OPTIMIZATION OF PLANT INTERNAL TRANSPORTATION ACCORDING TO THE CONTACT SCHEDULE

Popov, Alexey T., *Lipetsk State Technical University (LSTU), Lipetsk, Russia.*
Suslova, Olga A., *Lipetsk State Technical University (LSTU), Lipetsk, Russia.*
Voronina Olga V., *Lipetsk State Technical University (LSTU), Lipetsk, Russia.*

ABSTRACT

The presented article is a continuation of research on development of an alternative model for organization of transportation according to the contact schedule in the conditions of a metallurgical enterprise. The mathematical model is based on a dynamic transport problem with delays (DTPD). It is shown in what way an optimal transportation plan is obtained and minimization of transportation costs is ensured with the agreed production programs of supply shops and consumer shops.

The improvement of the system of transportation of empty cargo flow according to the contact schedule with the help of DTPD, as the authors argue, allows to abandon the strict assignment of cars to a specific transportation, supply of empty cars is carried out according to the most favorable option for a consumer (with a minimum of transport and production costs). The cars can be delivered to the consumer for loading onto the cargo front from under any used load.

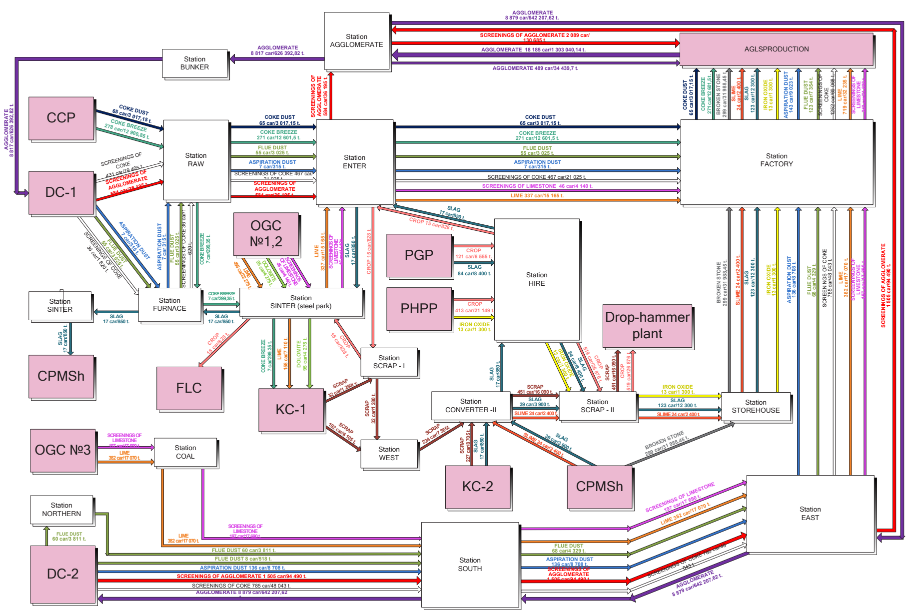
The use of a dynamic transportation problem with delays as the basis of a mathematical model for development of an optimal plan for transportation of cars according to the contact schedule helps to more than halve the transport and production costs of the shops of the metallurgical plant.

Keywords: *dynamic transport problem with delays, internal transportation, optimization of transportation, contact schedule, metallurgical plant, railway transport.*

Background. *The peculiarity of a metallurgical enterprise is presence of a stable and continuous connection between the production process and transport flows [1]. Transport serves as a link in production of metallurgical products. Finished products of some units become raw materials for others (transportation of molten iron, steel, slag) [2]. Sinter comes from a sintering plant to blast furnaces, from coke-chemical production or from external network – coke, from the same network – limestone (used as a flux). Liquid iron together with scrap, lime and dolomite are sent to steel-smelting shops. Then steel is transported to a continuous casting plant and then to rolling mills. Numerous types of waste have their own turnover [3, 4].*

According to the contact schedule, powerful homogeneous jets of agglomerate and production waste are clearly distinguished in the structure of transport flows: screenings of agglomerate, screenings of coke, limestone, blast furnace dust and aspiration dust (Pic. 1). Fluctuations in production waste depend on the quality and quantity of the main raw material. The use of raw materials and materials of inadequate quality aggravates irregularity of the work of production workshops. For example, excess arrival of cheap imported coke leads to a sharp increase in the volume of coke waste, an increase in agglomerate production contributes to the growth of transportation of its agglomerate screenings.

The dynamic transport problem with delays (DTPD), proposed as the basis for a mathematical model of intra-factory transportation optimization, promises an order of their organization with minimal transport and production costs, consisting of the cost of transporting and storing goods, as well as losses due to late delivery of loaded or empty cars in shop consumers.



Pic. 1. Scheme of cargo flows according to the contact schedule.

Objective. *The objective of the authors is to consider optimization of internal transportation according to the contact schedule.*

Methods. *The authors use general scientific methods, comparative analysis, graph construction, mathematical methods, statistical analysis.*

Results.

