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Setting Dynamic Problem of Logistic Support of Building Objects by Material Resources Taking into Account Random Factors Affecting Transportation Timing

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Abstract

This article considers deterministic (e.g. the exact time at which to deliver the goods, dimensions and characteristics of the vehicle, route length, waiting time in line, loading and unloading time) and non-deterministic factors (e.g. transport breakdowns; accidents; weather conditions; the time that the vehicle is at the consumer's after unloading; downtime due to non-payment; breakdowns of machines and mechanisms; low-quality materials; delays in subcontractors) that affect the time of transportation and the time of the beginning of the use of material resources.
Having identified the main deterministic and non-deterministic factors, it was made the analysis of existing models for solving the problems of organizing the provision of construction facilities with material resources without delays in time. It was determined that the existing models could not fully solve the problems associated with the peculiarities of the construction industry. The following factors are not taken into account: random factors that affect transportation, which increases the maximum cost, the specifics of the construction industry, which leads to inconsistencies, and as a consequence, the false results of the objective function.
Schedules were drawn up for the supply of construction resources by the transport organization and the use of the resources mentioned by the construction organization, taking into account random factors that affect the time of transportation. By intersecting these two graphs, two main equations that affect the time of transportation and the time of commencement of material resources and the relationship between these equations were identified.
Based on those equations, two target functions were drawn up, one of which takes into account the additional costs of the transportation organization logistics and the time for waiting for transporting, the other takes into account the additional costs of the construction organization for delays in starting work.
KEY WORDS: *deterministic factors, non-deterministic factors, transport time*

1. Introduction

The specifics of construction, as an industry, include the need to supply building materials, structures, and finished products to the construction site. Depending on the type or type of object being built, there is a difference in building materials. For example, for the construction of bridges or high-rise constructions, from monolithic reinforced concrete, constant receipt of concrete mix or components for its manufacturing is required [11-12]. Such materials can also include supporting steel, metal structures or formwork for concreting. Delays in the supply of materials or structures for such facilities can cause downtime, leading to significant losses for the construction organization. Conversely, delays in obtaining materials and resources direct to transport costs due to delays.

As it is known from practice, very often there are situations when there is a delay in the transportation, in the supply of construction materials or the construction organization does not invest in time, due to which the additional costs are required to be determined, those depending on the delay time of the construction or transport organization [13].

These delays can be caused by various factors. In [1-3], deterministic and non-deterministic factors that may affect the time of transportation of construction materials, and as a consequence, affect the formation of the initial conditions of the task of organizing the provision of material resources of construction sites were considered.

Deterministic factors known before the start of transportation of building materials include [2-4, 15]: the exact time at which to deliver the goods, dimensions and characteristics of the vehicle, route length, waiting time in line, loading and unloading time.

Non-deterministic unpredictable factors include [2-4, 14]: transport breakdowns; accidents; weather conditions; the time that the vehicle is at the consumer's after unloading; downtime due to non-payment; studies of machines and mechanisms; low-quality materials; delays in subcontractors.

All these factors affect the conditions of transportation of construction materials and, as a consequence, the provision of construction facilities with material resources may lead to downtime on construction sites and non-compliance with contractual obligations and increase of construction time.

2. Main Part

In [5], linear models of supplying material resources to the point of consumption were presented. These tasks solve routine, simple tasks concerning the supply of materials, the optimal distribution of materials without residues and with maximum revenue. However, these models do not include random factors that affect transportation, which increases the full cost.

In [6], a linear model and algorithm for solving supplying construction materials to the construction site, taking into account random factors and characteristics that affect the transportation time and the final target function were developed. The disadvantage of this model is its bulkiness. This is due to the fact that in this algorithm there are five target functions, each of which corresponds to a specific situation, with a delay in delivery.

In works [7-10] the formulations of dynamic transport problems for the supply of materials taking into account the time characteristics, are presented. The disadvantage of the presented algorithms is that they do not take into account the specifics of the construction industry, which leads to inconsistencies, and as a consequence, the false results of the objective function.

To set a dynamic problem to provide construction sites with material resources, taking into account random factors that affect the time characteristics of transportation, we formulate the following initial conditions.

Suppose it is the starting point of the route of transportation of material resources, i.e. it is the loading point of transport. J is the endpoint of the route of transportation of material resources, i.e. it is the point of unloading of transport.

