ESTIMATION OF CONSEQUENCES OF UNTIMELY TRANSPORT SERVICE OF SHOPS OF THE ENTERPRISE

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ABSTRACT

In real conditions, the schedule of transport maintenance of production facilities is very often violated, inter-operative downtime of technical equipment, of vehicles of cargo loading and unloading operations, production units and rolling stock arises. The authors propose to move towards the adaptive form of the schedule of organization of transportation through a dynamic transport task with delays in the network setting. The main criterion for optimization is establishing of minimum transport and production costs. The article presents a methodology for calculating the cost parameters needed to solve the task. The methodology allows to determine the cost of the components of the transport process, characteristic of the metallurgical plant. The calculation of cost coefficients is presented using the example of transportation required by the blast furnace shop.

Keywords: transportation organization, metallurgical plant, railway transport, transport and production costs, dynamic transportation task with delays, cost parameters.

Background. *Based on the results of the studies given in [1, 2], the authors came to the conclusion that it is possible to achieve reduction in transport costs and the cost of finished products in production by abandoning the rigid fixing of rolling stock for individual transportations, the fixed number of cars in the supply, the turnover time of cars, the interval of their departure and by developing a new form of organization of intra-plant shipments, where these parameters become operationally controlled [2].*

The production puts forward rather stringent requirements for transport, deliveries must be made on time and in the necessary (required) volume, the enterprise subdivisions fully subordinate the functioning of the transport to their own needs. In the conditions of uneven production processes, their irregularity is saved only by flexible form of organization of transportation by the contact schedule, which allows to meet the needs of shops with minimal losses for transport.

Objective. *The objective of the authors is to consider consequences of untimely transport service of shops of an enterprise and to suggest a flexible form of organization of transport services.*

Methods. *The authors use general scientific and engineering methods, mathematical apparatus, evaluation method, comparative analysis, management tools, dynamic transport problem solution tools.*

Results.

Model justification

In the article [5], the authors propose to calculate the contact graph in conditions of time-varying station utilization using a simulation model with a built-in flow control device for finite rhythms. In the work [6] the factors influencing the completeness and timeliness of the satisfaction of the needs of production units in transportation are systematized, and a system of priorities is proposed, on the basis of which a mathematical model is created to determine the sequence of delivery/removal of cars to loading/unloading areas.

In another case [7] there is a model of organization of unbranched transportation, a model of transportation in a group with a common reserve, a model of transportation in groups with lease. A lease is understood as a dynamic reserve of the first kind [8, p. 22], which is the exchange of cars between jets with mandatory return of leased cars for carriage of the goods for which they are secured.

The basis of its mathematical model is the dynamic transport task with delays (DTTD) in the network setting [9, 10], which relates to linear programming tasks. In the works of foreign authors [11–14] algorithms for analogs of this kind are considered in detail. One of the sources [15] describes classical optimization methods and suggests using dynamic optimization in production theory.

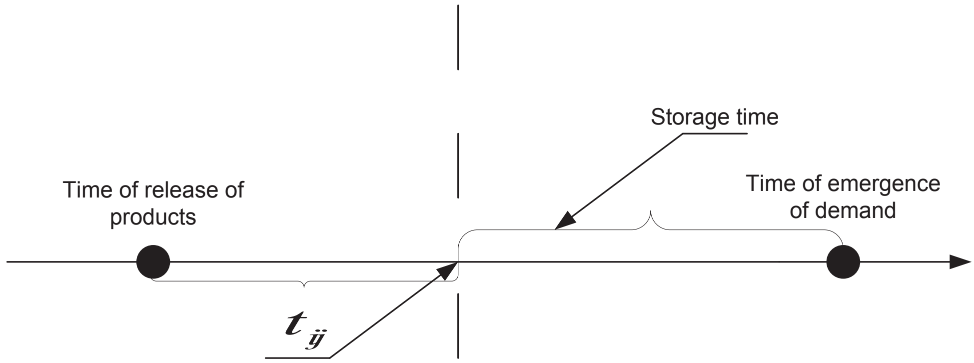
The following drawbacks of linear programming are noted: the lack of correlation between the specific transport costs and the condition of rolling stock (empty or laden) [16, 17], uncertainties with estimating the cost of transportation from the supplier shop to the consumer shop [18]. The methodology for calculating the cost coefficients developed by the authors takes into account these shortcomings and allows to eliminate them.

Applying DTTD in a network setting required a correction of the methodology for determining the cost of transporting the car; cost of storage of empty and loaded cars; the cost of locating the locomotive along with the cars during delivery/removal of cars to loading/unloading fronts, during unloading/loading of cars, during inter-operative downtime and storage of cargo at the station; the value of the lost profit of suppliers and consumers due to late delivery of empty or loaded cars.

