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IMPROVEMENT OF A SYSTEM CONTROLLING A PROCESS OF RAILCARS UNLOADING IN THE CONTEXT OF CHANGES IN TEMPERATURE MODE WHILE OPERATING

Context. The problems of cost minimizing for the delivery of raw materials, fuel and materials, while meeting all the requirements of end user in terms of transportation, condition, quality and amount of the cargo, the compliance of the rolling stock with the equipment of unloading points, etc. are still the key problems of efficient transportation management. A problem to improve a system controlling a process of cargo operations performance at industrial enterprises during the cold season, when well-managed process is considerably complicated by the influence of stochastic fluctuations in the environmental temperature remains to be topical one. Delivery cost experiences significant increase due to the growth of power consumption for the cargo defrosting.

The objective of the paper is to improve a system controlling a process of railcars unloading in terms of expectations of the negative changes in the temperature mode owing to optimization of the railcars distribution among the unloading points by the criterion of the idle time minimization.

Method. Two temperature modes are singled out: standard operating mode in terms of positive temperatures and a mode of necessity to recover looseness of frozen cargos. The method of operative disbalance of incoming cargo flows has been developed to provide more rational distribution of cargos within cargo loading/unloading complexes during the periods of temperature changes being typical for Ukrainian climate. A new procedure to solve dynamic transportation problem with the varying intensity factor of incoming cargo flows in terms of time has been developed. A factor of minimum period for cargo operation has been proposed as an optimization criterion.

Results. Methodology has been developed basing upon a method of operative disbalance of incoming cargo flows. Experiments concerning the methodology application have been carried out to improve the system controlling the process of railcars unloading in terms of changes in temperature mode.

Conclusions. Analysis of the research results has shown that the proposed approach decreases significantly the idle time of the railcars in terms of temperature mode changes, reduces expenses connected with the railcars use as well as the expenses connected with the recovery cargo looseness and operation of locomotives.

Keywords: cargo flow, dynamic transportation problem, criterion of minimum time, disbalance of supply stock, optimum distribution.

NOMENCLATURE

A_i is the amount of the i^{th} cargo delivered per day;

$a_i, i \in I$ is the amount of the i^{th} cargo delivered to an enterprise;

B_j is a maximum supply to the j^{th} loading/unloading complex;

$b_j, j\ J$ is the amount of the cargo delivered to the j^{th} unloading complex of an enterprise;

N is a daily amount of possible supplies to a unloading complex;

t_{ij}^{cargo} Is a standard time to unload one railcar loaded with the i^{th} cargo type at the j^{th} loading complex;

t_{cargo} is a total idle time of railcars being unloaded, hrs;

x_{ij}^{p} is the amount of the i^{th} cargo delivered to j^{th} loading complex in terms of the t^{th} delivery;

z_{ij}^{p} is the efficiency of the j^{th} loading complex in terms of the i^{th} cargo delivery taking into consideration the number of the t^{th} delivery;

B_{idle} is a total cost of railcars being unloaded;

B_{idle}^{actual} is an actual cost of idle time of railcars arrived to an enterprise per day;

B_{idle}^{calc} is a calculated value of idle time of railcars arrived to an enterprise per day;

C_{idle} is a prime cost of one hour of idle time of a railcar, UAH;

E_{day} is a cost saving per idle time of railcars being unloaded.

INTRODUCTION

A problem concerning the development and application of new approaches to the organization as well as control of transportation and cargo handling at the enterprise is the priority to improve its efficiency. Loading operations at the industrial enterprises depend on physical state of certain bulk cargos. During cold season such cargoes freeze requiring additional investment of time and energy to recover their looseness.

Under the above conditions, methods of the transportation management and control foresee measures to use preventing means against freezing; besides the measures should be aimed at accumulation of cargo stocks at the warehouses of a consuming enterprise during warm season being favorable for loading/unloading operations, establishing of points to heat frozen cargos in railcars as well as the use of other means to provide smooth process of loading/unloading operations.

The objective of the research was the improvement of a system controlling the process of railcars unloading under the conditions of possible changes in temperature mode of operation at the expense of optimization of the railcars

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distribution among the unloading points according to the criterion of idle time minimization.

The development of new methods for effective use of technical means involved in transportation and technological processes remains the topical research area.

1 PROBLEM STATEMENT

Suppose that X matrix with x_{ij}^p components is preset. The matrix is a set of the i^{th} cargoes delivered to j^{th} unloading complexes of the enterprise in terms of p^{th} feed according to transportation plan.

To describe the transportation problem, introduce following designations for coefficients and variables: $i \in I = \{1, 2, ..., m\}$, a set of the indices of the cargo type; $jJ = \{1, 2, ..., n\}$, a set of indices for unloading complexes; $pP = \{1, 2, ..., k\}$, a set of delivery number indices. Mathematical formulation of such transportation problem is (1):

$$F(X) = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{t=1}^{k} z_{ij}{}^{p} \cdot x_{ij}{}^{p} \to \min,$$

if $x_{ij}{}^{p} \geq 0$; $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$; $p = 1, 2, \ldots, k$.

It is required to minimize the number of railcars being unloaded within the unloading complexes. To do that, one should minimize time loses connected with raw material unloading.

