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THE APPLICATION OF SELECTED NETWORK METHODS FOR RELIABLE AND SAFE TRANSPORT BY SMALL COMMERCIAL VEHICLES

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Abstract:
In the article are characterized two network methods (critical path method – CPM and program evaluation and review technique – PERT). On the example of an international furniture company's product, it presented the exemplification of methods to transport cargos (furniture elements). Moreover, the study showed diagrams for transportation of cargos from individual components' producers to the final destination – the showroom. Calculations were based on the transportation of furniture elements via small commercial vehicles.

Key words: *network methods, road transport, transportation time*

INTRODUCTION

Transport of cargos via small commercial vehicles within the Central Europe is very popular. No speed limit to 90 km/h, as in the case of a truck, enables the faster movement of small commercial vehicles on roads and highways. The opportunity to deliver goods directly to the recipient located in the town center, which has an entry ban for trucks – this is their great advantage.

Manufacturers of light commercial vehicles do not only focus on the development and improvement of transport parameters of their cars, but also on the improvement of the driver's comfort, offering newer and newer solution such as: heated seats, built-in speakerphone, reversing cameras, parking sensors and other devices useful during the exploitation of the car in order to provide the driver the best workplace. The transportation of such products as frozen foods, vegetables, liquids or breads is no problem for the carriage via commercial vehicles. A wide range of car models allow the transport of almost any cargo, which requires special conditions. Vehicles with specially adapted bodyworks are not a rarity on roads in Europe. In Europe and all around the world, there is a need to search the fastest and the most cost-effective solutions. In order to facilitate their finding, there are more and more different calculation and estimation methods, which greatly help in receiving a response to posed questions. Light commercial vehicles are vehicles for the transportation of medium large cargos due to their maximum permissible total weight (GVW), which mostly amounts to 3.5 tones. They are usually able to transport loads that do not exceed weight of 1.5 tons, but there are cases, where this value is much higher. Almost every light commercial vehicle traveling on the European roads is driven by a diesel fuel. Diesel engines are very good for long intercity or international routes, where stopping and starting of the vehicle is much smaller than in the case of shorter city distances.

THE USE OF NETWORK METHODS FOR THE TRANSPORTATION OF CARGOS VIA SMALL COMMERCIAL VEHICLES

Network planning techniques are the main tools using for the preparation of the project's implementation plan [5]. Network programming, or in other words a network analysis, is a method through which it is possible to present a multifunctional project aiming to achieve a particular purpose by means of a graph or as a set of activities and its analysis [6]. Very important in these methods is an accurate determination of the sequencing of individual activities, because this has a direct impact on the result of the analysis [4].

Each project consists of elements [4]:

- event – most often presented in the form of circle. It is the moment of starting or finishing one or more amount of activities,
- action – presented by an arrow/vector. It is freely separated elements of the project along with a description of the duration and resource that have been used,
- apparent action – this is usually a broken arrow/vector. This action does not require the use of time or resources. It serves to present the dependence of events.

Actions are characterized by [4]:

- parallelism – actions are carried out at the same time,
- linearity – every subsequent action is performed after the completion of the precious activity.

In order to build a good network of venture, you should remember about the following issue [4]:

- initial event cannot have previous activities;

– final event cannot have following activities;
– events (next two) must be connected by only one activity;
– each event in the network should be both the start and end of at least one activity with the exception of the beginning and end.

Construction of the network comprises the following actions [4]:

1. Determination of activities constituting a certain project.
2. Determination of the final and initial event.
3. Determining the order of the following activities.
4. Numbering of events.

When the subject of analysis is a network with time function, each activity in the network has a non-negative value t_{ij}. It determines the time, in which the action occurring between event i and event j will be performed. Time analysis of individual events or the entire project has several elements:

