$= (2,4,5)[3,4,5]\ (route\ (4,1)) \tag{21}$$

$$\tilde{d}_{42}^4(\tilde{t}) = \min\{\tilde{d}_{41}^0(\tilde{t}) + \tilde{d}_{12}^3(\tilde{t}); \tilde{d}_{42}^0(\tilde{t}) + \tilde{d}_{22}^3(\tilde{t}); \tilde{d}_{43}^0(\tilde{t}) + \tilde{d}_{32}^3(\tilde{t})\}$$
$$= \min\{(2,4,5)[3,4,5] + (3,4,6)[1,3,5]; \infty$$
$$+ (0,0,0)[0,0,0]; \infty + \infty\}$$
$$= (5,8,11)[4,7,10](route\ (4,1) \rightarrow (1,2)) \tag{22}$$

$$\tilde{d}_{43}^4(\tilde{t}) = \min\{\tilde{d}_{41}^0(\tilde{t}) + \tilde{d}_{13}^3(\tilde{t}); \tilde{d}_{42}^0(\tilde{t}) + \tilde{d}_{23}^3(\tilde{t}); \tilde{d}_{43}^0(\tilde{t}) + \tilde{d}_{33}^3(\tilde{t})\}$$
$$= \min\{(2,4,5)[3,4,5] + (4,5,6)[2,3,4]; \infty + \infty; \infty$$
$$+ (0,0,0)[0,0,0]\} = (6,9,11)[5,7,9](route\ (4,1)$$
$$\rightarrow (1,3)) \tag{23}$$

Using equation (3), we obtain the following values of the elements of the matrix:

$$\tilde{d}_{14}^4(\tilde{t}) = \min\{\tilde{d}_{11}^3(\tilde{t}) + \tilde{d}_{14}^0(\tilde{t}); \tilde{d}_{12}^3(\tilde{t}) + \tilde{d}_{24}^0(\tilde{t}); \tilde{d}_{13}^3(\tilde{t}) + \tilde{d}_{34}^0(\tilde{t})\}$$
$$= \min\{(0,0,0)[0,0,0] + \infty; (3,4,6)[1,3,5] + \infty; \infty + \infty\}$$
$$= \infty \tag{24}$$

$$\tilde{d}_{24}^4(\tilde{t}) = \min\{\tilde{d}_{21}^3(\tilde{t}) + \tilde{d}_{14}^0(\tilde{t}); \tilde{d}_{22}^3(\tilde{t}) + \tilde{d}_{24}^0(\tilde{t}); \tilde{d}_{23}^3(\tilde{t}) + \tilde{d}_{34}^0(\tilde{t})\}$$
$$= \min\{\infty + \infty; (0,0,0)[0,0,0] + \infty; \infty + \infty\} = \infty \tag{25}$$

$$\tilde{d}_{34}^4(\tilde{t}) = \min\{\tilde{d}_{31}^3(\tilde{t}) + \tilde{d}_{14}^0(\tilde{t}); \tilde{d}_{32}^3(\tilde{t}) + \tilde{d}_{24}^0(\tilde{t}); \tilde{d}_{33}^3(\tilde{t}) + \tilde{d}_{34}^0(\tilde{t})\}$$
$$= \min\{\infty + \infty; \infty + \infty; (0,0,0)[0,0,0] + \infty\} = \infty \tag{26}$$

We recalculate values of the matrix by the formula (4) with the new values obtained in the previous step.

$$\tilde{d}_{12}^4(\tilde{t}) = \min\{\tilde{d}_{12}^3(\tilde{t}); \tilde{d}_{14}^4(\tilde{t}) + \tilde{d}_{42}^4(\tilde{t})\}$$
$$= \min\{(3,4,6)[1,3,5]; \infty + (5,8,11)[4,7,10]\}$$
$$= (3,4,6)[1,3,5](route\ (1,2)) \tag{27}$$

$$\tilde{d}_{13}^4(\tilde{t}) = \min\{\tilde{d}_{13}^3(\tilde{t}); \tilde{d}_{14}^3(\tilde{t}) + \tilde{d}_{43}^3(\tilde{t})\}$$
$$= \min\{(4,5,6)[2,3,4]; \infty + (6,9,11)[5,7,9]\}$$
$$= (4,5,6)[2,3,4](route\ (1,3)) \tag{28}$$

$$\tilde{d}_{21}^4(\tilde{t}) = \min\{\tilde{d}_{21}^3(\tilde{t}); \tilde{d}_{24}^3(\tilde{t}) + \tilde{d}_{41}^3(\tilde{t})\} = \min\{\infty; \infty + (2,4,5)[3,4,5]\}$$
$$= \infty \tag{29}$$

$$\tilde{d}_{23}^4(\tilde{t}) = \min\{\tilde{d}_{23}^3(\tilde{t}); \tilde{d}_{24}^3(\tilde{t}) + \tilde{d}_{43}^3(\tilde{t})\} = \min\{\infty; \infty + (6,9,11)[5,7,9]\}$$
$$= \infty \tag{30}$$