Statement of a mathematical apparatus

The production volumes x of manufacturing shops A_i, $i=\overline{1,x}$ and the demand volumes of y production shops B_j, $j=\overline{1,y}$ are known. Optimization period [0; T], $T \in Z_0$, $Z_0 = \{0, 1, 2,...\}$. We take $\upsilon^{*}_{ij}(t)$ – the number of cars with cargo sent from A_i and arriving in B_j at the moment of time $(t + t_{ij})$, and $t + t_{ij} \le T$, t_{ij} – duration of transportation from A_i to B_j; $\upsilon^{**}_{ji}(t)$ – number of empty cars sent from B_j and arriving at A_i at the moment of time $(t+t_{ji})$, with $t+t_{ji} \le T$, t_{ji} – duration of transportation from B_j to A_i; $S^{*}_{ij}(t)$ – cost of transporting the car with a load from A_i to B_j; $S^{**}_{ji}(t)$ – cost of transporting an empty car from B_j to A_i; $S^{B}_{j}(t)$ – cost of storing a unit of cargo at the moment of time t at the j-th consumer shop; $S^{A}_{i}(t)$ – cost of storing a unit of rolling stock at time t at the i-th supply shop; $Z^{A}_{i}(t)$ – required number of empty cars; $X^{A}_{i}(t)$ – reserve of empty cars on A_i; $Z^{B}_{j}(t)$ – required number of loaded cars; $X^{B}_{j}(t)$ – number of cars with cargo in reserve on B_j; t_{ii}, t_{jj} – technological delays (loading / unloading time, inter-operation downtime) on A_i and B_j.

The mathematical model is based on DTPD modification developed in [5–7]. The optimal transportation plan will be obtained by minimizing transportation costs with agreed production programs of supply shops and consumer shops $J = J_1+J_2$.

$$J_1 = \sum_{t=0}^{T}\sum_{i=1}^{x}\sum_{j=1}^{y} S^{*}_{ij}(t)\cdot\upsilon^{*}_{ij}(t)\cdot\Delta t + \sum_{t=0}^{T}\sum_{j=1}^{y} S^{B}_{j}(t)\cdot X^{B}_{j}(t)\cdot\Delta t, \quad (1)$$

$$J_2 = \sum_{t=0}^{T}\sum_{i=1}^{x}\sum_{j=1}^{y} S^{**}_{ji}(t)\cdot\upsilon^{**}_{ji}(t)\cdot\Delta t + \sum_{t=0}^{T}\sum_{i=1}^{x} S^{A}_{i}(t)\cdot X^{A}_{i}(t)\cdot\Delta t \quad (2)$$

subject to the following restrictions:

- *stock dynamics of empty cars*

$$X^{A}_{i}(t+1) = X^{A}_{i}(t) + \sum_{j=1}^{y}\upsilon^{**}_{ji}(t-t_{ji}) - Z^{A}_{i}(t); \quad (3)$$

- *stock dynamics of loaded cars*

$$X^{B}_{j}(t+1) = X^{B}_{j}(t) + \sum_{i=1}^{x}\upsilon^{*}_{ij}(t-t_{ij}) - Z^{B}_{j}(t); \quad (4)$$

- *process of transfer of empty cars into cars with cargo*

$$Z^{A}_{i}(t-t_{ii}) = \sum_{j=1}^{y}\upsilon^{*}_{ij}(t); \quad (5)$$

- *process of transition of loaded cars to empty*

$$Z^{B}_{j}(t-t_{jj}) = \sum_{i=1}^{x}\upsilon^{**}_{ji}(t); \quad (6)$$

- *no negative reserves and delivery volumes $\upsilon^{*}_{ij}(t) \ge 0$; $t + t_{ij} \le T$; $X^{B}_{j}(t) \ge 0$; $\upsilon^{**}_{ji}(t) \ge 0$; $t + t_{ji} \le T$; $X^{A}_{i}(t) \ge 0$.*

At the production and consumption points A_i and B_j, the cars do not stay in time intervals [0; min t_{ji} –1] and [0; min t_{ij} –1]. According to equation (5) in points A_i, reserves of cars with cargo are not formed, according to equation (6) additional reserves of empty cars in points B_j do not appear. Upon expiration of time t_{ii}, loading of cars $Z^{A}_{i}(0)$ to A_i ends, after expiration of time t_{jj} – unloading of cars $Z^{B}_{j}(0)$ to B_j. The departure from A_i ends at time t = T – min t_{ij}, and from B_j – at time t = T – min t_{ji}. Expression (5) is valid in the time interval [t_{ii}; T – min t_{ij}], expression (6) is true for the time interval [t_{jj}; T – min t_{ji}].

At the time t_2 = min (t_{jj} + t_{ji}), the cars loaded onto B_j arrive at A_i. At t_1 = min (t_{ii} + t_{ij}), the first cars loaded onto A_i arrive at B_j. The conditions of the stock of empty and loaded cars (3) and (4) are indicated for the time intervals [t_2, T] and [t_1, T].