An index of minimum time required for loading/unloading operations may be used as optimization criterion.

2 REVIEW OF THE LITERATURE

Logistic approach as for the optimization of cargo delivery processes is rather common [1–5]. Formation of objectives to improve the efficiency in the form of transportation problem while optimizing transportation process is quite popular. It depends on a great number of efficient methods for its solution.

However, practice often faces such problems which formalization cannot result in classic scheme of transportation problem. Solution of such problems requires serious methodological background, development of models and methods for cost optimization, and, what is more important, the development of decision-making support systems on the basis [6].

In terms of real organizational processes of cargo delivery, the intensity of raw materials supply and its demand are usually random values. Under such conditions, calculating factors of efficiency (namely, transportation cost) are also random values, if we mean optimizing problem solving. Together with standard properties of linear programming problem, the specific features stipulate a number of its peculiarities [7]. While solving optimization problem concerning cargo transportation from suppliers to consumers, current approach, unlike traditional methods, takes into consideration, for instance, such a condition that transportation cost is a random value with a preset distribution density [8].

Solving multiindex distribution problems often results in such problems as great dimension of the initial data and multiparametric character of the optimization problem [9]. There are various approaches to certain solutions of the problems [10–14]; a theory of solving multiindex problems of linear programming in general form has been developed [15]. The solution of the multiindex transportation problem can be obtained by the method of potential; nevertheless, implementation of the method is labour-intensive since it contains numerous iterations. To make the initial support plan for the multiindex problem of transportation logistics, it is proposed to use the null-transformation method of the initial value matrices [16].

There are three-index planar transportation problems with nonlinear cost functions [17]. Metaheuristic evolutionary algorithm is proposed for an approximate solution of the problems. The advantages of parallel search with several populations are in a higher rate of convergence and stability of the time required to obtain the solutions.

No methodology alone is fully adapted to implement the method of operational disbalance of input cargo flows. It is necessary to form new procedures to be based on common optimization algorithms.

3 MATERIALS AND METHODS

A process of railcars unloading depends on the environmental conditions. Single out standard operation mode at positive temperature and the mode of necessity to recover looseness (for freezing cargos) at negative temperature. At the territory of Ukraine, cold season is characterized by frequent changes in temperature, and, accordingly, modes of railcars unloading.

Under such conditions, while waiting for the transition from the standard mode to the looseness recovery mode, unloading process optimization is possible by means of distribution of railcars among loading/unloading points according to the criterion of minimum time required for loading/unloading operations. The optimization relies upon the possibility to unload certain cargos within several points. In this context, planned balance of warehouse stock as for the cargos experiences certain disbalance, which can be recovered if temperature conditions improve and standard operation mode is applied. Fig.1 demonstrates the method

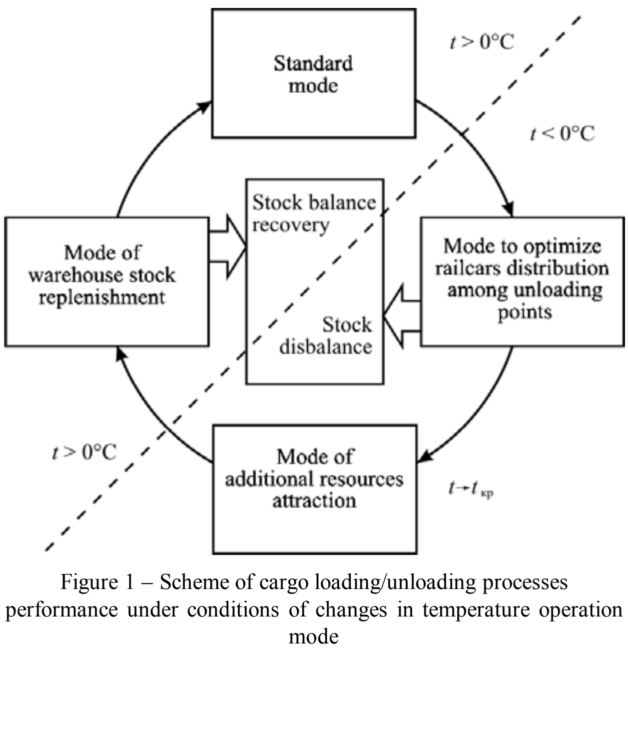

Figure 1 – Scheme of cargo loading/unloading processes performance under conditions of changes in temperature operation mode

of operational disbalance of incoming cargo flows using the scheme of cargo loading/unloading processes performance proposed by the paper.

Optimization process of railcars unloading. To optimize the unloading process by means of correction of planned distribution of railcars among loading/unloading complexes, one can use a new procedure based on traditional methods of transportation problem solution (formula (1)).

Fig. 2 demonstrates graphical representation of the transportation problem.

Description of the optimization procedure for the process of railcars unloading in terms of small transportation systems of enterprises. For the enterprises with small amounts of raw material delivery (up to 100 railcars per day), the number of deliveries for a certain unloading complex is limited; it is convenient to present the transportation problem in an expanded form.