For further calculation of matrix elements we use the formula (5):

$$\tilde{d}_{11}^4(\tilde{t}) = 0, \tilde{d}_{22}^4(\tilde{t}) = 0, \tilde{d}_{33}^4(\tilde{t}) = 0, \tilde{d}_{44}^4(\tilde{t}) = 0 \tag{31}$$

Fill the matrix $\widetilde{D}^4(\tilde{t})$

$$\widetilde{D}^4(\tilde{t}) = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{array}{cccc} 1 & 2 & 3 & 4 \\ (0,0,0)[0,0,0] & (3,4,6)[1,3,5] & (4,5,6)[2,3,4] & - \\ - & (0,0,0)[0,0,0] & - & - \\ - & - & (0,0,0)[0,0,0] & - \\ (2,4,5)[3,4,5] & (5,8,11)[4,7,10] & (6,9,11)[5,7,9] & (0,0,0)[0,0,0] \end{array} \qquad (32)$$

As a result, similar calculations obtain intermediate matrix of routes $\widetilde{D}^5(\tilde{t})$.

$$\widetilde{D}^5(\tilde{t}) = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \begin{array}{cc} 1 & 2 \\ (0,0,0)[0,0,0] & (3,4,6)[1,3,5] \\ - & (0,0,0)[0,0,0] \\ - & - \\ (2,4,5)[3,4,5] & (5,8,11)[4,7,10] \\ - & (2,5,7)[3,5,6] \end{array}$$

$$\begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \begin{array}{ccc} 3 & 4 & 5 \\ (4,5,6)[2,3,4] & - & (5,9,13)[4,8,11] \\ - & - & (2,5,7)[3,5,6] \\ (0,0,0)[0,0,0] & - & - \\ (6,9,11)[5,7,9] & (0,0,0)[0,0,0] & (7,13,18)[7,12,16] \\ - & - & (0,0,0)[0,0,0] \end{array} \qquad (33)$$

Using the $\widetilde{D}^5(\tilde{t})$ intermediate matrix performs calculations and obtain the resulting matrix routes.

$\widetilde{D}^6(\tilde{t})$

$$= \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} \begin{array}{ccc} 1 & 2 & 3 \\ (0,0,0)[0,0,0] & (3,4,6)[1,3,5] & (4,5,6)[2,3,4] \\ (11,19,27)[9,15,19] & (0,0,0)[0,0,0] & (15,24,33)[11,18,23] \\ (10,14,19)[6,10,14] & (11,17,22)[7,11,15] & (0,0,0)[0,0,0] \\ (2,4,5)[3,4,5] & (5,8,11)[4,7,10] & (6,9,11)[5,7,9] \\ (9,11,20)[6,10,13] & (2,5,7)[3,5,6] & (13,19,26)[8,13,17] \\ (5,8,12)[4,7,9] & (6,11,15)[5,8,10] & (19,13,18)[6,10,13] \end{array}$$

$$\begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} \begin{array}{ccc} 4 & 5 & 6 \\ (12,15,20)[5,9,13] & (5,9,13)[4,8,11] & (9,11,13)[4,6,9] \\ (9,15,22)[6,11,14] & (2,5,7)[3,5,6] & (6,11,15)]6,8,10] \\ (8,10,14)[3,6,9] & (9,12,15)[4,6,9] & (5,6,7)[2,3,5] \\ (0,0,0)[0,0,0] & (7,13,18)[7,12,16] & (11,15,18)[7,10,14] \\ (7,10,15)[3,6,8] & (0,0,0)[0,0,0] & (4,6,8)[2,3,4] \\ (3,4,7)[6,10,13] & (4,6,8)[2,3,4] & (0,0,0)[0,0,0] \end{array} \qquad (34)$$

5.   Conclusion

The specific management tool of MTS is routing. The proposed routing algorithm is applicable to any mechanical transport system. The use of the described routing method gives the best effect for MTS, which are operated in the unstable conditions for major changes of cargo flow intensity. This case of temporal dependence reflects the real environmental situation and its cost.

References

1. Black G. Intelligent Distributed execution and cyber-physical design of Baggage Handling automation with IEC 61499/ G. Black, V. Vyatkin // Proc. IEEE Int. Conf. on Industrial Informatics.– 2011.- pp. 573 – 578.
2. Belyakov S. Routing in the mechanical transport systems on the basis of knowledge / S. Belyakov, A. Bozhenyuk, I. Rozenberg // 14th IEEE International Symposium on Computational Intelligence and Informatics CINTI 2013, Budapest, Hungary, November 19-21, 2013.-pp.159-262
3. Cormen T. H., Leiserson, C E., Rivest, R. L., Stein C. Introduction to Algorithms. — 3rd. — MIT Press.- 2009
4. Kostakos V. Temporal graphs. In Proc. of Physica A: Statistical Mechanics and its Applications, vol.388, Issue 6, Elsevier, 2008, p.1007-1023.
5. Zimmermann, H.J. Fuzzy Set Theory and Its Applications. / H.J. Zimmermann. – 3rd ed. – Kluwer Academic Publishers – 1996. – 435 p.