From here, we can conclude that the total ideal transport time is $t_{ij}(t)$ and the total ideal route length is $S_{ij}(S)$, where t and S are direct functions corresponding to the time and length of the route, respectively.

Then $\tau_{ij}(t)$ - ideally corresponds to the point of time of unloading of material resources and the point, respectively, the beginning of their use. In practice, these two points are different and will be able to change by random variables, depending on the above factors. We represent these quantities as $\pm\varphi_j(t)$ and $\pm\omega_j(t)$. Where $\pm\varphi_j(t)$ is a random time value of delay or early delivery of material resources, and $\pm\omega_j(t)$ is a random time value of delay or early start of consumption of material resources.

Taking into account that and setting the time characteristics that consider the influence of deterministic and non-deterministic factors on the time of transportation and use of building materials, we determine the points of time of unloading material resources and points of their use, taking the form $\tau_j(t) \pm \varphi_j(t)$ and $\tau_j(t) \pm \omega_j(t)$, respectively. Suppose that the time transportation schedule of material resources and time of the beginning of consumption take into account random factors (Fig. 1-2).

It should be noted [6] that based on the characteristics of the construction industry, it is necessary to specify the maximum (t_{max}) and minimum consumption time (t_{min}) of building materials because, for example, for concrete mix, it can not be brought before installed formwork and later required mobility of concrete mix.

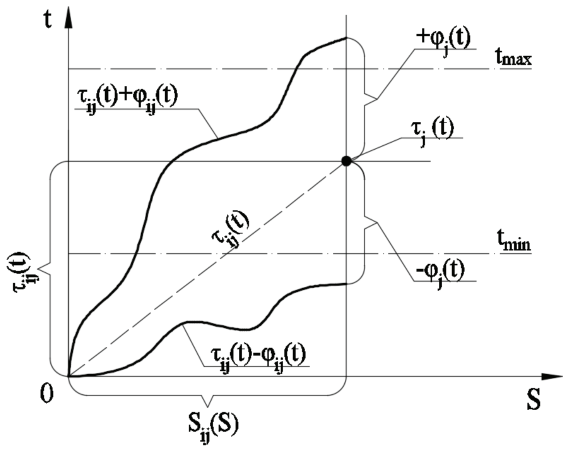

Fig. 1 Transportation schedule $\tau_{ij}(t) \pm \varphi_j(t)$

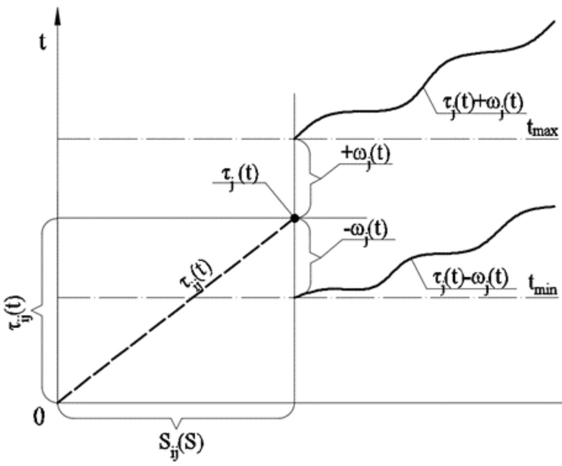

Fig. 2 Graph of usage $\tau_j(t) \pm \omega_j(t)$

Based on the given graphs $\tau_{ij}(t) \pm \varphi_j(t)$ and $\tau_j(t) \pm \omega_j(t)$ it can be concluded that under some conditions of the intersection of the two graphs, the losses from delay or early delivery of construction materials will be equal to zero. Also, under some conditions of the intersection of the two schedules, the losses from the early or late start of work will be zero. The intersection of the two graphs is shown in Fig. 3.

In [6], four possible cases of crossing the schedules of supply of construction materials and the beginning of the use of these materials were considered, namely:

1. Delayed delivery and the start of work ahead of schedule - maximum costs of the construction organization due to downtime crews;
2. Delivery of the previously specified term and the beginning of works later than the planned schedule - the maximum expenses of the transport organization because of transport delay;
3. Delivery of construction materials and the start of work with a delay - the costs are zero because the end of the

delivery schedule coincides with the plan of work;

4. Delivery of construction materials and the start of work before the specified date - the costs are zero, because the end of the delivery schedule coincides with the schedule of work.