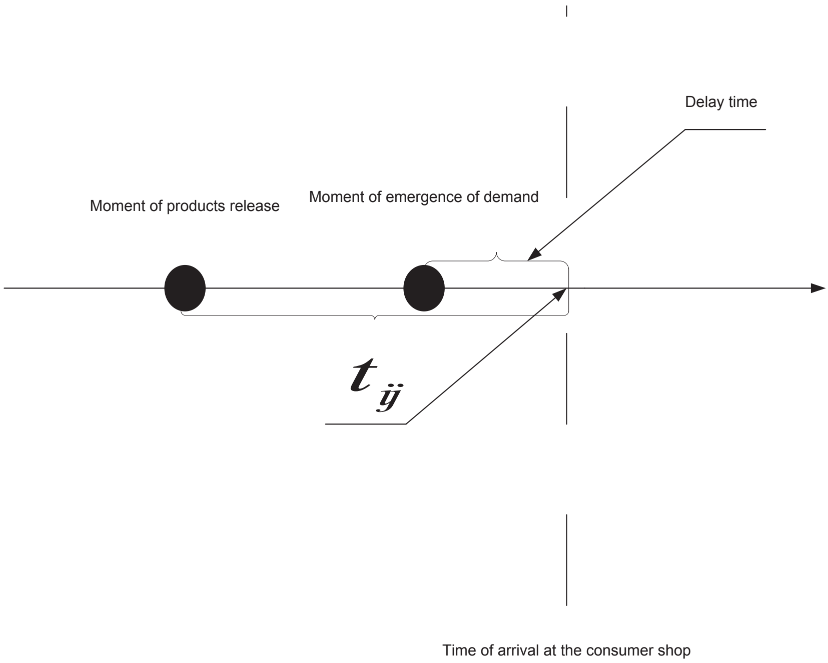
We know the production volumes x of the producer shops $a_i = \{a_i(t_{im})\}$, $i=\overline{1,x}$, $m=\overline{1,k_i}$, *and the demand volumes y of the consumer shops* $b_j = \{b_j(t_{jn})\}$, $j=\overline{1,y}$, $n=\overline{1,l_j}$, *where* $t \in Z$, $Z = \{1,2,\dots, T\}$, k_i *– the number of deliveries by the i-th producer shop during the considered period of time,* l_j *– the number of cases of demand for cargo by the j-th consumer shop,* t_{im} *– time of the m-th delivery of the goods by the i-th producer shop,* t_{jn} *– n-th demand of the j-th consumer shop for cargo, where* $\forall\, t_{im} \,\exists\, a_i(t_{im}) \neq 0$, $\forall\, t_{jn} \,\exists\, b_j(t_{jn}) \neq 0$. *The time of movement from the supplier shops to the consumer shops is known* $t = \|t_{ij}\|$, $i=\overline{1,x}$, $j=\overline{1,y}$.

C links between supplier shops and consumer shops $C(A_{im}, B_{jn}) \subset C$ *have been identified with the following conditions: absence of transfer of reserves between supply shops* $C(A_{im}, A_{i+1, m}) = 0$; *absence of exchange of reserves between consumer shops* $C(B_{jn}, B_{j+1, n}) = 0$; *absence of transfer of stocks from producer shops* $C(A_{im}, A_{i, m+1}) = 0$; *limitations of the capacity of the links* $d(A_{im}, B_{jn}) = d_{ij}(t_{im})$.

Transport and production costs for the transportation of products are defined as follows:



Pic. 1. Premature arrival of goods at the destination.



Pic. 2. Arrival of the goods to the destination with delay.

when $t_{jn} - t_{im} \geq t_{ij}$ *(Pic. 1)*

$$S\left(C\left(A_{im}, B_{jn}\right)\right) = S_{ij} + S_j^X\left(t_{jn} - t_{im} - t_{ij}\right); \qquad (1)$$

when $t_{jn} - t_{im} < t_{ij}$ *(Pic. 2)*

$$S\left(C\left(A_{im}, B_{jn}\right)\right) = S_{ij} + S_j^O\left(t_{im} + t_{ij} - t_{jn}\right), \qquad (2)$$

where S_{ij} *is cost of transporting a unit of rolling stock from the i-th producer shop to the j-th consumer shop;* S_j^X *– cost of storing a unit of rolling stock for a unit of time at the j-th consumer shop;* S_j^O *– cost of costs of the j-th consumer shop due to the untimely arrival of a rolling stock unit per unit time;* $(t_{jn} - t_{im} - t_{ij})$ *– time of production being in the reserve;* $(t_{jn} - t_{im})$ *– time interval between the moment of production of cargo and the moment of its consumption;* $(t_{im} + t_{ij} - t_{jn})$ *– time of delay of production at the moment of demand for it.*