To do this, the "Unloading complex" column is divided into additional columns which number depends on the number of deliveries per each loading complex. As for each of the complexes, determine daily number of possible deliveries using formula (2):

$$N = \left\lceil \frac{A_i}{B_j} \right\rceil . \tag{2}$$

It should be taken into consideration that in the majority of cases the last delivery will be "incomplete"; thus, determine its dimension using formula (3):

$$B_j^{last} = A_i - B_j \left(N-1 \right) . \tag{3}$$

For the first delivery series, z_{ij}^1 value is taken as:

$$z_{ij}^{\;1} = t_{ij}^{\;cargo} ,$$

Following cargo delivery should involve time spent to unload railcars from the first delivery:

$$z_{ij}^{\;2} = t_{ij}^{\;cargo} + t_{ij}^{\;cargo} \cdot B_j .$$

Similarly, one can calculate z_{ij}^p value for any number of deliveries (4):

$$z_{ij}^{\;p} = t_{ij}^{\;cargo} \left(1 + B_j \left(N-1 \right) \right) . \tag{4}$$

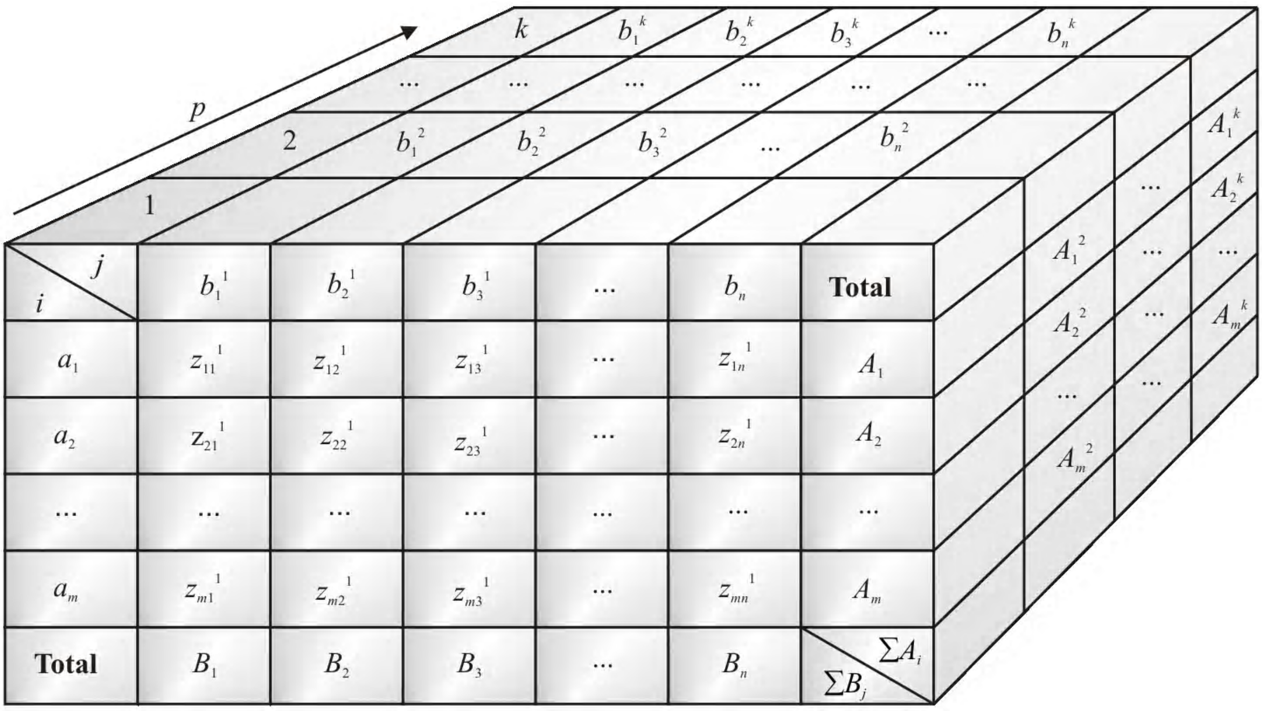

Figure 2 – General arrangement of the transportation problem taking into account delivery number

Table 1 – Cargo distribution for small transportation systems

Complex	b_1				b_2				…	b_n				
Cargo	$b_1^{\;1}$	$b_1^{\;2}$	…	$b_1^{\;k}$	$b_2^{\;1}$	$b_2^{\;2}$	…	$b_2^{\;k}$		$b_n^{\;1}$	$b_n^{\;2}$	…	$b_n^{\;k}$	
a_1	$z_{11}^{\;1}$	$z_{11}^{\;2}$	…	$z_{11}^{\;k}$	$z_{12}^{\;1}$	$z_{12}^{\;2}$	…	$z_{12}^{\;k}$		$z_{1n}^{\;1}$	$z_{1n}^{\;2}$	…	$z_{1n}^{\;k}$	A_1
a_2	$z_{21}^{\;1}$	$z_{21}^{\;2}$	…	$z_{21}^{\;k}$	$z_{21}^{\;1}$	$z_{22}^{\;2}$	…	$z_{22}^{\;k}$		$z_{2\,n}^{\;1}$	$z_{2n}^{\;2}$	…	$z_{2n}^{\;k}$	A_2
…			…				…					…		…
a_m	$z_{m1}^{\;1}$	$z_{m1}^{\;2}$		$z_{m1}^{\;k}$	$z_{m2}^{\;1}$	$z_{m2}^{\;2}$		$z_{m2}^{\;k}$		$z_{mn}^{\;1}$	$z_{mn}^{\;2}$		$z_{mn}^{\;k}$	A_m
	B_1	B_1	…	$B_1^{\;last}$	B_2	B_2	…	$B_2^{\;last}$		B_n	B_n	…	$B_n^{\;last}$	
	$B_1\,(N-1) + B_1^{\;last}$				$B_2\,(N-1) + B_2^{\;last}$				…	$B_n\,(N-1) + B_n^{\;last}$				

