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RESOURCE-SAVING TECHNOLOGIES OF RAILWAY TRANSPORTATION OF GRAIN FREIGHTS FOR EXPORT

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Abstract:

The research objective is to increase the efficiency of export railway transportation of grain freights in Ukraine by the introduction of consignor routing, a concentration of loading of grain on junction elevators and the organization of the movement of grain routes according to the schedule. According to the researchers in USA and EU, one of the effective directions for decreasing the expenses in a logistic chain of grain delivery to ports is consignor routing of railway transportation. Consignor routing of transportations of grain freights provides a concentration of their loading at junctions. The choice of junctions is proposed to be carried out on the basis of methods of the cluster analysis. For formation of regions for a concentration of grain loading the theory of sets and multicriteria optimization are used. As a result, on the basis of the modified simplex method are chosen 24 regions of possible concentration of grain loading that cover 70 stations on Ukrainian railways providing 7,5 million t consignor routing for grain in a year with minimal additional expenses. The assessment of the efficiency of railway transportation routing of grain freights is calculated with use of the developed simulation model. Researches showed that application of consignor routing allows to reduce a turn-round cycle for grain wagon in a logistic chain of deliveries up to 27%, and application of the schedule for consignor routes allows to reduce a turn-round cycle up to 62%, in comparison with transportation by car loading. Thus, as showed the calculations executed for one of the directions of grain transportation for export, the necessary operation park of grain-carrier wagons is reduced twice, thereby allowing to cut logistic expenses on a delivery of the Ukrainian grain through seaports to the world markets.

Key words:
grain export, elevators, rail transportation, consignor routing, concentration of loading, cluster analysis, simulation of railway transport network

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1. Introduction

Development of the Ukrainian economy under the conditions of deep euro-integration processes and globalization of world economy considerably depends on opportunities for its enterprises to create competitive products in the world market. The important key factor for the competitiveness of the Ukrainian goods is a reduction of the expenses in logistic chain, including expenses on power supply at an organization of export transportations. It demands coordination of actions of consignors, carriers, seaports and other participants of transportation process during all logistic chain. The grain is one of the strategic products which are offered today by Ukrainian economy. The grain branch is the main one and serves as a source of a sustainable development of agroindustrial complex and a basis of Ukrainian agrarian export. In this regard the problem of development of resource-saving logistic technologies for transportation of grain freights, first of all, for export needs, is a very actual for Ukrainian economy. At the same time, the obtained technical and technological solutions to solve problem must have a rigorous scientific justification, which requires the development of a special methodology.

2. Analysis of a perspective

Currently, Ukraine surely takes the leading positions among global manufacturers and exporters of grain. So, over the last 10 years production of grain increased in Ukraine by 2.25 times – from 29.3 MT in 2007 to record 66.1 MT in 2016 (State Statistics Service of Ukraine, 2017). The statistical data are presented in Figure 1.

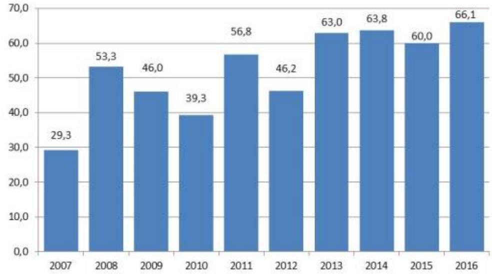

Fig. 1 Dynamics of grain production volume in Ukraine, MT

Considering that domestic demand is about 22-24 MT in a year, grain becomes one of the main export goods of Ukraine. For the last decade the volume of the Ukrainian grain export grew by 11,8 times – from 3.7 MT in 2007/2008 marketing year to 43.8 MT in 2016/2017 marketing year (Fig. 2). It is also necessary to note that the share of grain in a total amount of export for mentioned period grew from 3.5% (1.35 billion USD) to 16.7% (6.1 billion USD), conceding currently only to export of ferrous metals (19.9%) (State Statistics Service of Ukraine, 2017). According to forecasts of the Ukrainian grain Association by 2020 more than 90 MT of grain will be harvested in Ukraine and not less than 60 MT of grain will be exported (The Center for Transport Strategies, 2017).