$$\sum\nolimits_{c \in C} S(C(A_{im}, B_{jn}))P(A_{im}, B_{jn}) \to \min, \qquad (3)$$

where $P(A_{im}, B_{jn})$ *– transportation plan for the network, subject to the following conditions for restrictions: consumption without a remainder by the consumer shops of a one-off production volume of the supplier shops* $P(A_{im}, B) = a_i(t_{im})$*; absolute satisfaction of a one-time demand of consumer shops* $P(A, B_{jn}) = b_j(t_{jn})$*; accounting for network capacity* $0 \leq P(A_{im}, B_{jn}) \leq d_{ij}(t_{im})$*; static balance of production and consumption volumes*

$$\sum_{i=1}^{x}\sum_{m=1}^{k_i} a_i\left(t_{im}\right) = \sum_{j=1}^{y}\sum_{n=1}^{l_j} b_j\left(t_{jn}\right);$$

dynamic balance of production and consumption volumes for each interval $t_{im} \leq T_0 - t_{ij}$ *и* $t_{jn} \leq T_0$

$$\sum_{i=1}^{x}\sum_{m=1}^{k_i} a_{im}\left(t_{im}\right) \geq \sum_{j=1}^{y}\sum_{n=1}^{l_j} b_{jn}\left(t_{jn}\right).$$

This means that for any time of demand for cargo, the amount of the previous volumes of consumption should not exceed the sum of the previous volumes of production during time $[0; T_0 - t_{ij}]$*; produced earlier than the moment of demand for cargo for the period of time from the supplier shop to the consumer shop* t_{ij}*.*

Methodology for calculating cost indicators

Data on the volume of production and consumption per day by supplier shops and consumer shops (in cars), the times of the emergence of the «supply» for cargo, the demand for «cargo» and their number, time of movement from the producer shops to the supplier shops (in minutes) are defined for calculation of cost indicators on the basis of the conducted researches with use of statistical materials and the existing schedule of the organization of intrafactory transportations at a metallurgical works plant. It should be noted that the substantial meaning of the expression «the moment of the emergence of the «supply» for cargo» is equivalent to the expression «the moment for the demand for empty cars» by supplier shops, and the moment of time for demand for cargo is similarly equivalent to the time of supply of empty cars to consumers by suppliers. That is, it is obvious that production and transport are a unified system, and mutually beneficial cooperation between them will benefit both sides.

1. Determination of the cost of transportation of empty and loaded cars from the supplier to the consumer:

$$S_{ij} = \frac{S_B + S_P + S_G + S}{N_B}, \quad (4)$$

where S_L – costs of using locomotives; S_B – costs of using cars; S_P – costs of maintaining tracks, along which the transportation is carried out; S_G – costs of transportation of goods in cars; N_B – number of cars participating in transportation.

$$S_L = \sum T_L \cdot e_L, \quad (5)$$

where $\sum T_L$ – number of locomotive-hours required for transportation; e_L – cost of 1 locomotive-hour, according to data as of May 2017 e_L = 2493,78 rub.

$$S_B = N_B \cdot e_B \cdot t_{ij}, \quad (6)$$

where e_B – cost of 1 car-hour, according to May 2017 data e_B = 41,98 rub.; t_{ij} – duration of transportation from the i-th supplier to the j-th consumer.

$$S_P = \frac{C_L}{L \cdot T_P} \cdot l_{ik} \cdot t_{ij}, \quad (7)$$

where C_L – total annual costs of the shop of track for maintenance of the entire track superstructure; $C_L = L \cdot S_W + n \cdot S_C$ = 67094821,32 rub.; L – total length of railway tracks of the plant, L = 510 km; T_P – annual time during which the operation of railways is carried out; T_P = 8760 hours; l_{ik} – length of the railway lines, for which operations on the transport service of the k-th shop are performed at the i-th station and cars are transported from the supplier to the customer, km; S_W – cost of maintenance of 1 km of a track within a year, S_W = 104382,80 rub.; S_C – cost of maintenance of a switch turnout within a year, S_C = 9454,02 rub.; n – number of switch turnouts, n = 1466 [19].

$$S_Г = \frac{q_B \cdot N_B \cdot S_H}{8760} \cdot t_{ij}, \quad (8)$$

where q_B – single volume of transportation (q_B is equal to the load capacity of the car, t); S_H – average price of 1 ton of cargo; 8760 – the number of hours per year.

It should be noted that in the conditions of a metallurgical enterprise, the cost of transporting 1 ton of cargo is insignificantly dependent on the transportation distance [19].