Description of the optimization procedure for the process of railcars unloading in terms of large transportation systems of enterprises. Large enterprises require constant delivery of raw materials for the continuous production. Such enterprises have more complicated transportation systems; thus, it is rather difficult to determine in advance the required number of deliveries and sometimes it is even impossible.

Transportation problem consisting of p-number of blocks depending on each other is proposed for such cases. Each of the blocks is a transportation problem for a separate delivery series. The initial data for the first delivery series are the cargo volumes arriving per the estimated period of time, maximum delivery amount per each unloading complex and the time required to unload one railcar in accordance with the capacity of each complex.

A_i value is assumed as that being equal to the total number of railcars with a certain cargo delivered to the enterprise. Since B_j value is taken as the number of railcars within one delivery, it is obvious that A_i sum will exceed significantly B_j sum. Optimum plan of the problem will be singular one, i.e. not all cargo will be unloaded within loading/unloading complexes. Consequently, for the following delivery series, A_i value will be equal to the number of the railcars remaining after the previous delivery, etc., until the whole cargo is distributed among loading/unloading complexes.

z_{ij}^1 value for the first delivery series is assumed as that to be equal to the period required to unload one railcar with certain cargo within the corresponding complex. For all subsequent delivery series, z_{ij}^p value is found using formula (5):

$$z_{ij}{}^{p} = t_{ij}{}^{cargo} + t_{ij}{}^{cargo} \cdot B_j{}^1 + t_{ij}{}^{cargo} \cdot B_j{}^2 + ... + t_{ij}{}^{cargo} \cdot B_j{}^k . \quad (5)$$

As a result, we obtain a transportation problem which general form is represented in Fig. 3.

4 EXPERIMENTS

To demonstrate implementation of the procedure optimizing a process of the railcars unloading, consider the application of the method for such transportation problem solving in terms “Zaporizhstal” integrated works.

Basic freezing cargoes (i.e. ore, coal, coke and limestone in hoppers and open box cars) arrive to five basic unloading complexes: Aglofabryka station, “Bunkery” park (railway lines #2 and #4), Rudna station, Vuhilna station, and Pidbirkova station. In this context, some of them can be unloaded only within one complex (ore and coal) while the rest are distributed among several complexes.

Each of the unloading complexes has different capacities. Unloading duration within certain complex depends on the delivered cargo type. Moreover, it should be taken into consideration that certain cargoes should be delivered only to certain complexes.

It is necessary to minimize the time spent for raw materials unloading.

The initial table of the transportation problem can be represented as follows (Table 2).

Since the amount of stock (volumes of cargo deliveries) is not equal to the sum of the demand (the delivery amount in terms of loading/unloading complexes), than the obtained transportation problem is open one. To solve the problem it is necessary to transform it into a closed one. To do this, introduce a theoretic consumer (loading/unloading complex) for excessive cargo amount.

Obtain optimum plan for the first delivery series cargo distribution within loading/ unloading complexes:

– “Bunkery” park, railway line #2 – 9 railcars with coke (0.43 hrs/railcar);

– “Bunkery” park, railway line # 4 – 9 hoppers with limestone (0.07 hrs/railcar);