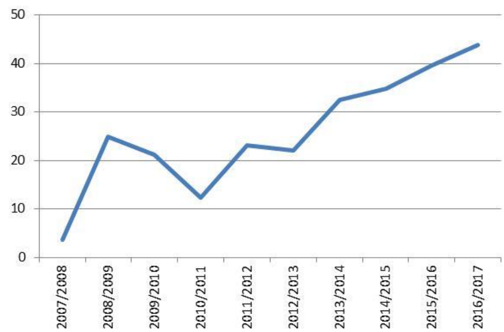

Fig. 2 Dynamics of grain export in Ukraine, MT

An important factor for ensuring the export of the Ukrainian grain is the effective logistic system of its delivery from producers in seaports, through which about 97% of the Ukrainian export grain is carried out (Kozachenko, D. et al, 2017). At the same time, it should be noted that the Ukrainian logistic system demonstrates rather a low efficiency now. According to the World Bank the index of logistic efficiency (LPI) for Ukraine in 2016 was 2,74 (the 80th place); in comparison, for Poland – 3,43 (the 33rd place), and for Germany that is the leader of a rating – 4,23 (The World Bank, 2016). In grain sector of Ukraine logistic expenses make 50 … 55 USD/t that is equal to 35% of grain cost, in the USA these expenses make about 30 USD/t (10%) (The World Bank, 2015).

The main export streams of grain (about 63%) follow to seaports by railways (Kozachenko, D. et al, 2017). Ukrainian railways carry out about 90% of all goods turnover with a use of electric traction. Furthermore, Ukraine is the largest producer in Europe of the electric power. At the same time, road transportation requires more than 70% of all oil products; 80% of oil products are imported by Ukraine (State Statistics Service of Ukraine, 2017). Thus, increasing of the transportation efficiency of grain freights, first of all, in railway-water field is one of the key tasks which need to be solved for decreasing the logistic expenses in an organization of Ukrainian grain export.

3. Routing of transportations

The system of its transportation from linear elevators in seaports by railway transport is “bottle neck” of a logistic chain of the Ukrainian grain export. One of the key problems at the organization of railway transportation is the considerable scattering of grain loading at a large number of cargo stations. According Ukrainian researchers, for 67% of Ukrainian stations the average loading does not exceed 1 wagon per day (Kozachenko, D. et al 2015). As a result, grain follows to ports on the basis of car load that significantly increases both terms and cost of its delivery because of additional rearrangements of trains at technical stations.

One of the most effective methods for organization of traffic volumes is consignor routing considering the concentration of freight traffics at one basic loading station one is carried out loading for all structure (route) that follows without rearrangement at technical stations to the destination (port station) (Kozachenko, D. et al., 2015a). The organization of the transportation of such route trains on the basis of the schedule is also a very prospective method (Kozachenko, D. et al., 2016) including using of private operators’ locomotives (Kozachenko, D. et al., 2012).

Regarding the question of a routing of railway transportation of grain freights experience of the USA which is the main exporter of grain in the world deserves special attention.

Till 70th years of the XX century the technology of transportation of grain by the railways in the USA was similar to Ukrainian. After unloading empty cars went to marshaling yard, from where groups of 1 … 25 cars were moved at a station of grain loading. After loading the group of cars with grain went to marshaling yard again for an accumulation of trains according to a train-formation diagram. Change of transportation technology for grain freights on railway transport began at 1972-1973 when the USA faced rapid growth, both in production and in grain export. To sustain the competition from road and water transport, the railways started stimulating consignors to increase the number of cars in the sending parties due to differentiation of tariffs for a car, group and route sendings. Thus, consignors began to increase significantly loading capacities of elevators to 100 cars per day (Schnake, L. D. et al., 1983). The efficiency of grain transportation by routes is connected to decreasing of the expenses on stations, rational use of load limit of cars, transport and carrying capacity of the railways. At the same time this technology demands development of access roads and loading capacities of elevators (Hauser, R. J. et al., 1984). As showed researches, due to more effective use of a rolling stock at consignor routing cost of transportations of grain decreases to 50% (Kenkel, P. et al., 2004).