2. Determination of the cost of storage of empty and loaded cars.

In case if raw materials or rolling stock arrive earlier than the main products, the consumer bears the costs associated with storage.

When calculating the cost of storing one empty/loaded car per unit of time (the storage time is taken equal to 1 hour) we use such a concept as «the cost of cargo on wheels». The only difference is that the cost is calculated not for the annual volume of transportation, but for the freight volume of one car.

The cost of cargo «on wheels» S_Y is determined by the formula [20]:

$$S_Y = \frac{Q_P \cdot S_H \cdot T_H}{8760}, \quad (9)$$

where Q_P – annual volume of transportation, t; S_H – average price of 1 ton of cargo, thousand rubles; T_H – average time of delivery of cargo, h; 8760 – number of hours per year.

In the proposed methodology, the cost of storing the laden car S_G^X on the station's tracks is made up of the cost of cargo in the car, the cost of using the car (the costs of using the car) and the costs of maintaining the railways where the goods are stored in cars, and the cost of storing the empty car S_P^X is made of the cost of using the rolling stock and the costs of maintaining the tracks.

$$S_G^X = \left(\frac{q_B \cdot S_H}{8760} + e_B\right) \cdot \left(\left(T_H - t_{ij}\right) + \left(t_{jn} - t_{im} - t_{ij}\right)\right) + \left(\frac{C_L}{L \cdot T_P} \cdot l_P^G \cdot \left(t_{jn} - t_{im} - t_{ij}\right)\right), \quad (10)$$

$$S_P^X = e_B \cdot \left(\left(T_Q - t_{ij}\right) + \left(t_{jn} - t_{im} - t_{ij}\right)\right) + \left(\frac{C_L}{L \cdot T_P} \cdot l_P^P \cdot \left(t_{jn} - t_{im} - t_{ij}\right)\right), \quad (11)$$

where t_{im} – moment of time of the m-th delivery of cargo by the i-th producer shop; t_{jn} – moment of time of the n-ht demand of the j-th consumer shop for cargo; q_B – one-time transportation volume (q_B is equal to the equivalent of load capacity of the car, t); S_H – average price of 1 t of cargo; T_H – average time of cargo delivery; T_Q – average time of delivery of the empty car;8760 – number of hours in a year; l_P^G and l_P^P – length of railway tracks at which at the i-th station a loaded/empty car is stored, km.

The average delivery time includes the cost of transporting cargo, delivery/removal of cars to freight fronts, unloading/loading of trains, and inter-operational downtime [20].

3. Determination of the cost of stay of the locomotive along with S_{LB}^G loaded cars and together with empty cars S_{LB}^P during delivery/removal of cars to loading/unloading areas, at the time of unloading/loading of cars, during inter-operational downtime and storage of the load at the station $((T_{H/Q} - t_{ij}) + (t_{jn} - t_{im} - t_{ij}))$.

$$S_{LB}^G = e_L((T_H - t_{ij}) + (t_{jn} - t_{im} - t_{ij})), \quad (12)$$

$$S_{LB}^P = e_L((T_Q - t_{ij}) + (t_{jn} - t_{im} - t_{ij})), \quad (13)$$

where T_H – average time for delivery of cargo; T_Q – average time of delivery of an empty car; t_{ij} – duration of transportation from the i-th supplier to the j-th consumer.

In cases where the locomotive is with the cars for a time $((T_{H/Q} - t_{ij}) + (t_{jn} - t_{im} - t_{ij}))$, the components (12) or (13) are added to the cost of storing the empty/loaded car per unit time.

4. Determination of the lost profit of suppliers and consumers because of untimely delivery of empty or loaded cars.

It is necessary to calculate the potential losses, possible losses of the consumer due to late arrival of cargo, losses of the supplier due to the absence of empty cars for loading. Due to the late arrival of one unit of cargo per unit of time, the consumer suffers damage S^O.

Table 1

In-plant transportation for maintenance of the blast furnace shop

Name of cargo	Departure station	Destination station	Kind of a car	Load capacity of a car, t
Sparkling dust	C	B	gondola car	64
Sparkling dust	D	B	gondola car	64
Aspiration dust	C	B	gondola car	64
Aspiration dust	C	B	gondola car	64
Coke waste	C	B	gondola car	61
Screening of agglomerate, pellets	C	A	hopper	63

In developing the methodology, the authors considered two options for calculating potential losses.

1st option. Calculation of the cost of production losses from the short delivery of one empty/loaded car using the coefficients $k_{X/Y}$:

$$S^O = \frac{q_B}{k_{X/Y}} \bullet S_t \,, \tag{14}$$

where q_B – load capacity of the car; $k_{X/Y}$ – coefficients of consumption of raw materials and materials k_X and output of finished products and production waste k_Y per 1 t of products, respectively; S_t – cost of 1 ton of products.