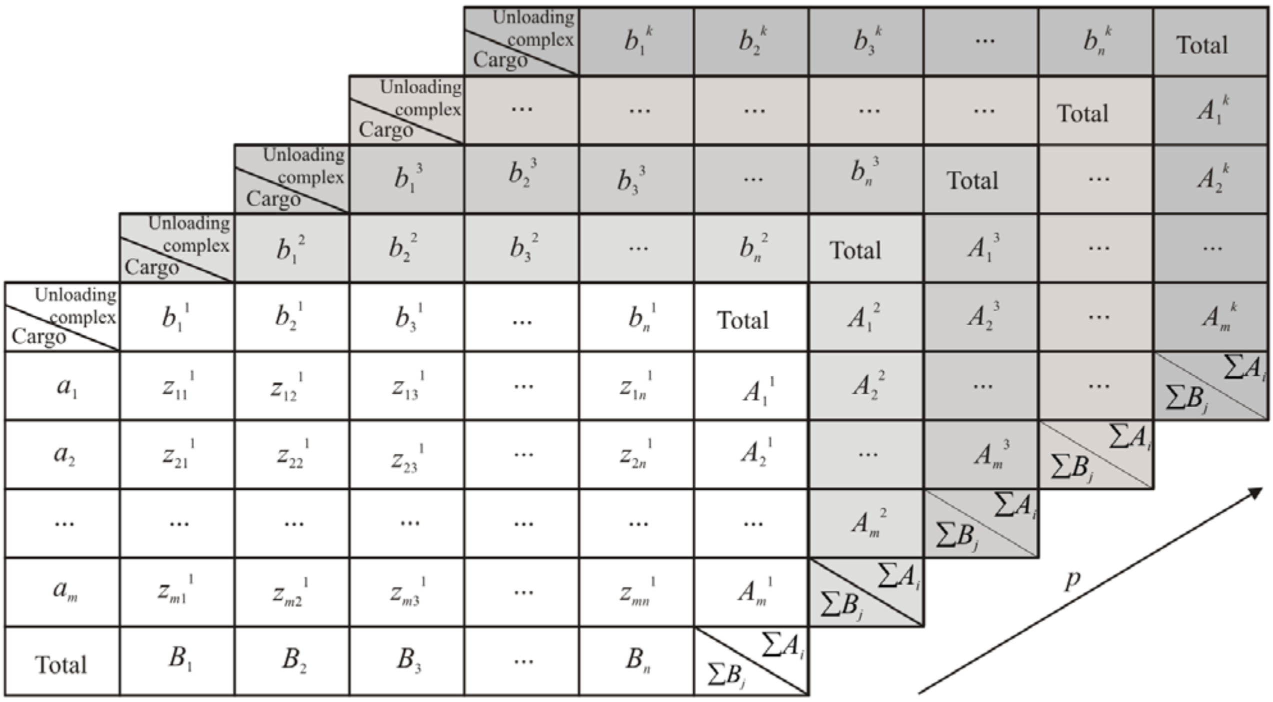

Figure 3 – General arrangement of transportation problem for transportation systems of metallurgical enterprises with continuous production process

Table 2 – The initial table of the transportation problem of freezing cargos delivery to a metallurgical enterprise

Cargo	Loading/unloading complex					Total
	“Bunkery” railway line #2	“Bunkery” railway line #4	Rudna station	Vuhilna station	Pidbirkova station	
Ore	–	–	0.06	–	–	137
Coal	–	–	0.06	0.06	–	17
Limestone in open box cars	–	–	–	–	0.32	23
Limestone in hoppers	–	0.07	–	–	0.07	37
Coke	0.43	–	0.06	–	–	74
Total	9	9	15	14	9	288
	56					

– Rudna station – 15 railcars with ore (0.06 hrs/railcar);

– Vuhilna station – 14 railcars with coal (0.06 hrs/railcar);

– Pidbirkova station – 9 hoppers with limestone (0.07 hrs/railcar).

Minimum time spent to unload the first delivery series is:

$F(x) = 0.06{\cdot}15 + 0.06{\cdot}14 + 0.07{\cdot}9 + 0.07{\cdot}9 + 0.43{\cdot}9 = 6.87$ hrs.

As it is understood, the optimum plan is singular one as not the whole amount of cargo has been distributed. Thus, the rest of the cargo is transferred to following transportation problem of the second delivery series as A_i value, and the unloading period per one railcar (z_{ij}^2 value) is calculated using formula (5) taking into account cargo type and the unloading complex capacity (Fig. 4).

Similarly, all following delivery series are distributed until all the cargos are unloaded within the loading/unloading complexes.

5 RESULTS

Result of the dynamic transportation problem solving will help obtain optimum distribution of cargo deliveries to the unloading complexes:

– 9 coke series (8 of them are 9 railcars, and 1 is 2 railcars) will be delivered to Agglofabryka station, “Bunkery” park, railway line #2;

– 3 limestone series (2 of them are 9 railcars, and 1 is 1 railcars) will be delivered to Agglofabryka station, “Bunkery” park, railway line #4;