– path or road in the network characterizing the sequence of activities and events. It enables the transition from beginning to end,
– critical path determining the longest time required for the network's transition,
– the shortest possible time of the occurrence of event j which is calculated by the sum of the earliest moment of previous event i's occurrence and the duration of action between events i and j:

$$t_j^0 = \max_i \left\{ t_i^0 + t_{ij} \right\}, \; i < j \quad (1)$$

– the latest possible term of the event i is the difference between the latest allowable time of the event j and the duration of actions between events:

$$t_i^l = \min_j \left\{ t_j^l - t_{ij} \right\}, \; i < j \quad (2)$$

– time margin (total margin) L_j determines how much the occurrence of a certain event without affecting the completion date of the project can be delayed:

$$L_j = t_j^1 - t_j^0 \quad (3)$$

– free margin L determines the time, which does not affect the reserve of time associated with other activities:

$$L_s = t_j^0 - t_i^0 - t_{ij} \quad (4)$$

– conditional margin L_w – it is a time reserve, which does not affect the volume of previous action's reserves located on a certain path:

$$L_w = t_j^1 - t_i^1 - t_{ij} \quad (5)$$

– independent margin L_n – it is a time reserve, which does not affect the volume of any other actions' reserve:

$$L_n = t_j^0 - t_i^1 - t_{ij} \quad (6)$$

If $L_n < 0$, then you should take an independent margin equal to 0. The diagram of network is the most commonly presented in a form of circle (Fig. 1), which includes information about the earliest possible moment of the event t_j^0, the latest possible moment of the event t_j^1 as well as the time margin L_j.

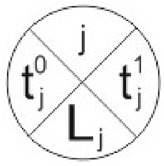

Fig. 1 Network diagram
Source: [6].

Networks of activities can be deterministic or stochastic networks. They differ in the durations of fixed actions or random variables. The deterministic network occurs when the duration of individual activities is known in advance – e.g. the critical path method (CPM). When durations of actions are random variables, we deal with the stochastic network. This network is an example of the program evaluation and review technique (PERT).

Critical path method (CPM)

Method CPM is the most commonly used among all network methods. It concerns the time analysis of network with the knowledge of all terms for time events and their duration. It enables the determination of the earliest possible term for the completion of the project. The process also shows truly important tasks needed to complete the project on time. The most important in determining the critical path are dependences – relations between tasks. The new task cannot be started until the completion of the previous task. Effective designation of the critical path requires [3]:

– dividing the project into tasks,
– determination of relations between tasks,
– determination of correct time estimations for tasks.

If the first two conditions are met, you can proceed to the third condition – the duration of the task. The critical path is a sequence of tasks with the longest total duration. An important aspect in this case is a zero time margin – it is a possible time for delays on the path, which does not delay the completion of the entire project. Each delay on the path causes the postponement of the project's realization (a zero time margin) [3]. The critical path shows tasks that should be carried out in order to accelerate the implementation of the project. Sometimes, all tasks are accelerated without distinguishing whether it is sensible [3]. Examples of critical paths are shown in Fig. 2 and Fig. 3.

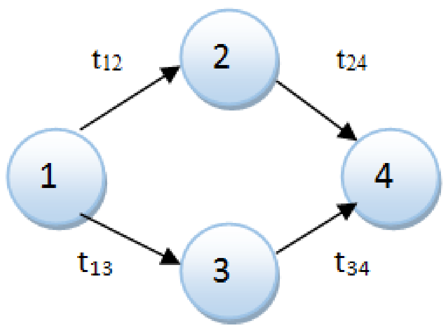

Fig. 2 Critical path (example 1): the minimum time = max{$t_{12}+t_{24}$; $t_{13}+t_{34}$}
Source: [1].

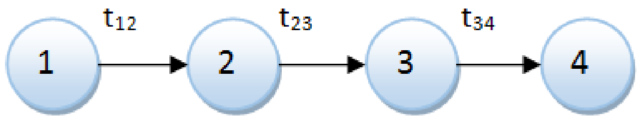

Fig. 3 Critical path (example 2): the minimum time = $t_{12}+t_{23}+t_{34}$
Source: [1].

Method of vertices numbering is as follows (it must be performed so that the top – an event with a higher number is not preceded the vertex – an event with a lower number):
- allocation for the free vertex (without any arc) No. i=1,
- removal of arches connecting blank vertices with numbered vertices,
- assignation of numbers i+1, i+2, ..., for fee vertices.

Program evaluation and review technique (PERT)

Problems with precise determination of durations for individual actions forced the search of a method, which takes into account the uncertainly related to the implementation of the project. One of the first methods of this kind was the PERT method [5]. This method assesses the probability of execution the project in a scheduled time and estimation whether it is profitable to put more costs in the project along with the extension of the deadline. This method takes advantage of the critical path method, which increases the effectiveness of estimating the duration of the project. Presentation of this method is done with the use of a graph and a grid of actions, which consist of the project's realization and the identification of the critical path. The next step is to identify activities, which can be a threat for the timely completion of the project, and then the use of these actions to control the implementation of the project's performance. In the PERT method, durations of each action are random variables with unknown schedules. It is understood that the distribution of time:
- has a continuous character,
- has one extremum,
- density contacts at two non-negative points with an abscissa axis.