Accepted in USA by the Congress "The law on revival of the railways and reform of regulation" (1976) (Railroad Revitalization and Regulatory Reform Act, 1976) and "Staggers's act of railway transport" (1980) (Staggers Rail Act, 1980) considerably simplified to the railroads for railways the procedure of closing of low-active lines and stations, and also gave them large powers regarding tariff policy. Thus, there was a transition from transportation tariffing based on proportion to the mass of freight towards tariffing depending on consignment type (car, group, route).

Since 1990, USA started actively use the shuttle-train technology which consists in the organization of grain transportation by trains with 100 … 130 cars. Such trains run between an elevator with big loading capacity and ports (Ndembe, E., 2015). For stimulation of consignor, who form "shuttle-trains", was envisaged the 52% discount to a basic transportation tariff for by group consignors. Grain routes are loaded within about 15 hours and follow on lines according to tough schedules (according to contracts on 6 … 9 months) without rearrangement at stations (Sarmiento, C. et al., 2005). For ensuring grain’s consignment on routes one made a concentration of its loading on nodal elevators, the number of linear elevators was considerably reduced, and the average delivery distance of grain by farmers to nodal elevators increased from 19 to 51,5 km (Ndembe, E., 2015). In general, the effective logistic system that operates on the railways in the USA, reduces the prime cost of grain and provides its competitiveness on the world markets.

Currently, the average level of consignor routing in Ukraine makes 40 … 45%, however for grain freights this indicator does not exceed 10 … 12% (for comparison, in the USA at the general level 60% of the routing of railway transportation, up to 95% of grain freights are transported by consignor routes) (Sarmiento, C et al 2005). It should be noted that now in Ukraine there is no system of the differentiated tariffs for transportation depending on consignment type (Kozachenko, D et al 2013). The combination of such factors as a sharp increase of the grain production and export, critical wear of grain-carriers (Myamlin, S. et al., 2013) and big competition in the world markets causes the necessity for improvement of the logistic system for transportation of grain freights. Under these conditions in Ukraine one can use the USA approach that consists in a concentration of grain loading on nodal elevators and use of routes for railway transportation of grain freights on the basis of the special lowered tariffs.

The research objective is to develop the technology for railway transportation of grain freights from nodal elevators in Ukrainian seaports for export by consignor routes and to assess the efficiency of the mentioned technology.

4. Formation of an export-oriented network of nodal elevators

Now in Ukraine loading of the grain is carried out on 630 railway stations (Kozachenko, D. et al., 2017), however, as it was noted above, on 2/3 of stations the average daily loading does not exceed 1 car. The widespread introduction of consignor routing for grain freights envisages organizing of a network of concentration regions for grain loading with an allocation of specialized (junction) loading stations for route trains.

The choice of nodal elevators (stations) and formation on their base of concentration regions for grain loading represents a very complex multivariate and multiple-factor optimizing task. For solving of the specified task it is necessary to consider the existing infrastructure of stations and elevators, possibilities of their development, existing and expected volumes of grain loading, and also the additional expenses connected with storage of grain, loading of routes, delivery of grain to junctions by road transport, expenses on transportation of grain by railway transport to ports (Kozachenko, D. et al., 2017).

Problem definition. The problem of definition of the regions for a concentration of grain loading and junctions corresponding to them on which loading of grain routes will be carried out, can be formulated as follows. On the route area there is a set *of S* stations of grain loading S = { *s1*, *s2, … si,… sz*). Distances l_{ij} between each couple of s_i and s_j stations (s_i, $s_j \in S$) can be presented as a matrix of distances $L=\{l_{ij}\}$ (Ukrainian Railways, 2001).