2nd option. Calculation of the cost of losses, taking into account the hourly output of finished products, i.e. how many products would be produced per hour, if the delivery was made on time:

$$S^O = q_{CH} \cdot S_t, \tag{15}$$

where q_{CH} – production hourly output, $q_{CH}^A = 1783$ t/h of the agglomerate, $q_{CH}^{CH} = 394$ t/h of cast iron.

Results of the study

At the example of the group of carriages necessary for transport service of the blast furnace shop (Table 1), we calculate the transportation cost S_{ij}, the cost of storage S^X, the cost of delaying S^O of the empty/loaded car per unit time; the cost of locating the locomotive along with loaded or empty cars – S_{LB}^G and S_{LB}^P respectively.

For calculation, we assume that the cost of sparkling and aspiration dust is 5–8 % of the cost of cast iron, coke breeze – 8–10 % of the cost of coke [21]. The cost of sintering of the agglomerate, pellets will be considered equal to the average cost of the agglomerate.

The average prices of domestic producers for metals and raw materials excluding VAT, excises, transportation costs are as follows: iron ore agglomerate – 2730[1] rub. 1 per 1 ton; pig iron – 20000 rub[2]. per 1 t; coke – 28000 rub[1]. per 1 ton.

The values of the raw material consumption factors k_X and the yield factors for k_Y waste products per 1 ton of production are indicated in Tables 2 and 3.

The results of the calculations are presented in Tables 4, 5, 6 and 7.

When calculating S_{LB}^G and S_{LB}^P the term $(t_{jn} - t_{im} - t_{ij})$ is assumed to be zero. This means that in case of forced storage of goods on the tracks of the railway station, the locomotive, along with the cars, does not participate in waiting.

The calculation is carried out for a blast furnace with a useful volume of less than 5 000 m³.

The 1st option. The results of the calculation for the 1st option are summarized in Table 7, below there are some examples with an explanation of the calculation. The example of calculation of cost of losses of production in connection with delay of one

[1] The largest open-access database on the metal market. [Electronic resource]: http: //infogeo.ru. Last accessed 17.05.2017;

[2] Online shop for the sale of cast iron and cast-iron products. [Electronic resource]: http://chugun.ru. Last accessed 17.05.2017.

Table 2

Coefficient of consumption of raw materials and materials, output of finished products and production waste per 1 ton of agglomerate and coke [22]

Needs		Output	
Raw materials and materials	Coefficient of consumption per 1 t of products k_X	Products and waste of production	Coefficient per 1 t of products k_Y
I. Agglomeration factory			
Iron ore	0,8–1,00	Agglomerate	1,00
Manganese ore	0,01–0,1		
Limestone, dolomite	0,49		
Sparkling dust	0,02–0,04		
Coke, coke breeze	0,072–0,156		
Ocalin	0,00–0,03		
II. Coke oven shop			
Coking coal	1,27–1,3	Coke	1,00
Other	0,002–0,004	Including:	
		coke	0,020
		chemical products	0,053

Table 3

Coefficient of consumption of raw materials and materials, output of finished products and production wastes per 1 ton of pig iron [23]

Cargo	From (where)	Coefficient of consumption (output) of cargo t/t of cast iron with a useful volume of the furnace		
		less than 5000	5000	5500
Arrival				
Coke	CCS	0,56	0,375	0,37
Agglomerate	AF	1,547	1,00	0,837
Iron ore	RZD	0,10	0,055	0,055
Pellets	RZD	0,15	0,68	0,81
Limestone	RZD	0,055	0,063	0,063
Lime for spraying slag trucks	LBS	0,0004	0,0004	0,0004
Sand for refilling gutters on furnaces	RZD	0,0045	0,001	0,001
Refractory masses: a) airframe and case – coke	CCS	0,0007	0,0007	0,0007
– clay	RZD	0,0003	0,0003	0,0003
– chamotte powder	RZD	0,0004	0,0004	0,0004
– carbon additive	RZD	0,0003	0,0003	0,0003
– coal mass	RZD	0,0003	0,0003	0,0003
b) for filling gutters on furnaces – carborundum powder	RZD	0,001	0,0005	0,0005
– coke breeze	CCS	0,0005	0,0003	0,0003
– coal peck	RZD	0,0002	0,0001	0,0001
– refractory clay	RZD	0,0003	0,0001	0,0001
Departure				
Cast iron	AFS, OCS, RZD, FM, MS	1,00	1,00	1,00
Slag	HGG, PSP, PCFCH, PFSC	0,55	0,325	0,325
Flue dust caught (60 % of total carry over)	AF	0,046	0,015	0,015
Screening of fines from coke (6,5 % of weight of skip coke)	AF, B	0,036	0,0244	0,0244
Screening of fines from the agglomerate (5 % of weight)	AF	0,077	0,05	0,042
Screening of fines from pellets (2 % of weight)	AF	0,003	0,014	0,016
Loss of cast iron in scrap at the furnace	SRB	0,0105	0,0095	0,0095
Garbage	D	0,0086	0,0041	0,004