In the intervals [0; t_2–1] and [0; t_1–1] deliveries do not occur, and points A_i and B_j must function at the expense of own reserves

$$X^{A}_{i}(0) = \sum_{t=0}^{t_2-1} Z^{A}_{i}(t), \quad X^{B}_{j}(0) = \sum_{t=0}^{t_1-1} Z^{B}_{j}(t).$$

Let us accept that

$$X^{A}_{i}(t_2) = X^{B}_{j}(t_1) = 0.$$

Points A_i and B_j are connected by a single closed technological process from the moment of rolling stock arrival from other production workshops [min (t_{jj} + t_{ji}); T – t_{ii} – min t_{ij}] and until the end of technological operations in the workshop under consideration [min (t_{ii} + t_{ij}); T – t_{jj} – min t_{ji}].

From the equations of the dynamics of stocks of loaded cars (4) and transition of empty cars into cars with cargo (5) it follows:

$$\sum_{j=1}^{y}\sum_{t=\min(t_{ij}+t_{ii})}^{\delta} Z^{B}_{j}(t) \le \sum_{i=1}^{x}\sum_{j=1}^{y}\sum_{t=0}^{\delta-t_{ii}-t_{ij}} Z^{A}_{i}(t). \quad (7).$$

The expression (7) means that at the previous point in time (δ – t_{ii} – t_{ij}) the need for empty cars is greater than or equal to the need for loaded cars at the next time point δ. Similarly, from the equations of stock dynamics of empty cars (3) and the transition of loaded cars into empty cars (6) we get

$$\sum_{i=1}^{x}\sum_{t=\min(t_{ij}+t_{ii})}^{\delta} Z^{A}_{i}(t) \le \sum_{i=1}^{x}\sum_{j=1}^{y}\sum_{t=0}^{\delta-t_{jj}-t_{ji}} Z^{B}_{j}(t). \quad (8)$$

For the time interval δ ϵ [0, T] the simultaneous fulfillment of the conditions δ > t_{ii} + t_{ij}; δ > t_{jj} + t_{ji}; δ – t_{ii} – t_{ij} > min (t_{jj} + t_{ji}); δ – t_{jj} – t_{ji} > min (t_{ij} + t_{ii}) ensures the exchange between supply shops and consumer shops. From inequations (7) and (8) it follows:

$$\sum_{i=1}^{x}\sum_{t=\min(t_{ij}+t_{ii})}^{\delta} Z^{A}_{i}(t) \le \sum_{j=1}^{y}\left(\sum_{t=0}^{\min(t_{ij}+t_{ii})} Z^{B}_{j}(t) + \sum_{t=\min(t_{ij}+t_{ii})}^{\delta} Z^{B}_{j}(t)\right) \le$$
$$\le \sum_{j=1}^{y} X^{B}_{j}(0) + \sum_{j=1}^{y}\sum_{t=\min(t_{ij}+t_{ii})}^{\delta} Z^{B}_{j}(t) \le \sum_{j=1}^{y} X^{B}_{j}(0) + \quad (9)$$
$$+ \sum_{i=1}^{x}\sum_{j=1}^{y}\sum_{t=0}^{\delta-t_{ii}-t_{ij}} Z^{A}_{i}(t);$$

$$\sum_{j=1}^{y}\sum_{t=\min(t_{jj}+t_{ji})}^{\delta} Z^{B}_{j}(t) \le \sum_{i=1}^{x} X^{A}_{i}(0) + \sum_{i=1}^{x}\sum_{t=\min(t_{jj}+t_{ji})}^{\delta} Z^{A}_{i}(t) \le$$
$$\le \sum_{j=1}^{x} X^{A}_{i}(0) + \sum_{j=1}^{y}\sum_{i=1}^{x}\sum_{t=0}^{\delta-t_{jj}-t_{ji}} Z^{B}_{j}(t). \quad (10)$$

Table 1

Internal transportation for servicing of DC-1 and CCP

No. of the schedule	Name of cargo	Departure station	Destination station	Type of a car
24	blast dust	Blast	Factory	g/c
24	aspiration dust	Blast	Factory	g/c
28	coke breeze	Raw	Factory	g/c
29	coke breeze	Raw	Factory	g/c
31	coke dust	Raw	Factory	g/c
32	coke dust	Raw	Factory	g/c
30	coke waste	Raw	Factory	g/c
15	coke waste	Raw	Factory	g/c
33	coke waste	Blast	Factory	g/c
36	screenings of agglomerate, pellets	Raw	Agglomerate	hopper

Table 2

Internal transportation for servicing DC-2

No. of the schedule	Name of cargo	Departure station	Destination station	Type of a car
50 (DC-6)	flue dust	South	Factory	g/c
50 (DP-7)	flue dust	Northern	Factory	g/c
50 (DP-6)	aspiration dust	South	Factory	g/c
50 (DP-7)	aspiration dust	South	Factory	g/c
5	coke waste	South	Factory	g/c
36	screenings of agglomerate, pellets	South	Agglomerate	hopper

Table 3

The start time of cargo loading and the amount of demand for empty cars for loading of screenings per day