Each element in a set *S* (station) is characterized by a number of parameters:

$$s_i = \{I, N, c, q, p, \mathbf{T}, \mathbf{K}\}, \tag{1}$$

where: I – the identifier of station (ESR code); N – name of station (Ukrainian Railways, 2001); c – class of station; q – average annual volume of grain loading, wag.; p – capacity of elevator infrastructure on simultaneous storage of grain, thousands of tons.; T – the vector characterizing distance from the station to the main seaports; K – the vector characterizing the volume of additional capital investments on a development of station's infrastructure of at realization of loading of routes with grain.

Vector T includes elements characterizing of the tariff corresponding to distances from given station s_i ($s_i \in$ S) to one of the seaports (Ukrainian Railways, 2009):

$$\mathbf{T}_i = \{t_1, t_2, ...t_n\}, \tag{2}$$

Elements of a vector **K** characterize the volumes of the additional capital investments necessary for development of infrastructure on s_i station (elevator and railway) for ensuring loading of 1 … 3 routes in a week:

$$\mathbf{K}_i = \{k_1, k_2, k_3\}. \tag{3}$$

Considering that obtaining the values of a elements k_1, k_2, k_3 in terms of cost for each station represents very time-consuming task, the authors used the parameterized dimensionless values in the range [0; 1]: $k_j=0$ means that additional resources for development of infrastructure on station for formation *of j* of grain routes in a week is not required, and $k_j=1$ – formation *of j* grain routes in a week at this station is inappropriate because of considerable investments in infrastructure; in other cases – $0 < k_j < 1$. Concrete values of the parameters k_1, k_2, k_3 for each station are defined by an expert on the basis of the analysis of its infrastructure.

On the basis of the statistical analysis of data of the Automated control system for freight transportation of Ukrainian Railways (ASUTP-UZ) were determined the average annual volumes of grain loading q_i for each station. Data classes of each station and capacity of its elevator infrastructure can be received from automated workplace.

On the basis of the specified basic data it is necessary:

1) from a set *of S* to allocate subset S^* ($S^* \subset S$) of the junctions stations s_u^* ($s_u^* \in S^*$, $u=1, 2, \ldots, m$), on which loading of routes with grain will be carried out;
2) for each junction station s_u^* (type U) to define the region of concentration of loading R_u ($u=1, 2,\ldots,m$), i.e. a set of $s_v \in S$ (type V), from which grain transportation by road transport on the junction station s_u^* will be organized:

$$R_u = \left\{ I_r, Q_r, s^*, s_1, s_2, \ldots, s_v, \ldots, s_f \right\}, \quad s_v \in S \tag{4}$$

where I_r – the identifier of the concentration region; Q_r – total annual loading of grain at all stations in the region, wag.

Forming concentration regions for loading it is necessary to consider the following conditions:

1) the distance from junction *U-station* s_u^* in *Ru* region to any *V-station* of this region s_v ($s_v \in R_u$) should not exceed maximum value l_{max} (for this task the maximum accepted distance of grain transportation by road transport is *lmax=30* km):

$$(\forall s_v \in R_u)(\forall s_u^* \in R_u)(l_{uv} \le l_{\max}), \quad v = 1, 2, \ldots, f_u, \ \ u = 1, 2, \ldots, m \tag{5}$$

2) the total annual volume of grain that is shipped at stations in the concentration region *Ru* has to be not less than Q_{min} (for this task it is accepted *Qmin=3000* wag / year that provides shipment not less than 1 route with grain in a week):

$$(\forall R_u)(Q_r \ge Q_{\min}), \ u = 1, 2, \ldots, m \tag{6}$$

Besides, the solution of a task has to provide the minimum annual operational costs connected with a routing of grain transportation for export to ports. Generally, these expenses can be presented as

$$\sum_{u=1}^{m} E_u^{avt} + \sum_{u=1}^{m} E_u^{xp} + \sum_{u=1}^{m} E_u^{gdm} + \sum_{u=1}^{m} E_u^{gdv} + \sum_{u=1}^{m} E_u^{inf} \to \min \tag{7}$$

where:

E_u^{avt} – additional expenses on grain transportation on a junction station in region R_u by road transport from linear elevators, mln. UAH; E_u^{xp} – additional expenses on grain storage at a junction station in region *Ru* for an accumulation of a route, mln. UAH; E_u^{gdm} – expenses on grain transportation to ports from a junction station in region R_u, mln. UAH; E_u^{gdv} – expenses on grain transportation to ports by car loading from stations in region *Ru*, mln. UAH; E_u^{inf} – the additional reduced costs connected with the development of elevator and railway infrastructure on a junction station in region R_u, mln. UAH.

Definition of junctions stations for loading of routes. The initial set of stations of grain loading S can be divided into two subsets: 1) S^*, which includes junction stations for a possible concentration of loading (U-station); 2) S', which includes stations at which loading of grain routes is inappropriate. Considering a significant amount of stations for grain loading (more than 600), for receiving the specified subsets effectively one can use methods of the cluster analysis (Durant, B. et al., 2012).

For allocation of a set S^* of junction station was used the agglomerative algorithm of direct classification (Durant, B. et al., 2012). On the first step each classified object represents a separate cluster. On each following step of the algorithm there is an association of two closest clusters. It repeats until the number of clusters does not reach specific value defined in advance (in this case there are two clusters).

For effective using of classification methods and receiving reliable results it is very important to determine the informative parameters, on the basis of which classification of objects is carried out (in given case - railway stations). In this regard from a set of the parameters characterizing freight station

(1) on the basis of methods of multidimensional statistical analysis, taking into account expert assessments the following informative parameters were chosen: class of station – *c*, annual volume of grain loading – *q*, existing capacity of elevator's infrastructure – *p*, additional expenses on development of elevator and railway infrastructure for ensuring loading of grain routes – k_1, k_2, k_3.

Standardization of values of informative parameters for their reduction to dimensionless sizes could be done on the basis of the equation:

$$X_{i,j}^{/} = \frac{X_{i,j}}{X_j^{\max} - X_j^{\min}}, \tag{8}$$

where: $X_{i,j}$, $X_{i,j}'$ – value of j-th parameter for *i-th* object, respectively before standardization; $X_j^{\min}$, $X_j^{\max}$ – the max and min value of j-th parameter respectively among all objects for selection.

Among the considered measures of distinction d_{ab} between objects (clusters) *a* and *b* the smallest error at a classification of a "reference" set of stations was shown by a "kanberrovsky measure" (Durant, B. et al., 2012).

$$d_{ab} = \sum_j^N \frac{\left|x_{aj} - x_{bj}\right|}{\left|x_{aj}\right| + \left|x_{bj}\right|}, \tag{9}$$

Besides, taking into account the efficiency of various strategy for association in agglomerative algorithm, for classification of stations for grain loading Ward's strategy was chosen (Ward J.H., 1963)

Thus, on the basis of agglomerative method of the cluster analysis, on Ward's strategy of association and on "kanberrovsky" measure of distinction between objects, the initial set of stations of grain loading S was divided into two subsets – S^* which includes junction station for possible concentration of loading (U-station) – 43 stations, and S', which includes stations at which loading of grain routes is inappropriate – 587 stations.

Definition of regions for a possible concentration of grain loading. On the basis of the subset of junction station S^*, considering the territorial proximity *of V*-stations to junction *U*-station (5), was created *m=43* regions for a possible concentration of grain loading *Ru*, which consists of *n=82* stations (43 junction and 39 not junction).