Each of activity should get three estimates of time [7]:
- the most probable m – this is the most probable estimation,
- optimistic a – estimation in the most favorable conditions,
- pessimistic b – estimation in the most adverse conditions with a fulfilled relations .

Distributions of time in the case of PERT method correspond to the beta degradation. This distribution is characterized by three points: a, b, m. Point a and point b correspond to the point of contact beta graph with the abscissa axis, and in point m density of distribution reaches the extremum. If a<b, a is an optimistic assessment of the activities' realization, whereas b – the pessimistic evaluation of actions. Expected value t_0 and variation σ^2 for the duration of each activity are calculated on the basis of the following relations [2]:

$$t_0 = \frac{a + 4m + b}{6} \tag{7}$$

$$\sigma^2 = \left(\frac{b-a}{6}\right)^2 \tag{8}$$

After calculating the expected value t_0, further calculations are the same as with the use of CPM method. In the PERT method, duration of each action is a random variable, which has an asymptotically normal distribution, so the Chance to meet the project's deadline is 50%. The term of the realization is an expected value t_p, which is equal to the expected value for the earliest date and the variation σ^2, which is equal to the sum of variance duration of activity belonging to the critical path. There is also the possibility to determine the probability of the project earlier in the settled time t_u. The statistic is calculated in accordance with the following formula:

$$u = \frac{t_u - t_p}{\sigma} \tag{9}$$

Then, in succession to the determined statistics u, the probability of meeting the assumed date is estimated the basis of a table for normal distribution function [6]:

$$P\{t_u \leq t_p\} = F(u) \tag{10}$$

THE USE OF SELECTED NETWORK METHODS IN THE TRANSPORTATION REALIZED VIA SMALL LIGHT COMMERCIAL VEHICLES

The following example concerns the furniture company producing and assembling exclusive chairs. The company has its own factories and assembly halls in 5 cities in Europe. In Dortmund (Germany), the company produces chair legs, in Berlin (Germany) supports, in Szczecin (Poland) the company connects components produced in Berlin and Dortmund. In Gryfice (Poland) it manufactures sears and rests. Components are assembled in Szczecin and produced in Gryfice. Then, they are transported to Praga/Prague (Czech Republic), where they are mounted into the final product and sent to the main showroom in Wiedeń/Vienna (Austria). Without the time of reloading and assembly, it was made the analysis of actions, time margins and the estimation of probability for the realization of transportations in a given time, using the previously described methods.

CMP method

Fig. 4 presents a schematic diagram for supply of individual components in the company. Cities are marked by respective numbers j from 1 to 6. Letters from a to e determine tracks between departments, and the numbers below present time (in minutes), which is necessary to overcome the route. These data were downloaded from the ViaMichelin website at the following address: http://www.viamichelin.pl/web/Trasy. Arrows between circles define the route and direction, at which light commercial vehicles will be moved.

The assumption of this task shows that the driver on the route c driving from point 3 (Szczecin) to point 5 (Praga/Prague) may set off only when carriers from point 1 (Dortmund) and point 2 (Berlin) reach Praga/Prague. A similar situation occurs in the case of point 5 (Praga/Prague), where the shipment to point 6 (Wiedeń/Vienna) can depart after arriving transports from points 4 (Gryfice) and 3 (Szczecin) to point 5 (Praga/Prague).