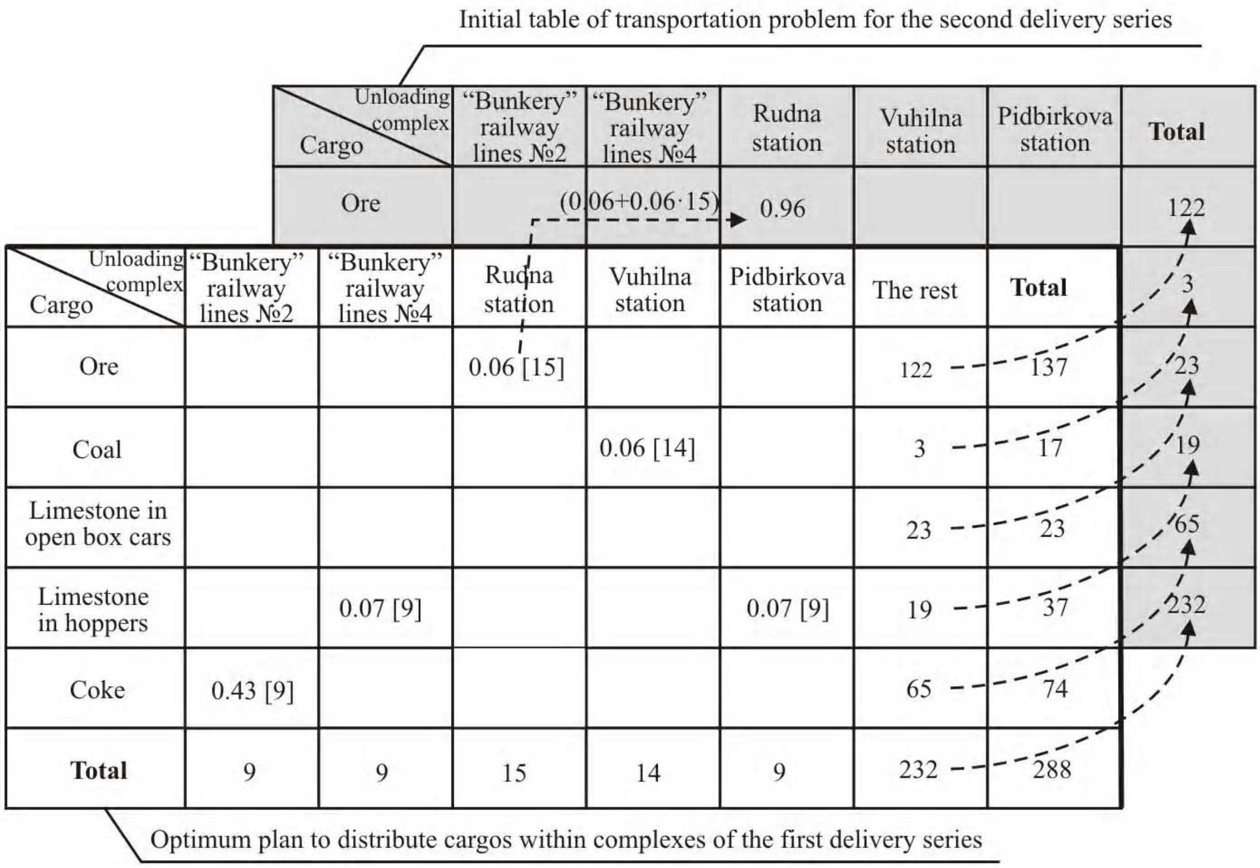

Figure 4 – Calculation of the data and formation of the initial table for the transportation problem of the second delivery series

– 10 ore series (9 of them are 15 railcars, and 1 is 2 railcars) will be delivered to Rudna station;

– Vuhilna station will get 2 coal series (14 railcars and 3 railcars).

– 2 series of limestone in hoppers (9 railcars each) and 3 series of limestone in open box cars (2 series of 9 railcars and 1 series of 5 railcars) will be delivered to Pidbirkova station.

Table 3 contains total minimum time spent to unload all delivery series involving unloading complex as well as comparison of the obtained values with the actual ones.

The difference in the number of railcars within loading/unloading complexes in the actual and calculated variant is insignificant. The difference can be easily added in a less strenuous period, i.e. if the temperature conditions improve, when it will not be necessary to heat the cargos. Thus, one can assume that the requirements of all unloading complexes are met.

The difference between the actual and calculated idle time of railcars within the determined loading/unloading complexes is shown in Fig. 5.

The method cannot take into consideration the fact that under the conditions of continuous production period new cargos can arrive even before previous cargos were distributed and unloaded. The factor may affect significantly the capacity of loading/unloading complexes as well as the distribution of delivery series within the complexes. Therefore, in future it is planned to improve the optimization method of railcars unloading process.

Table 3 – Comparison of the obtained calculated values with the actual ones

Unloading complex	Actual values			Calculated values		
	Number of railcars	Number of deliveries	Total idle time, hrs	Number of railcars	Number of feeds	Total idle time, hrs
“Bunkery”, railway line #2	72	12	312.08	74	9	280.36
“Bunkery”, railway line #4	15	6	51.25	19	3	11.41
Rudna station	140	15	136.58	137	10	121.74
Vuhilna station	16	2	18.67	17	2	12.3
Pidbirkova station	45	14	110.33	45	5	71.18
Total	288	49	628.92	288	29	496.99