Consumer	Consumer shops of empty cars	Number of releases per day					
		1	2	3	4	5	6
B1	DC-1 (24 – flue dust)	8–30	–	–	–	–	–
B2	DC-1 (24 – aspiration dust)	12–00	–	–	–	–	–
B3	DC-1 (33 – coke waste)	11–30	–	–	–	–	–
B4	CCP (28 – coke breeze)	01–00	09–00	17–00	–	–	–
B5	CCP (29 – coke breeze)	01–00	05–00	09–00	13–00	17–00	21–00
B6	DC-1 (30 – coke waste)	02–00	10–00	18–00	–	–	–
B7	DC-1 (15 – coke waste)	13–30	01–30	–	–	–	–
B8	CCP (31 – coke dust)	10–00	–	–	–	–	–
B9	CCP (32 – coke dust)	17–00	–	–	–	–	–
B10	DC-1 (36 – screenings of agglomerate from DP-5)	13–30	01–30	–	–	–	–
B11	DC-1 (36 – screenings of agglomerate from DP-3,4)	02–00	10–00	18–00	–	–	–

These inequations (9) and (10) show the existence of a coordinated connection of a single technological process with production programs:

$$\sum_{i=1}^{x} \sum_{\substack{t=\min \\ (t_{ij}+t_{ji})}}^{\delta} Z_i^A(t) - \sum_{j=1}^{y} \sum_{\substack{t=\min \\ (t_{ij}+t_{ii})}}^{\delta} Z_j^B(t) \le \sum_{j=1}^{y} X_j^B(0); \qquad (11)$$

$$\sum_{j=1}^{y} \sum_{\substack{t=\min \\ (t_{ii}+t_{ij})}}^{\delta} Z_j^B(t) - \sum_{i=1}^{x} \sum_{\substack{t=\min \\ (t_{ij}+t_{ji})}}^{\delta} Z_i^A(t) \le \sum_{i=1}^{x} X_i^A(0). \qquad (12)$$

From inequations (11) and (12), obtained from expressions (9) and (10), it follows that the initial reserves have a very significant smoothing effect, which allows to get out of situations in which the programs of supply shops and consumer shops are not coordinated.

In the simulated situation, we assume that the number of cars with cargo that are in reserve at B_j and the stock of empty cars at A_i are equal to zero.

In case when loaded or empty cars arrive at their destination without temporary delays $t_{jn} - t_{im} \ge t_{ij}$, transport and production costs are found by the formula

$$S\left(C\left(A_{im}, B_{jn}\right)\right) = S_{ij} + S_j^X \cdot \left(t_{jn} - t_{im} - t_{ij}\right), \qquad (13)$$

where $C(A_{im}, B_{jn})$ – communication between supply shops and consumer shops;

S_{ij} – cost of transporting a unit of rolling stock unit from the i-th manufacturing shop to the j-th consumer shop;

S_j^X – costs of storing a unit of rolling stock unit for a unit of time at the j-th consumer shop;

Table 4

Volumes of production per day (in cars) for CCP and DC-1

Supply shops	Number of releases per day					
	1	2	3	4	5	6
DC-1 (24 – flue dust)	1–9	–	–	–	–	–
DC-1 (24 – aspiration dust)	1	–	–	–	–	–
DC-1 (33 – coke waste)	1–2	–	–	–	–	–
CCP (28 – coke breeze)	1–2	1–2	1–2	–	–	–
CCP (29 – coke breeze)	1–2	1–2	1–2	1–2	1–2	1–2
CCP (31 – coke dust)	1	–	–	–	–	–
CCP (32 – coke dust)	1	–	–	–	–	–
DC-1 (30 – coke waste)	1–4	1–4	1–4	–	–	–
DC-1 (15 – coke waste)	1–4	1–4	–	–	–	–
DC-1 (36 – screenings of agglomerate from DP-5)	1–7	1–7	–	–	–	–
DC-1 (36 – screenings of agglomerate from DP-3, 4)	1–7	1–7	1–7	–	–	–

Table 5

The start time of cargo unloading and the number of offers of empty cars for loading of screenings per day

Supplier	Supply shops of empty cars	Number of empty cars for loading of screenings					
		1	2	3	4	5	6
A1	AGP (24 – flue dust)	23–00	06–00	–	–	–	–
A2	AGP (24 – aspiration dust)	23–00	–	–	–	–	–
A3	AGP (33 – coke waste)	16–30	–	–	–	–	–
	AGP (28 – coke breeze)	06–00	16–30	–	–	–	–
	AGP (29 – coke breeze)	06–00	16–30	–	–	–	–
	AGP (31 – coke dust)	06–00	16–30	–	–	–	–
	AGP (32 – coke dust)	06–00	16–30	–	–	–	–
	AGP (30 – coke waste)	06–00	16–30	–	–	–	–
	AGP (15 – coke waste)	06–00	16–30	–	–	–	–
A4	AGP (36 – screenings of agglomerate from DP-5)	06–30	18–30	–	–	–	–
	AGP (36 – screenings of agglomerate from DP-3,4)	00–30	06–30	12–30	–	–	–