Accepted designations: AF – agglomeration factory, B – blooming, OCS – oxygen converter shop, CCS – coke chemical shop, D – dump, FM – filling machine, SRB – scrap base, HGG – hydro-granulation plants, PCFCH – plants for casting fractionated crushed stone, PFSC – plants for the production of cast fractionated crushed stone from bucket residues, PSP – plants for the production of slag pumice, MS – steel mold shop, LBS – lime-burning shop, AFS – arc furnace shop.

empty car for loading flue dust or untimely removal of one car loaded with it from railway tracks is resulted.

The yield of flue dust from 1 ton of pig iron is $k_{УКР}$ = 0,046 (Table 3). Load capacity $q_В$ = 64 tons. Cost of 1 ton of cast iron S_{tCH} = 20000 rub. =>

$$S^O_{KP} = \frac{64}{0,046} \cdot 20000 = 27826086,96 \text{ rub.}$$

The example of calculation of cost of losses of production in connection with delay of one empty car for loading of coke wastes is shown.

The yield of coke wastes with 1 ton of pig iron is $k_{УКО}$ = 0,036 (Table 3). Load capacity $q_В$ = 61 tons. Cost of 1 ton of cast iron S_{tCH} = 20000 rub. =>

$$S^O_{KO} = \frac{61}{0,036} \cdot 20000 = 33888889 \text{ rub.}$$

An example is given of calculating the cost of product losses due to the delay of one loaded car for unloading of coke breeze into the agglomeration factory.

The coefficient of consumption of coke breeze per 1 ton of agglomerate is k_{XKM} = 0,114 (Table 2). Load capacity $q_В$ = 61 tons. Cost of 1 ton of agglomerate S_{tA} = 2730 rub. => $S^O_{KM} = \frac{61}{0,114} \cdot 2730 = 1460789,47$ *rub.*

Table 4

Calculation of the cost of transporting one loaded S_{ij}^{G} and empty S_{ij}^{P} cars

Name of cargo	ΣT_L, h	S_L, rub.	N_B, car	t_{ij}, h	S_B, rub.	l_{ik}, km	S_P, rub.	S_G, rub.	S_{ij}^{G}, rub.	S_{ij}^{P}, rub.
Flue dust	0,5	1246,89	1÷3	0,5	41,98	9,72	72,99	8,77	685,32	680,93
Flue dust	1,0	2493,78	1÷3	1,0	83,96	11,22	168,50	17,53	1381,89	1373,12
Aspiration dust	0,5	1246,89	2÷6	0,5	83,96	9,72	72,99	17,53	355,34	350,96
Aspiration dust	0,5	1246,89	2÷6	0,5	83,96	9,72	72,99	17,53	355,34	350,96
Coke waste	0,5	1246,89	8÷23	0,5	335,84	9,72	72,99	140,38	112,26	103,48
Screening of agglomerate, pellets	0,5	1246,89	9÷15	0,5	251,88	9,23	69,31	117,80	140,49	130,67

Table 5

Calculation of the cost of storage of empty S_P^X and loaded S_G^X cars per unit time ($t_{jn} - t_{im} - t_{ij} = 1$ h)

Name of cargo	q_B, t	S_H, rub.	T_H, h	l_P^G, km	S_G^X, rub.	T_Q, h	l_P^P, km	S_P^X, rub.
Flue dust	64	1200	27,5	0,36	1426,33	20,5	0,25	885,33
Flue dust	64	1200	27,0	0,36	1375,58	21,0	0,25	906,33
Aspiration dust	64	1200	15,5	0,36	817,36	8,5	0,25	381,57
Aspiration dust	64	1200	15,5	0,36	817,36	8,5	0,18	380,52
Coke waste	61	2520	15,5	0,37	958,00	8,5	0,18	380,52
Screening of agglomerate, pellets	63	2730	5,67–14,17 (accepted as 10,5)	0,20	680,75	5,0	0,18	233,59