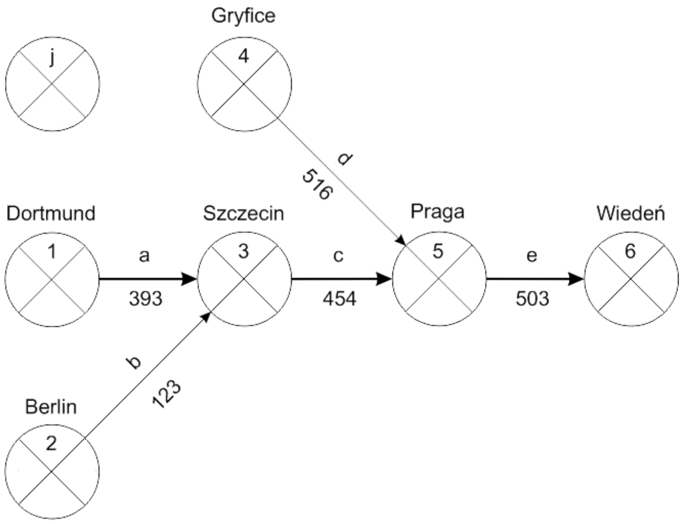

Fig. 4. Schematic diagram for the network of company's structures

Table 1
Parameters of actions

Actions	Event	Previous action	Duration [min.]
a	1-3	-	393
b	2-3	-	123
c	3-5	a, b	454
d	4-5	-	516
e	5-6	c, d	503

Table 1 contains important information taken from the graph (Fig. 4) in order to present the data needed in order to solve the example.

In order to determine the earliest and latest times for events and possible time margins, it should be assumed that the first event "a" starts the entire project, so the earliest possible time for the event is equal to 0:
$t_1^0 = 0$ min

Next event "b" is also a starting event, so its time is equal to 0:
$t_2^0 = 0$ min

Performance of action c requires the completion of events "a" and "b". The earliest time for the occurrence of "c" is estimated as follows:
$t_2^0 = \max \{t_2^0 + t_{12}; t_2^0 + t_{22}\} = \max \{0+393; 0+123\} = \max \{393; 123\} = 393$ min.

In accordance with previous cases (t_1^0; t_2^0), if event has a starting nature (as in the case of "d"), its time is equal to 0:
$t_4^0 = 0$ min.

When calculating the time of occurring "e", we should use the same method of calculation as in the previous case for t_2^0:
$t_5^0 = \max \{t_4^0 + t_{45}; t_2^0 + t_{35}\} = \max \{0+516; 393+454\} = \max \{516; 847\} = 847$ min.

Assumed project will be completed after the realization of the last action, which is the sum of the time of occurring t_5^0 and time for the completion of activity "e":
$t_6^0 = t_5^0 + t_{56} = 847+503=1350$ min.

The next stage of the network analysis is to determine the latest possible times of occurring that do not cause delays in the entire project.

Assuming that the latest possible time of a certain event's occurrence is equal to the difference between the latest previous time and time for a certain action's performance, we can obtain:

- calculation from the time, in which the project has been completed:
  $t_6^1 = t_6^0 = 1350$ min.
- the latest time of occurrence for action "e" (i.e. the beginning of route from Praga/Prague to Wiedeń/Vienna) is calculated on the basis of the following difference t_6^i, t_{56}:
  $t_5^1 = t_6^1 - t_{56} = 1350-503=847$ min.
- a similar procedure should be followed in order to calculate next times:
  $t_4^1 = t_5^1 - t_{45} = 847-516=331$ min.
  $t_2^1 = t_3^1 - t_{23} = 393-123=270$ min.
  $t_3^1 = t_5^1 - t_{35} = 847-454=393$ min.
  $t_1^1 = t_3^1 - t_{13} = 393-393=0$ min.

Then, time margins, which are the difference between previously determined times of activities, are successively calculated:

$L_1 = t_1^1 - t_1^0 = 0-0=0$ min. $L_4 = t_4^1 - t_4^0 = 331-0=331$ min.
$L_2 = t_2^1 - t_2^0 = 270-0=270$ min. $L_5 = t_5^1 - t_5^0 = 847-847=0$ min.
$L_3 = t_3^1 - t_3^0 = 393-393=0$ min. $L_6 = t_6^1 - t_6^0 = 1350-1350=0$ min.

On the basis of presented calculations, it is possible to determine that from the beginning of the project, carriers in Berlin (L_2) and Gryfice (L_4) can have delays in the transportation respectively 270 and 331 minutes. Thus, on the basis of realized calculations, it was presented in Table 2 and showed in Fig. 5 information about the earliest t_j^0 and the latest t_j^1 possible times of occurrence events j and their time margins L_j.

From the above calculated it can be seen that in order to finalize the entire supply chain via the critical path methods from individual points to the showroom in Vienna, the minimum of 1350 minutes are required.