Table 6

Volumes of demand per day (in cars) for CCP and DC-1

Consumer shops	Number of demand for laden cars					
	1	2	3	4	5	6
AGP (24 – flue dust)	1–4	3–9	–	–	–	–
AGP (24 – aspiration dust)	1	–	–	–	–	–
AGP (33 – coke waste)	1–2	–	–	–	–	–
AGP (28 – coke breeze)	9–22	7–18	–	–	–	–
AGP (29 – coke breeze)	9–22	7–18	–	–	–	–
AGP (31 – coke dust)	9–22	7–18	–	–	–	–
AGP (32 – coke dust)	9–22	7–18	–	–	–	–
AGP (30 – coke waste)	9–22	7–18	–	–	–	–
AGP (15 – coke waste)	9–22	7–18	–	–	–	–
AGP (36 – screenings of agglomerate from DP-5)	2–15	1–10	–	–	–	–
AGP (36 – screenings of agglomerate from DP-3,4)	5–15	2–15	5–15	–	–	–

Table 7

The start time of cargo loading and the amount of demand for empty cars for loading of screenings per day

Consumer	Consumer shops of empty cars	Number of releases per day					
		1	2	3	4	5	6
B12	DC-2 (50 – flue dust from DP-6)	13–00	–	–	–	–	–
B13	DC-2 (50 – flue dust from DP-7)	12–01	–	–	–	–	–
B14 (1 cargo front); B15 (2 cargo front)	DC-2 (50 – aspiration dust from DP-6)	12–00	12–00	–	–	–	–
B16 (1 cargo front); B17 (2 cargo front)	DC-2 (50 – aspiration dust from DP-7)	12–30	12–30	–	–	–	–
B18	DC-2 (5 – coke waste from DP-6)	00–30	06–30	12–30	18–30	–	–
B19	DC-2 (5 – coke waste from DP-7)	01–00	05–00	09–00	13–00	17–00	21–00
B20	DC-2 (36 – screenings of agglomerate, pellets DP-6)	00–30	06–30	12–30	18–30	–	–
B21	DC-2 (36 – screenings of agglomerate, pellets DP-7)	01–00	05–00	09–00	13–00	17–00	21–00

Note: cells highlighted in color mean that loading is performed simultaneously on different cargo fronts, in different ways.

Table 8

Production volumes per day (in cars)

Supple shops	Number of releases per day					
	1	2	3	4	5	6
DC-2 (50 – flue dust from DP-6)	1–3	–	–	–	–	–
DC –2 (50 – flue dust from DP-7)	1–3	–	–	–	–	–
DC –2 (50 – aspiration dust from DP-6)	1–3	1–3	–	–	–	–
DC –2 (50 – aspiration dust from DP-7)	1–3	1–3	–	–	–	–
DC –2 (5 – coke waste from DP-6)	1–4	1–4	1–4	1–4	–	–
DC –2 (5 – coke waste from DP-7)	2–5	2–5	2–5	2–5	2–5	2–5
DC –2 (36 – screenings of agglomerate, pellets DP-6)	4–8	4–8	4–8	4–8	–	–
DC –2 (36 –screenings of agglomerate, pellets DP-7)	5–8	5–8	5–8	5–8	5–8	5–8

Table 9

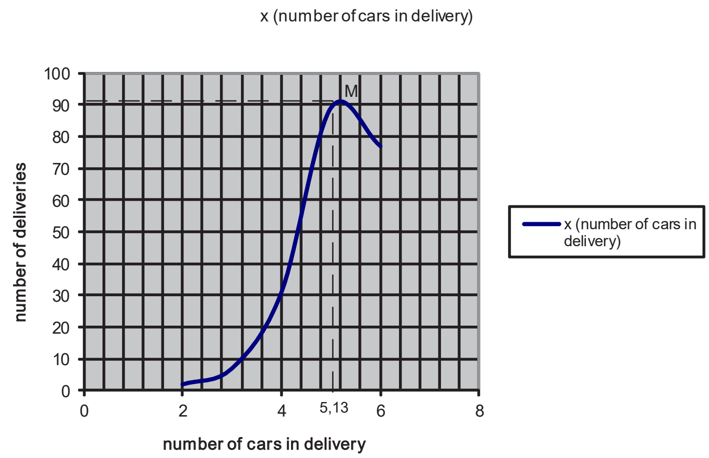
The start time of unloading cargo and the number of offers of empty cars for loading screenings per day

Supplier	Supply shops of empty cars	Number of empty cars for loading screenings					
		1	2	3	4	5	6
A5	AGP (50 – flue dust from DP-6, 7)	23–00	–	–	–	–	–
A6	AGP (50 – aspiration dust from DP-6, 7)	03–30	–	–	–	–	–
A7	AGP (5 – coke waste from DP-6, 7)	03–30	15–30	–	–	–	–
A8	AGP (36 – screenings of agglomerate, pellets DP-6)	03–30	10–00	15–30	22–00	–	–
	AGP (36 – screenings of agglomerate, pellets DP-7)	03–30	10–00	15–30	22–00	–	–