Table 6

Determining the cost of locating the locomotive together with loaded/empty cars

Name of cargo	T_H, h	T_Q, h	t_{ij}, h	S_{LB}^G, rub.	S_{LB}^P, rub.
Flue dust	27,5	20,5	0,5	67332,06	49875,60
Flue dust	27,0	21,0	1,0	64838,28	49875,60
Aspiration dust	15,5	8,5	0,5	37406,70	19950,24
Aspiration dust	15,5	8,5	0,5	37406,70	19950,24
Coke waste	15,5	8,5	0,5	37406,70	19950,24
Screening of agglomerate, pellets	5,67–14,17 (accepted as 10,5)	5,0	0,5	29925,36	11222,01

Table 7

Calculation of the cost of product losses from short delivery of one empty S_G^O and loaded S_P^O cars using $k_{X/Y}$ (1st option)

Name of cargo	Flue dust	Aspiration dust	Coke waste	Screening of agglomerate, pellets
S_G^O, thous. rub.	27826,09	41290,32	1460,79	15750,00
S_P^O, thous. rub.	27826,09	41290,32	33888,89	15750,00

The 2nd option. Calculation of the cost of losses relative to a single output.

Delay of one empty car for loading flue dust/aspiration dust/screening of agglomerate, pellets/coke waste or untimely removal of one loaded car from the railway tracks is shown below.

The cost of 1 ton of cast iron S_{tCH} = 20000 rub. => $S^O = 394 \cdot 20000 = 7880000$ rub.

Delay of one loaded car for unloading of coke breeze into the agglomeration factory.

The cost of 1 t of agglomerate S_{tA} = 2730 rub. => $S_{GKM}{}^O = 1783 \cdot 2730 = 4867590$ rub.

Of two options for calculating the cost of product losses due to late delivery of an empty/loaded car, the first option is clearer from the authors' point of view.

Conclusions. *The proposed methodology for calculating cost parameters when used in conjunction with a dynamic transport task with delays in the network setting will not only make up the optimal transportation plan by the criterion of the minimum of transport and production costs, but will also estimate, in monetary terms, the consequences of the forced stay of empty/loaded cars on the tracks of railway stations in anticipation of cargo operations, untimely arrival of empty/loaded cars to the loading/unloading front.*

The joint use of the mathematical apparatus of DTTD and the developed methodology makes it possible to take *into account the obtained cost coefficients not only in the static state, but also in the dynamics of the computational period of the computational experiment. This helps to take into account and evaluate the impact of non-standard situations arising in the process of transportation of various kinds, urgent, extra-urgent and emergency situations, intermittent increases and decreases in the volume of production of the shops. Similarly, the same principle applies to the value of the cost of storing a loaded/empty car, and the value of the resulting losses and damages of the consumer shops and supplier shops.*

The methodology is universal for any kind of industrial enterprises, regardless of the nature of their activities. It should be remembered here that the size of the lost profit is nonlinearly dependent on the dimension of the problem being solved, the number of supplier shops and consumer shops, and the larger is the system in question, the wider are the management capabilities and the more significant is the calculation result.

REFERENCES

1. Popov, A. T., Voronina, O. V. Problems of the existing organization of intra-plant shipments in the conditions of the metallurgical combine [*Problemy sushhestvujushhej organizacii vnutrizavodskih perevozok v uslovijah metallurgicheskogo kombinata*]. *Sovremennye problemy transportnogo kompleksa Rossii*, 2014, Iss. 5, pp. 29–37.

2. Popov, A. T., Voronina, O. V. Study of the influence of the nonrhythmicity of production processes on the number of cars in turnover [*Issledovanie vlijanija neritmichnosti proizvodstvennyh processov na kolichestvo vagonov v oborote*]. *Transport Urala*, 2016, Iss. 3, pp. 54–59.

3. Perepelyuk, A. V., Khoruzhy, A. S. The economics of industrial transport of metallurgy [*Ekonomika promyshlennogo transporta metallurgii*]. Moscow, Metallurgia publ., 1982, 190 p.

4. Economics and organization of industrial transport: Textbook [*Ekonomika i organizacija promyshlennogo transporta: Uchebnik*]. Ed. by N. P. Zhuravleva, I. S. Besedin. Moscow, Zheldorizdat publ., 2001, 440 p.

5. Kozlov, P. A., Chetverikov, V. A. Automation of calculation of the contact schedule of the transport service of production [*Avtomatizacija raschjota kontaktnogo grafika transportnogo obsluzhivanija proizvodstva*]. *Promyshlennyj transport XXI vek*, 2010, Iss. 3, pp. 32–34.

6. Novikov, A. S. Optimization of the working fleet of cars of industrial enterprises on the basis of the priority system for management of the transportation process. Ph.D. (Eng) thesis [*Optimizacija rabochego parka vagonov promyshlennyh predprijatij na osnove sistemy prioritetov upravlenija perevozochnym processom. Dis... kand. tehn. nauk*]. Magnitogorsk, 2008, 155 p.