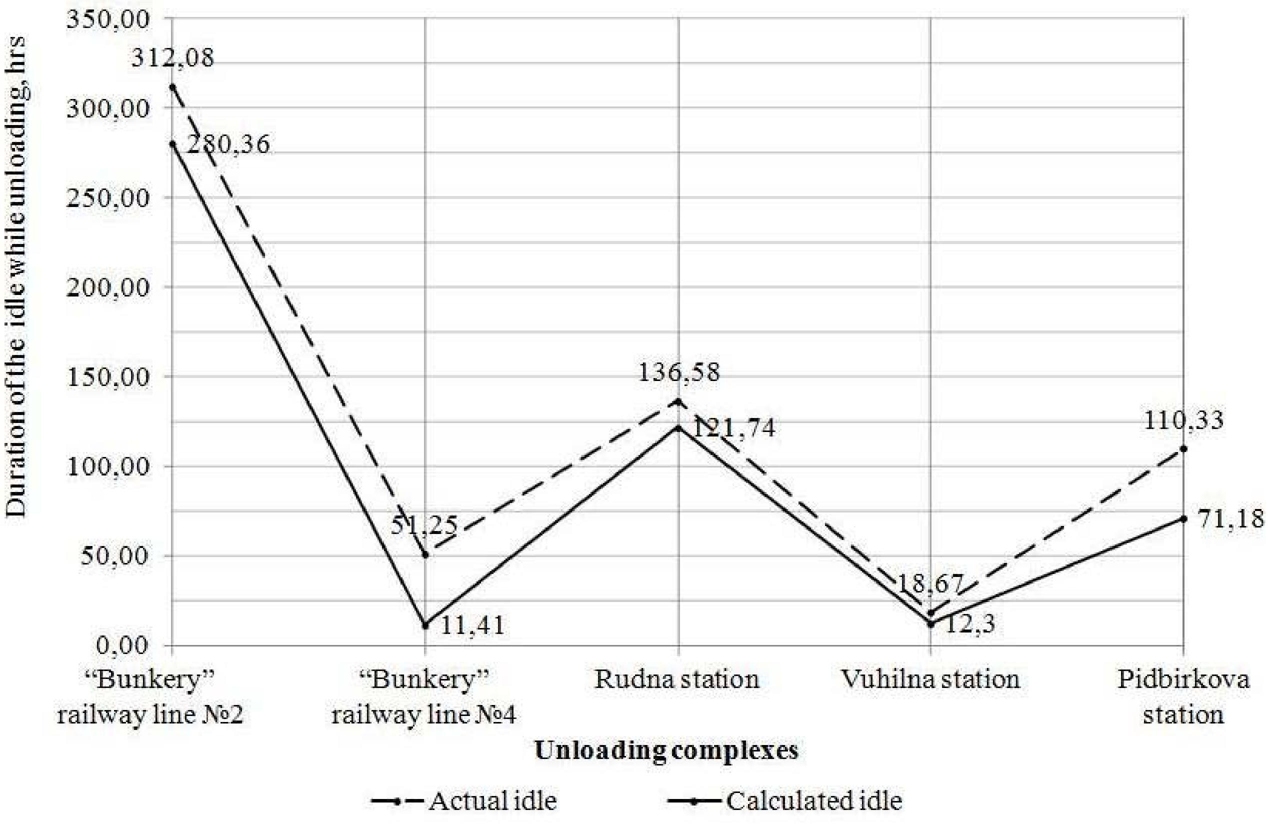

Figure 5 – Curves of changes in railcars idle period within loading/unloading complexes

Total cost of idle time of the railcars being unloaded is determined using formula (6):

$$B_{idle} = t_{cargo} \cdot C_{idle}. \quad (6)$$

Cost of one hour of railcar idle time at "Zaporizhstal" PJSC as of January 2015 was 12.04 UAH/hour.

Therefore, the cost of idle time of the railcars arrived at the enterprise during 6 January 2015 actually was:

$$B_{idle}^{actual} = 12.04 \cdot 628.92 = 7572.16 \text{ UAH}.$$

Application of the above method of railcars distribution will help reduce the cost of idle time of those very railcars:

$$B_{idle}^{calc} = 12.04 \cdot 496.99 = 5983.76 \text{ UAH}.$$

Determine the cost savings in idle time of the railcars being unloaded and the railcars arrived within a day (7):

$$E_{day} = B_{idle}^{actual} - B_{idle}^{calc}. \quad (7)$$

$$E_{day} = 7572.16 - 5983.76 = 1588.4 \text{ UAH}.$$

6 DISCUSSION

Owing to more rational distribution of railcars according to the deliveries involving the capacity of loading/unloading complexes, the number of deliveries has experiences significant reduction. That makes it possible to shorten idle time of the railcars during when transportation system of an enterprise is overloaded. Cost savings can account for UAH 1.588,4 (21%) when the method is applied.

Average idle time of the railcars depended upon the necessity to heat cargos during cold season is 2 hours. Taking into consideration the number of days with a temperature differential, annual effect can be up to UAH 1500000 per year considering the reduction of expenditures connected with defrosting of cargos if it is required.

The proposed method does not take into account the necessity to recover the balance of incoming cargo flows and the replenishment of disbalanced warehouse stock; thus, it requires further improvement to obtain more accurate results and efficiency indices.

CONCLUSIONS

The paper has solved the burning problem concerning the improvement of a system controlling a process of railcars unloading in terms of expectations of the negative changes in the temperature mode owing to optimization of the railcars distribution among the unloading points by the criterion of the idle time minimization.

Scientific novelty of the research is that the innovative method of operational disbalance of incoming cargo flows has been proposed. The method makes it possible to organize more efficient operation loading/unloading complexes of an industrial enterprise, to shorten railcars idle time under the condition of frequent temperature changes during cold season.

A procedure to optimize a process of railcars unloading for small transportation systems of enterprises for short-time period has been proposed. The procedure solves dynamic transportation problem by means of its reducing to a common form.

A procedure optimizing a process of railcars unloading for large transportation systems of enterprises has been proposed. The procedure involves the dynamic transportation problem solving with time varying factor of intensity of incoming cargo flows.

Practical importance of the obtained results is as follows: at the expense of the use of operational disbalance of incoming cargo flows and procedures optimizing unloading process during cold season, optimization of transportation system functioning is performed according to the criterion of minimum railcars driveway time during unloading operations; that helps cut the cost for railcars use by 21%. Annual saving is up to UAH 1500000.