Table 2
Summary of event times and time margins for calculated data

j	t_j^0 [min.]	t_j^1 [min.]	L_j [min.]
1	0	0	0
2	0	270	270
3	393	393	0
4	0	331	331
5	847	847	0
6	1350	1350	0

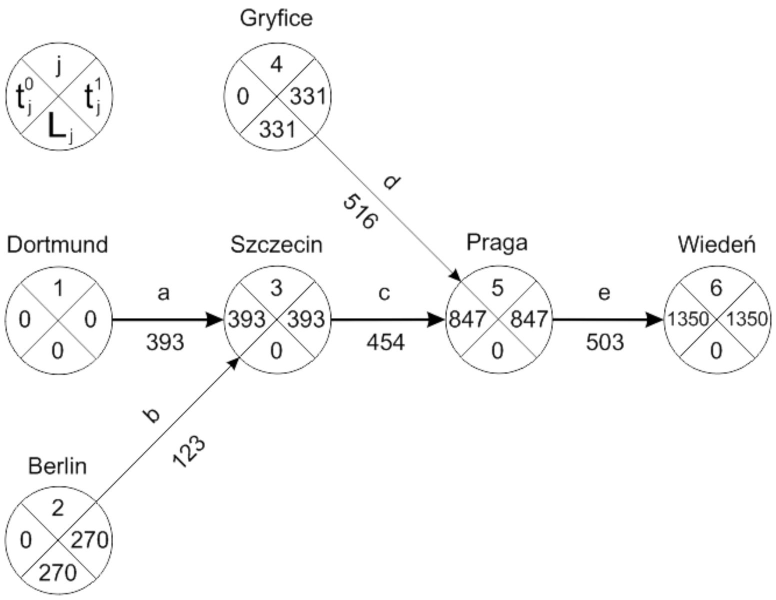

Fig. 5. Schematic diagram for the network of company's structures supplemented with times

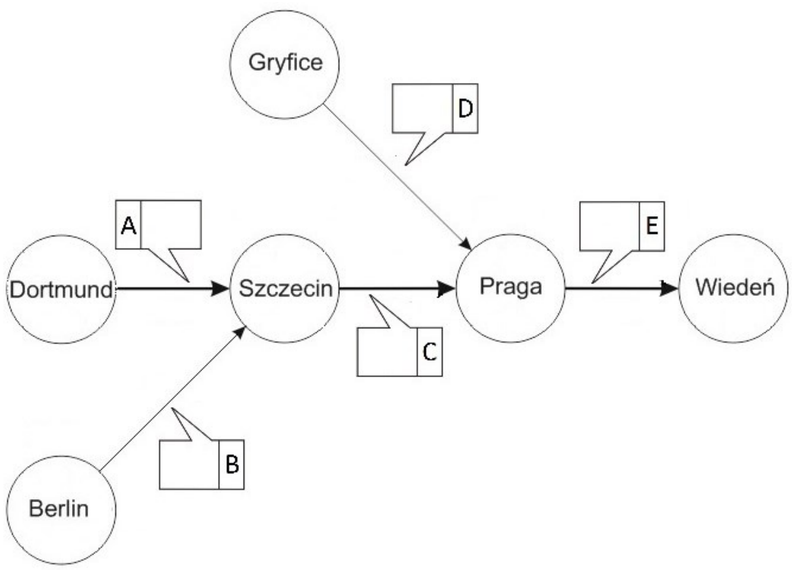

Fig. 6. Schematic diagram for the network of company's structure

It is important that from the beginning of the project, factories in Berlin and Gryfice have time margins, which allow them to start transportation in a wide time margin.

PERT method

Fig. 6 presents the ideological structure of the company required for analysis by PERT method. Letters from A to E determine routes that must be driven by light commercial vehicles in order to transport certain goods between cities. Table 3 shows the summary of information about the required preceding actions, which are necessary to start the next stages and three types of expected times for each activity (optimistic a, probable m, pessimistic b).