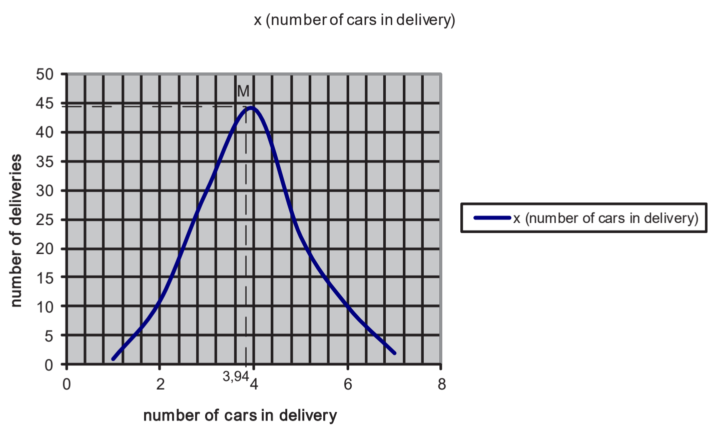
Table 10

The volume of demand per day (in cars)

Consumer shops	Number of demand for laden cars					
	1	2	3	4	5	6
AGP (50 – flue dust from DP-6, 7)	2–6	–	–	–	–	–
DC-2 (50 – aspiration dust from DP-6, 7)	4–12	–	–	–	–	–
AGP (5 – coke waste from DP-6, 7)	8–23	8–23	–	–	–	–
AGP (36 – screenings of agglomerate, pellets DP-6)	9–15	10–15	9–15	10–15	–	–
AGP (36 – screenings of agglomerate, pellets DP-7)	9–15	10–15	9–15	10–15	–	–



Pic. 2. Sample by acts for contact schedule No. 36 – screenings of agglomerate, pellets from DC-1 (DP-3, 4) during loading.



Pic. 3. Sample by acts for the contact schedule No. 36 – screenings of agglomerate, pellets from DC-1 (DP-5) during loading.

($t_{jn} - t_{im} - t_{ij}$) – time when the products are in reserve;

($t_{jn} - t_{im}$) –time interval between the moment of production of cargo and the moment of its consumption [8].

The formula (13) makes it possible to take into account the costs of transporting a unit of production S_{ij} and transport and production costs attributable to idle time of cars and storing goods for a period of time ($t_{jn} - t_{im} - t_{ij}$) until the moment of demand for them by the consumer shop.

In case when loaded or empty cars arrive at the front of loading/unloading with a delay of time ($t_{im} + t_{ij} - t_{jn}$), we determine the transport and production costs by the formula

$$S\left(C\left(A_{im}, B_{jn}\right)\right) = S_{ij} + S_j^O \cdot \left(t_{im} + t_{ij} - t_{jn}\right), \quad (14)$$

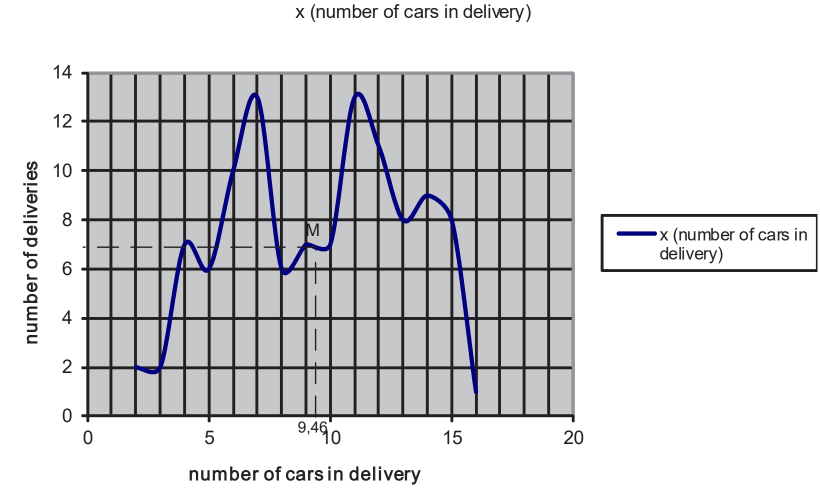
where S_j^O – cost of expenses of the j-th consumer shop due to late arrival of a rolling stock unit;

($t_{im} + t_{ij} - t_{jn}$) – the time of production being late by the time of demand for it [8].