Each created region has to provide sending not less than 1 grain route in a week (6). Taking into account this condition was finally created the set $R=\{R_u\}$, which includes *m=41* regions of concentration, *n=76* stations (41 junction and 35 not junction) with a total value of grain loading 15 mln. t in a year.

Choice of effective concentration regions for grain loading. Analysis showed that the majority of the received sets R_u ($u=1, 2,\dots, 41$) are crossed, i.e. one or several elements (stations) of one set (region) are at the same time elements of other sets (regions). Thus, in the received set *R* it is necessary to allocate subset R^*, all elements m^* of which (concentration regions of loading R_u, $u=1, 2,\dots, m^*$) would be mutually non-overlapping sets. The total volume of grain loading in a total subset R^* has to be maximal, and the total value of the expenses connected with the concentration of grain loading and formation of grain routes has to be minimal (7), i.e.:

$$\begin{cases} Q(R^*) \to \max \\ E(R^*) \to \min \end{cases} \Rightarrow \begin{cases} \sum_{i=1}^{m^*} Q_{r(i)} \to \max \\ \sum_{i=1}^{m^*} E_i \to \min \end{cases} \tag{10}$$

The required subset $R^* \subset R$ represents such union of non-overlapping sets R_u^* ($u=1, 2,\dots, m^*$)б for which objective function (10) reaches an extremum.

The following procedure was developed for the solution of the task. At the beginning one allocates in the initial set *R* not overlapping and overlapping subsets R_u ($u=1, 2,\dots, m$). For this purpose was used one of the DSU- algorithms (Kormen T., et al., 2013) This algorithm gives a matrix $G = |g_{uv}|$ (u=1, 2,…, m; v=1, 2,…, m) as a result, in which every row u and column v are connected to the certain set (the concentration region) R_u and R_v respectively, and each element of a matrix g_{uv} represents the list of stations s_i ($s_i \in S$), which at the same time are parts of regions (sets) R_u and R_v. Thus, it is necessary to execute rearrangement of the general elements for all couples of overlapped sets R_u and on the basis of it to create sets R_u^* in order that objective function (10) reaches an extremum.

Transform matrix G to a matrix $X=|x_{ut}|$ (u=1, 2,…, m; t=1, 2,…, n), in which every row u corresponds to a certain set (region) R_u, and each column t – to a certain U-station or V-station. Each element of a matrix represents the Boolean variable x_{ut} = {0; 1}, which takes the value x_{ut} = 1, if the station s_t can be included in structure of the concentration region R_u ($s_t \in R_u$), otherwise ($s_t \notin R_u$) and x_{ut} = 0. Each station s_t corresponds to a certain value of average annual volume of grain loading q_t(1) , and also to the some parameter e_{ut} characterizing the value of additional expenses at adding of station s_t in the concentration region of grain loading R_u. The objective function (10) can be transformed as follows:

$$\begin{cases} \sum_{u=1}^{m}\sum_{t=1}^{n} q_t x_{ut} \to \max \\ \sum_{u=1}^{m}\sum_{t=1}^{n} e_{ut} x_{ut} \to \min \end{cases} \Rightarrow \begin{pmatrix} \sum_{u=1}^{m}\sum_{t=1}^{n} q_t x_{ut} \\ -\sum_{u=1}^{m}\sum_{t=1}^{n} e_{ut} x_{ut} \end{pmatrix} \to \max \qquad (11)$$

The task has the constraints:

$$(\forall s_t)(\sum_{u=1}^{m} x_{ut} \le 1),\ t = 1,2,...,n \qquad (12)$$

$$(\forall R_u^*)(\sum_{t=1}^{n} q_t x_{ut} \ge Q_{\min} \vee \sum_{t=1}^{n} q_t x_{ut} = 0), u = 1,2,...,m \qquad (13)$$

$$(\forall s_t \notin R_u)(x_{ut} = 0),\ u = 1,2,...,m;\ t = 1,2,...,n \qquad (14)$$