Table 3
Durations of transportations between certain points in the company

Action	Preceding action	Duration of the activity [min.]		
		Optimistic (a)	Probable (m)	Pessimistic (b)
A	-	342	388	393
B	-	105	123	164
C	A, B	326	362	454
D	-	348	380	516
E	C, D	204	227	503

Table 4
Results of calculations for the PERT method

j	a [min.]	m [min]	b [min]	Waiting time [min.]	Variance
A	342	388	393	381	72.25
B	105	123	164	127	96.69
C	326	362	454	371	455.11
D	348	380	516	397	784
E	204	227	503	269	2483.36

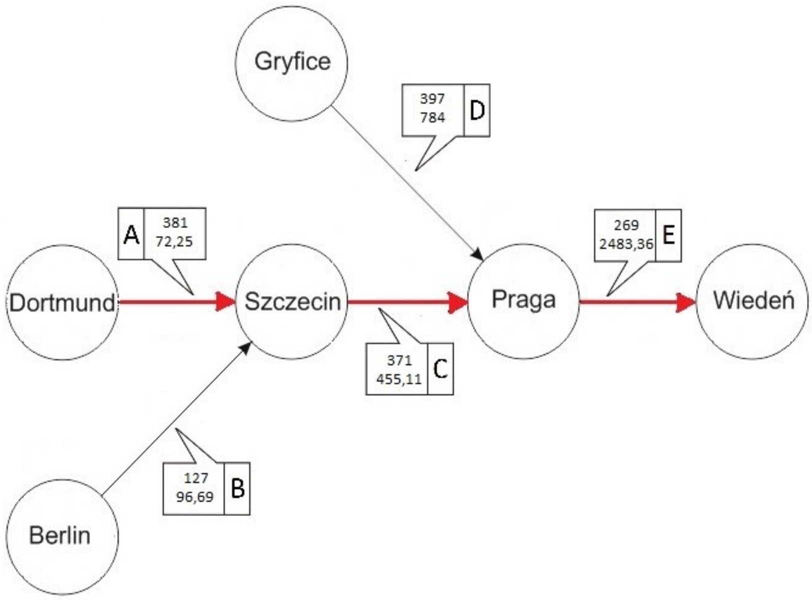

Fig. 7. Critical path obtained for the PERT method

On the basis of times presented in Table 3, it is possible to estimate the expected value t_0, which will be the most probable time for transport on individual sections of routes. It is calculated based on dependences (7). On particular sections A, B, C, D and E of the route, it amounts to (respectively):

$$t_A = \frac{342 + 4(388) + 393}{6} = 381 \text{ min.}$$

$$t_B = \frac{105 + 4(123) + 164}{6} = 127 \text{ min.}$$

$$t_C = \frac{326 + 4(362) + 454}{6} = 371 \text{ min.}$$

$$t_D = \frac{348 + 4(380) + 516}{6} = 397 \text{ min.}$$

$$t_E = \frac{204 + 4(227) + 503}{6} = 269 \text{ min.}$$

The next calculation step is the calculation of waiting time variance for individual section of the route (8):

$$\sigma_A^2 = \left(\frac{392 - 342}{6}\right)^2 = 72.25 \text{ min.}$$

$$\sigma_B^2 = \left(\frac{164 - 105}{6}\right)^2 = 96.69 \text{ min.}$$

$$\sigma_C^2 = \left(\frac{454-326}{6}\right)^2 = 455.11 \text{ min.}$$

$$\sigma_D^2 = \left(\frac{516-348}{6}\right)^2 = 784 \text{ min.}$$

$$\sigma_E^2 = \left(\frac{503-204}{6}\right)^2 = 2483.36 \text{ min.}$$

Obtained results were presented in Table 4 and supplemented by the schematic diagram of networks in Fig. 7.

Subsequently, the expected times for the realization of entire event t_p were calculated and the variance σ^2 this event. They are the sum of expected values for the critical path:

t_p= 381+397 = 1047 min.

σ^2= 72.25+455.11+2483.36 = 3010.72 min.

σ = 54.87 min.

On the basis of calculated times, dependences (9) and tables of normal distribution function [8, 9], the probability for the realization of transport in a certain term was estimated t_u = 1350 min. From the dependence (9), it was obtained:

$$u = \frac{1350-1047}{54.87} = 5.52 \text{ min.}$$

what correspond to chances for complete the tasks in a given time in 99.99%.

The obtained result is high and it can be assumed that only in truly adverse conditions, the transport project will not be completed.

SUMMARY

Road transport is mainly focused on finding the shortest and fastest routes connecting many loading and unloading points, which in these methods must be arbitrarily determined. This is not a problem for the courier industry, which has fixed distribution points, and the earliest and the latest times for events and time margins calculated with the use of various methods allow more accurately determine the time of delivery of the consignment and facilitate the cooperation between carriers.

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