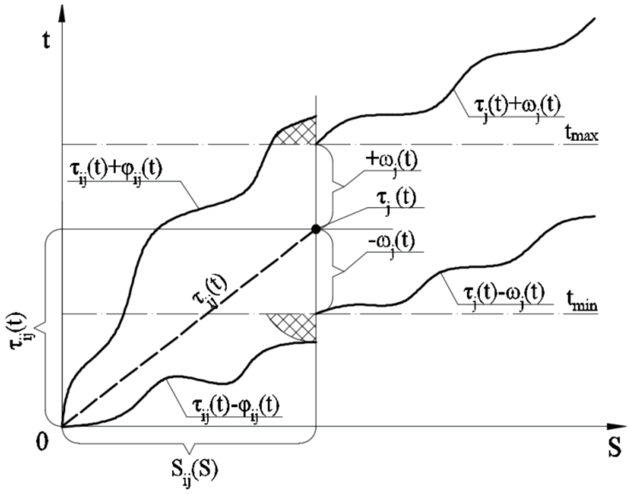

Fig. 3 Intersection of graphs $\tau_{ij}(t) \pm \varphi_j(t)$ and $\tau_j(t) \pm \omega_j(t)$

These intersections are also valid for the dynamic task of providing construction sites with material resources, but it should be noted that the supply schedule may go beyond (due to non-deterministic factors) the maximum (tmax) and minimum (tmin) time of use of these building materials.

If the condition $\tau_{ij}(t) \pm \varphi_j(t)$>tmax is met, the losses are borne not only by the construction organization due to idle crews but also by the transport organization, as there is a high probability of loss of the necessary parameters of material resources.

If the condition $\tau_{ij}(t) \pm \varphi_j(t) <$ tmin is met, then the losses are borne only by the transport organization because the transport with construction materials arrived earlier, before the preparatory scheduled time.

Having considered possible intersections of schedules of delivery of building materials and the beginning of the use of this material, we will define three potential cases of additional expenses depending on time of a delay:

1. If $\varphi_j(t) = \omega_j(t)$ (1) or $-\varphi_j(t) = -\omega_j(t)$ (2) - there are no additional costs, i.e. they are zero, because the delay or advance of delivery and consumption is equal to one one;
2. If $\varphi_j(t) < \omega_j(t)$ (3) or $-\varphi_j(t) > -\omega_j(t)$ (4) - the costs for waiting at the transport organization will approach the maximum because in this case the start time is later during the delivery of construction materials;
3. If $\varphi_j(t) > \omega_j(t)$ (5) or $-\varphi_j(t) < -\omega_j(t)$ (6) - the costs of delaying the start of work in the construction organization will approach the maximum because the delivery time of construction materials is delayed according to the time of the beginning of works.

Consider Eqs. (1) and (2). If we move the right part of the equation to the left and equate the values to zero, we obtain the same Eq. (7):

$$\varphi_j(t) - \omega_j(t) = 0. \tag{7}$$

We can state that with the difference between the delay of delivery time and the delay of consumption time, the cost of these delays will be zero.

Consider Eqs. (3-6). We get rid of the minus sign in Eqs. (4) and (6) by dividing them by -1, and we obtain Eqs. (3) and (5), respectively, i.e., the value of Eq. (3) corresponds to Eq. (4), and Eq. 5) corresponds to Eq. (6).

After analyzing Eqs. (1-6), we can conclude that there are two main variables of equations, namely, (3) and (5), based on which we make two objective functions to determine the cost of transportation and use of building materials, taking into account possible non-deterministic factors, affecting the time of transportation and start of use, and as a consequence, additional costs (option with the loss of material of required indicators, in this case, is not considered):

$$L_1(x) = c_1 \cdot n + c_2 \cdot t_{ij} + \int_{\omega_j}^{\varphi_j} c_2 \cdot tdt + c_3 \cdot t_{j,j+1} \to min\,; \tag{8}$$

$$L_2(x) = c_1 \cdot n + c_2 \cdot t_{ij} + c_3 \cdot t_{j,j+1} + \int_{\varphi_j}^{\omega_j} c_3 \cdot tdt \to min\,, \tag{9}$$

where c_1 – the cost of building materials; n – the number of building materials supplied; c_2 – the cost of transportation per unit time; t_{ij} – transportation time; c_3 – the cost of wages to employees of the construction company per unit time; $t_{j,j+1}$ – the time during which the construction organization performs this type of work.