7. Kudryashova, M. S. Improvement of organization of technological transport in the transport systems of metallurgical plants. Ph.D. (Eng) thesis [*Sovershenstvovanie organizacii tehnologicheskih perevozok v transportnyh sistemah metallurgicheskih kombinatov. Dis... kand. tehn. nauk*]. Moscow, 1985, 226 p.

8. Kozlov, P. A., Kozlova, V. P. Optimization of the functional structure of the transport node [*Optimizacija funkcional'noj struktury transportnogo uzla*]. *Nauka i tehnika transporta*, 2005, Iss. 1, pp. 17–31.

9. Milovidov, S. P., Kozlov, P. A. Dynamic transport problem with delays in the network setting [*Dinamicheskaja transportnaja zadacha s zaderzhkami v setevoj postanovke*]. *Izvestija AN SSSR. Tehnicheskaja kibernetika*, 1982, Iss. 1, pp. 211–212.

10. Popov, A. T. Optimization of interaction between technological rail transport and production (using the example of a metallurgical combine). Ph.D. (Eng) thesis [*Optimizacija vzaimodejstvija tehnologicheskogo zheleznodorozhnogo transporta i proizvodstva (na primere metallurgicheskogo kombinata). Dis... kand. tehn. nauk*]. Moscow, 1984, 237 p.

11. Ford, L., Fulkerson, D. Flows in the networks [Russian title: *Potoki v setjah: Trans. from English*]. Moscow, Mir publ., 1966, 276 p.

12. Ford, L. R., Fulkerson, D. R. Constructing Maximal Dynamic Flows from Static Flows. *Operations Research*, 1958, Vol. 6, Iss. 3, pp. 419–433.

13. Phillips, D., Garcia-Diaz, A. Fundamentals of network analysis [*Metody analiza setej: Transl. from English*]. Moscow, Mir publ., 1984, 496 p.

14. Mesarovic, M., Macko, D., Takahara, Y. Theory of hierarchical, multi-level systems [*Teorija ierarhicheskih mnogourovnevyh sistem: Transl. from English*]. Moscow, Mir publ., 1973, 342 p.

15. Intriligator, M. Mathematical methods of optimization and economic theory [*Matematicheskie metody optimizacii i ekonomicheskaja teorija: Trans. from English*]. Moscow, Airis-press, 2002, 576 s.

16. Kazovsky, I. G. Rationalization of cargo transportation on railways [*Racionalizacija perevozok gruzov na zheleznyh dorogah*]. Moscow, Transport publ., 1977, 280 p.

17. Osminin, A. T. The rational organization of car flows on the basis of multicriteria optimization methods. Abstract of D.Sc. (Eng) thesis [*Racional'naja organizacija vagonopotokov na osnove metodov mnogokriterial'noj optimizacii/Avtoref. dis. dok. tehn. nauk*]. Samara, 2000, 48 p.

18. Industrial transport [*Promyshlennyj transport*]. Ed. by A. T. Deribas. Moscow, Transport publ., 1974, 560 p.

19. Suslova, O. A. Optimization of the technological process of industrial railway transport of a metallurgical plant. Ph.D. (Eng) thesis [*Optimizacija tehnologicheskogo processa promyshlennogo zheleznodorozhnogo transporta metallurgicheskogo kombinata. Dis... kand. tehn. nauk*]. Lipetsk, 2006, 210 p.

20. Tikhonov, K. K. Technical and economic calculations in operation of railways [*Tehniko-ekonomicheskie raschjoty v ekspluatacii zheleznyh dorog*]. Moscow, Publishing House of the Ministry of Railways, 1962, 252 p.

21. Banny, N. P., Banny, D. N. Technical-economic calculations in the ferrous metallurgy [*Tehniko-ekonomicheskie raschjoty v chjornoj metallurgii*]. Moscow, Metallurgia publ., 1979, 393 p.

22. Balandyuk, G. S., Kurtukov, Ya. M. Technology of work of railway transport of metallurgical plants [*Tehnologija raboty zheleznodorozhnogo transporta metallurgicheskih zavodov*]. Moscow, Metallurgia publ., 1985, 256 p.

23. Popov, A. T., Suslova, O. A., Liberman, B. A. Methodical instructions to the course and diploma project «General plans and transport of industrial enterprises» [*Metodicheskie ukazanija k kursovomu i diplomnomu proektirovaniju «General'nye plany i transport promyshlennyh predprijatij»*]. Lipetsk, LSTU publ., 2004, 27 p. ●

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