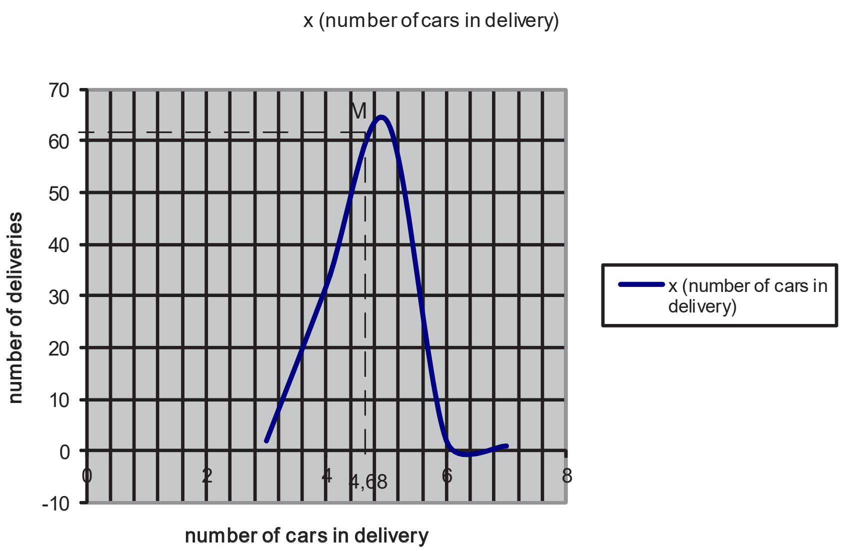
Table 11

Results of solution of DTPD

Volume of transportation, cars	Delay time, car/h	Storage time, car/h	Cost of transportation, rub	Cost of delay, rub	Cost of storage, rub	Total cost, rub
296	91	66	56046	4448690	49433	4554169



Pic. 4. Sample by acts for the contact schedule No. 36 – screenings of agglomerate, pellets from DC-1 (DP-3, 4, 5) during unloading.



pic. 5. sample by acts for the contact schedule no. 36 – screenings of agglomerate, pellets from dp-6 (dc-2) during loading.

The formula (14) allows to take into account production losses due to the late delivery of empty or loaded cars to loading and unloading fronts in accordance with the needs of production.

The defining moment for construction of an initial transportation plan is an answer to a question: is the task to be solved closed? The equation of static balance of volumes (capacities) of production and consumption helps to answer it [8]:

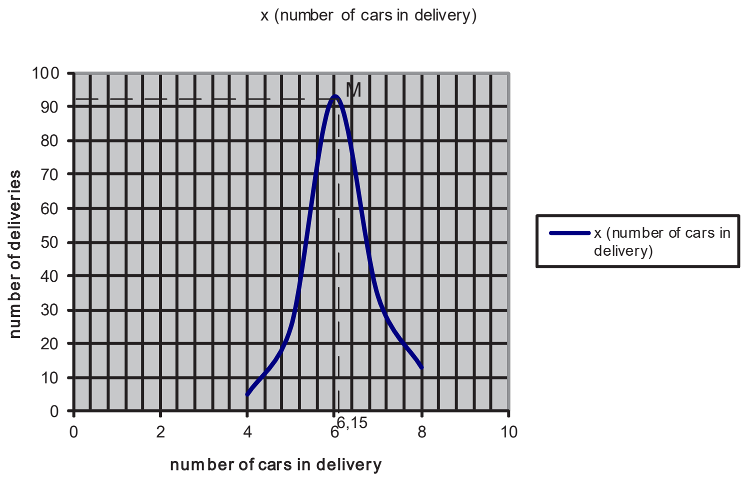
$$\sum_{i=1}^{x}\sum_{m=1}^{k_i} a_i\left(t_{im}\right)=\sum_{j=1}^{y}\sum_{n=1}^{l_j} b_j\left(t_{jn}\right). \qquad (15)$$

If the equation (15) is satisfied, then the problem is considered closed, otherwise it is open, which, in turn, requires reducing it to a closed form. This can be done by introducing into the conditions of the transport problem a fictitious supplier or consumer [9].

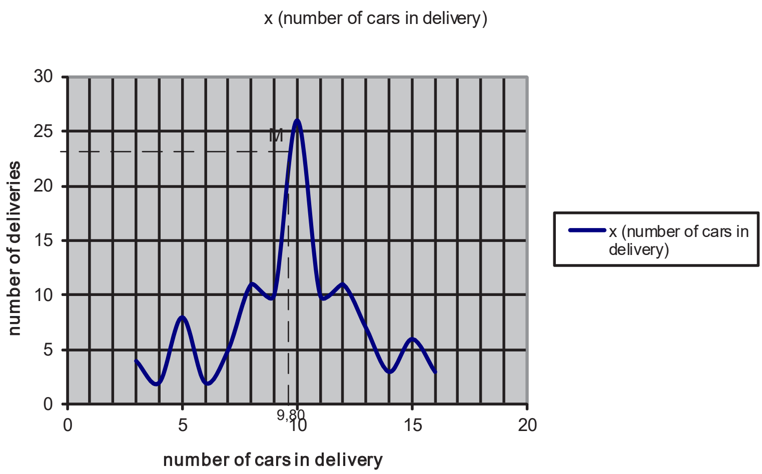
Fictitious supplier – conditional manufacturing shop $a_{i+1}(t_{im})$ with a delivery volume identical to the missing quantity to fulfill the equation (15).

Fictitious consumer is a conditional consumer shop $b_{j+1}(t_{jn})$ with a consumption volume equal to the missing quantity for the equation (15).

Fictitious supplier/consumer does not change the solution of the transport problem, does not «break»



Pic. 6. Sample by acts for the contact schedule No. 36 – screenings of agglomerate, pellets from DP-7 (DC-2) during loading.