Prospects for the future research is to determine the effectiveness of the proposed method taking into consideration the reduction of idle time of railcars before their unloading and involving the replenishment of warehouse stock during transition period from the mode of unloading process optimization (when negative temperatures are forecasted) to the standard operational mode.

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УДОСКОНАЛЕННЯ СИСТЕМИ УПРАВЛІННЯ ПРОЦЕСОМ РОЗВАНТАЖЕННЯ ВАГОНІВ В УМОВАХ ЗМІНИ ТЕМПЕРАТУРНОГО РЕЖИМУ РОБОТИ

Актуальність. Головними задачами ефективного управління на транспорті залишаються завдання мінімізації витрат на доставку сировини, палива та матеріалів за умов дотримання всіх вимог кінцевого споживача щодо термінів перевезень, стану, якості та кількості вантажу, відповідності рухомого складу обладнанню вантажоприймальних пунктів та ін. Серед цих завдань актуальною є задача удосконалення системи управління процесом виконання вантажних робіт на промислових підприємствах в холодний період року, коли відрегульований процес виконання вантажних робіт значним чином ускладнюється під впливом стохастичних коливань температури навколишнього середовища. Вартість доставки суттєво збільшуються через зростання витрати енергоносіїв на розморожування вантажів.

Мета роботи – удосконалення системи управління процесом розвантаження вагонів в умовах очікування негативних змін температурного режиму роботи за рахунок оптимізації розподілу вагонів по пунктах вивантаження за критерієм мінімізації часу простою.

Метод. Виділено звичайний режим роботи при позитивних показниках температури та режим необхідності відновлення сипкості вантажів, які змерзаються. Розроблено метод оперативного дисбалансу вхідних вантажопотоків, який забезпечує більш раціональний розподіл вантажів по вантажним фронтам в періоди зміни температурних режимів, який є характерним для клімату України. Була розроблена нова процедура розв'язку динамічної транспортної задачі зі змінним фактором інтенсивності вхідних вантажопотоків за часом. В якості критерію оптимізації запропоновано показник мінімального часу виконання вантажних операції.

Результати. На основі методу оперативного дисбалансу вхідних вантажопотоків розроблено методику та проведено експерименти по її застосуванню для удосконалення системи управління процесом розвантаження вагонів в умовах зміни температурного режиму роботи.

Висновки. Аналіз результатів досліджень показав, що при запропонованому підході значно скорочується простій вагонів в умовах зміни температурних режимів, зменшуються витрати на плату за користування вагонами, на відновлення сипкості вантажу та експлуатацію локомотивів.

Ключові слова: вантажопотік, динамічна транспортна задача, критерій мінімального часу, порушення балансу запасів, оптимальний розподіл.

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СОВЕРШЕНСТВОВАНИЕ СИСТЕМЫ УПРАВЛЕНИЯ ПРОЦЕССОМ ВЫГРУЗКИ ВАГОНОВ В УСЛОВИЯХ ИЗМЕНЕНИЯ ТЕМПЕРАТУРНОГО РЕЖИМА РАБОТЫ

Актуальность. Главными задачами эффективного управления на транспорте остаются задачи минимизации затрат на доставку сырья, топлива и материалов при условии соблюдения всех требований конечного потребителя по срокам перевозок, состояния, качества и количества груза, соответствия подвижного состава оборудованию грузоприемных пунктов и др. Среди этих задач актуальной является задача совершенствования системы управления процессом выполнения грузовых работ на промышленных предприятиях в холодный период года, когда отрегулированный процесс выполнения грузовых работ в значительной степени осложняется под влиянием стохастических колебаний температуры окружающей среды. Стоимость доставки существенно увеличиваются из-за роста расхода энергоносителей на размораживание грузов.

Цель работы – совершенствование системы управления процессом разгрузки вагонов в условиях ожидания негативных изменений температурного режима работы за счет оптимизации распределения вагонов по пунктам выгрузки по критерию минимизации времени простоя.

Метод. Выделены обычный режим работы при положительных показателях температуры и режим необходимости восстановления сыпучести смерзающихся грузов. Разработан метод оперативного дисбаланса входящих грузопотоков, который обеспечивает более рациональное распределение грузов по грузовым фронтам в периоды смены температурных режимов, что характерно для климата Украины. Была разработана новая процедура решения динамической транспортной задачи с переменным фактором интенсивности входящих грузопотоков по времени. В качестве критерия оптимизации предложен показатель минимального времени выполнения грузовых операций.

Результаты. На основе метода оперативного дисбаланса входящих грузопотоков разработана методика и проведены эксперименты по ее применению для усовершенствования системы управления процессом разгрузки вагонов в условиях изменения температурного режима работы.

Выводы. Анализ результатов исследований показал, что при предложенном подходе значительно сокращается простой вагонов в условиях изменения температурных режимов, уменьшаются расходы на плату за пользование вагонами, на восстановление сыпучести груза и эксплуатацию локомотивов.

Ключевые слова: грузопоток, динамическая транспортная задача, критерий минимального времени, нарушение баланса запасов, оптимальное распределение.

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