In order to determine the variables $\varphi_j(t)$ and $\omega_j(t)$, it is necessary to establish the actual values of delivery time of

construction materials (t_{fact1}) and the actual start time of works (t_{fact2}), where using formulas 10 and 11 to set variable time values:

$$\varphi_j(t) = t_{fact1} - \tau_j(t); \quad (10)$$

$$\omega_j(t) = t_{fact2} - \tau_j(t). \quad (11)$$

Based on the equations of the objective function, we make an algorithm for solving a dynamic problem of providing construction sites with material resources, taking into account random factors that affect the time characteristics of transportation and use of resources and which will consist of the following steps:

1. We define the initial data (quantity of construction materials supplied; cost of construction materials; cost of transportation per unit time; planned time of transportation; wage costs of employees of the construction organization per unit time; time for which the construction organization performs this type of work, maximum and minimum delivery time and start time);
2. We define the deviation in time from the planned delivery time and start time;
3. We compare the obtained values of deviation from the planned delivery time and the planned start time. Depending on the predominant value, we define which organization bears the additional costs;
4. Using specific formulas of the objective function, we define the quantitative value of additional costs borne by the transport or construction organization.

The block diagram of the algorithm for solving the dynamic problem of providing construction sites with material resources, taking into account random factors that affect the time characteristics of transportation in a dynamic setting, is shown in Fig. 4.

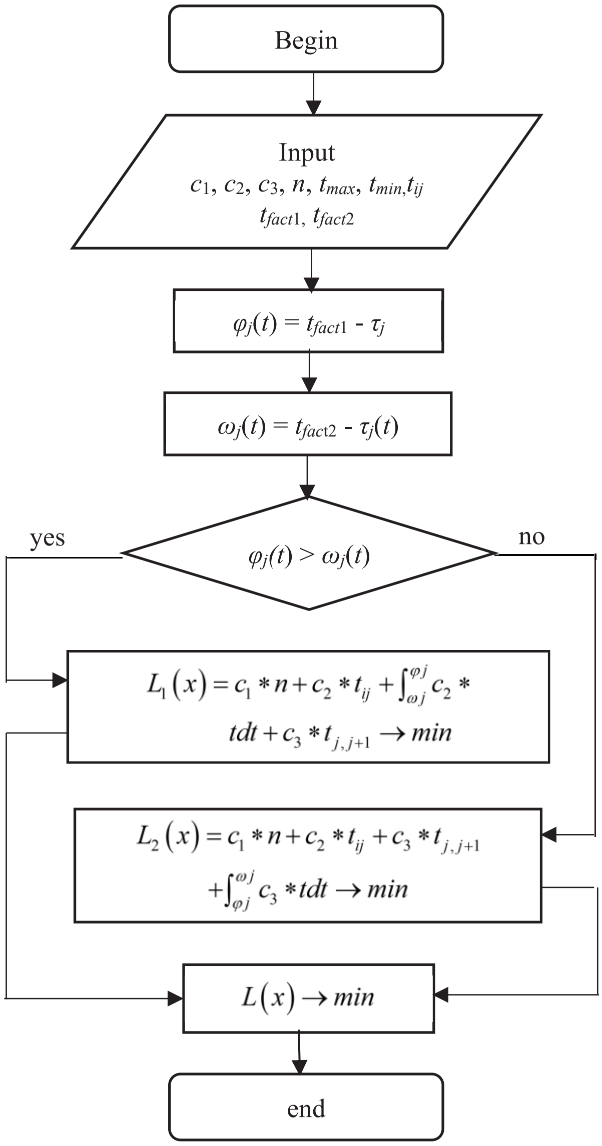

Fig. 4 Block diagram of the algorithm for solving the dynamic problem of providing construction sites with material resources, taking into account random factors that affect the time characteristics of transportation and the beginning of the use of resources

3. Conclusions

Two target functions were drawn up, one of which takes into account the additional costs of the transportation organization logistics and the time for waiting for transporting, the other takes into account the additional costs of the construction organization for delays in starting work.

After analyzing the target functions, the algorithm for solving a dynamic problem of providing construction sites with material resources was developed, taking into account random factors that affect the time sites with material resources was compiled, taking into account random factors that affect the time characteristics of transportation and the beginning of resource use, which can determine the additional costs of both transportation and construction organizations.

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