Pic. 7. Sample by acts for the contact schedule No. 36 – screenings of agglomerate, pellets from DP-6, DP-7 (DC-2) during unloading.

it. The introduction of fictitious suppliers or consumers with zero cost indicators makes it possible to unambiguously determine the volumes and moments of the mismatch, without changing the functional [10].

Research results

Despite the variety of technological cargo nomenclature at the plant, intra-plant shipments can be grouped according to the following features:

- *homogeneous by type of cargo;*
- *homogeneous or interchangeable according to the type of rolling stock used to transport these goods;*
- *on a territorial basis, with matching destination stations and departure stations, and, therefore, the same transportation route.*

Let us single out two fairly powerful jets in transportation of goods by the criterion of servicing the same production shop (on a territorial basis). The first group includes shipments for servicing blast furnace shop No. 1 (DC-1) and coke-chemical production (CCP) (see table 1), the second group – for servicing blast furnace shop No. 2 (DC-2) servicing (see table 2), with the exception of sinter shipments, which are allocated in a separate category.

Data on the volume of production and consumption per day by supply shops and consumer shops (in cars); the moments of time for emergence of «supply» for cargo, «demand» for cargo and their quantity are determined on the basis of the conducted studies using statistical data and the existing schedule for organizing intra-plant transportation at the plant. All of them are presented in tables 3–10. The average delivery time of a loaded T_H and an empty T_O car from consumer shops to supply shops, the cost of transporting, storing and delaying cars was calculated using the methodology given in [8]. The calculation of the cost of being late for an empty/loaded car takes into account production losses from an undelivered rolling stock or cargo, shows the size of possible production losses, the non-transport effect.

The first group of CCP, DC-1

Abbreviations accepted in tables 3–10: DC-1 – blast furnace shop number 1, DC-2 – blast furnace shop number 2, CCP – coke chemical production, DP-3, 4 – blast furnace No. 3 and No. 4, DP-5 – blast furnace No. 5, DP-6, 7 – blast furnaces No. 6 and No. 7, AGP – sinter production.

Second group DC-2

Due to the fact that the volumes of production and consumption of goods by the workshops of the enterprise were initially set at certain allowed intervals (Tables 4, 6, 8, 10) and not at fixed values, this made *it necessary to conduct additional research and calculate the frequency of car deliveries to cargo fronts with their fixed number.*

For an example, a part of the study for contact schedule No. 36 is shown – screenings of agglomerate, pellets. Pic. 2–7 presents the frequency of supply of cars with a fixed number.

The above data allows to visually determine how many cars in the supply is present as often as possible, and are used when calculating the contact schedule using DTPD.

The solution of DTPD is carried out using the method of potentials [11].

For an empty cargo flow of blast furnaces, we introduce a fictitious supplier A9 with a delivery volume equal to 21 units of empty cars. This is due to the fact that in the model, formed from statistical data, as often as possible arising in reality, suppliers are ready to provide 275 units of empty cars, and 296 units of rolling stock are required for consumers.

For laden cargo flow, verification of the static balance conditions (15) of supplied and consumed loaded cars should be made taking into account the type of cargo (aspiration dust, flue dust, screenings of coke, agglomerate, pellets).

Considered optimization period of 48 hours. The cost of the initial transportation plan is 11101879 rubles. In the course of solving DTTT, 123 iterations were performed. The cost of the optimal transportation plan was 4554169 rubles.

The optimal plan calculated by the program for supplying empty cars to the loading fronts of production workshops is a matrix, the cells of which indicate the cost of transportation (first digit) and the number of cars (second digit) delivered by the i-th supplier to the j-th consumer at time t.

After analyzing, we see that there are cases of mismatch between the production programs of supply shops and consumer shops related to the untimely arrival of empty cars on cargo routes (53 cases) or to stay of rolling stock waiting for loading on the tracks (36 cases).

The final results of the solution of the transport problem are summarized in Table 11.

Conclusions.

The improvement of the system of transportation of empty cargo flow according to the contact schedule with the help of DTPD allowed us to abandon the strict assignment of cars to a specific transportation, supply of empty cars is carried out according to the most favorable option for a consumer (with a minimum of transport and production costs). The cars can be delivered to the consumer for loading onto the cargo front from under any used load.

The use of a dynamic transportation problem with delays as the basis of a mathematical model for development of an optimal plan for transportation of cars according to the contact schedule helps to more than halve the transport and production costs of the shops of the metallurgical plant.

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Information about the authors:

Popov, Alexey T. – Ph.D. (Eng), associate professor, head of the department of organization of transportation of Lipetsk State Technical University (LSTU), Lipetsk, Russia, popov@stu.lipetsk.ru.

Suslova, Olga A. – Ph.D. (Eng), associate professor of Lipetsk State Technical University (LSTU), Lipetsk, Russia, suslova_2003@mail.ru.

Voronina Olga V. – Ph.D. student of Lipetsk State Technical University (LSTU), Lipetsk, Russia, lelechka7@bk.ru.

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