Constraint (12) means that each station s_t can be included no more than in one region of concentration R_u^*, however, it can be not included in the region. Constraint (13) defines that the total volume of grain loading for each region of concentration R_u^* has to be not less than Q_{min} (6), otherwise such region is excluded, and the stations belonging to it are redistributed between other regions. Constraint (14) excludes a possibility of the addition of station s_t to the region R_u^*, if it is not provided in an initial set of regions R. The task (11)-(14) represent a problem of multi-criteria optimization. However, the features of this task allow us to refer it to linear programming model with Boolean variables (Kornut A. A. et al., 1969). On the basis of a linear convolution with rationing of criteria the given optimizing task was transformed in a one-criterion task, which was solved by a simplex method, modified for tasks with Boolean variables (Kornut A. A. et al., 1969).

As a result, was created a subset R^* that represents a union of non-overlapping sets R_u^*; each set R_u^* corresponds to a certain concentration region of grain loading, in which the concentration is the most effective. Finally, was chosen the structure of 24 concentration regions for grain loading that consists of the 70 stations that provide minimal additional expenses at a maximal total volume of grain loading by routes of 7.5 MT in a year.

5. Simulation of transportation process of grain routes

The assessment of the efficiency of various options for railway transportation technology of grain freights in seaports (car sending, consignor routes, the organization of the transportation of grain trains on the basis of the schedule) was carried out by developed simulation model taking into account the stochastic work of railway transport (Kozachenko, D. et al., 2015b).

Development of a model. Logistic grain supply chain from elevators to ports could be considered as the closed transport system for development of the model. The cars represent the objects, on which in the course of their turnover certain technological operations are carried out. In model, each car is described by structure

$$v = \{i, t_n, t_к, s\}, \qquad (15)$$

where:

i – the car identifier; t_n, t_k – respectively, the moment of the beginning and of the end of a performance of the technological operation; s – identifier of a structure.

During simulation, the turnover of each is divided into stages, durations of which are presented as random variables. The main stages of car service are (fig. 3):

– stay at the loading station ;
– running from loading station to a marshaling yard;
– stay in a marshaling yard;
– running of the car from a marshaling yard to harbor station;
– stay of the car on harbor station for unloading.

Service devices in the logistic system of grain delivery are represented as subsystems of acceptance, freight work, formation and departure railway stations, and also the railway lines between stations (Bobrovskiy, V. et al., 2014). Each service device d_j

corresponds to the set of the cars V, which are in processing, the identifier n of the following service device, the distribution function of a random variable - service time q

$$d = \{\mathbf{V}, n, q_{\mathrm{v}}, q_{\mathrm{n}}\}. \quad (16)$$

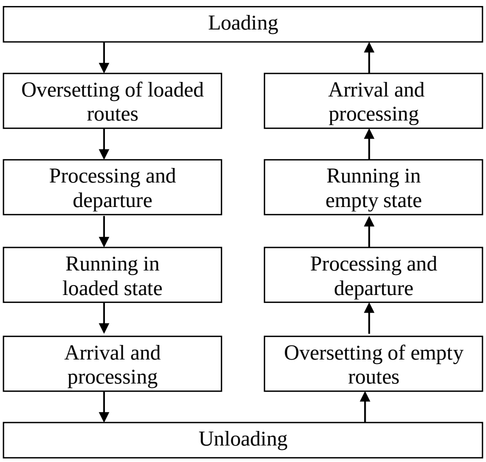

Fig. 3. Schematic diagram of the simulation model of car traffic with grain

System timer with some step t_c changes the condition of service devices by command. At the time of car v_i arrival is defined the moment of the service beginning t_n and is calculated the moment of the service completion

$$T_{\mathrm{k}} = t_{\mathrm{n}} + f(q_{\mathrm{v}}\ \mathbf{q_n}). \quad (17)$$

Technological operations with cars are considered completed when $t_k < t_c$.

For parametrization of model were used the results of the statistical analysis of data from ASUGP UZ regarding duration of staying of cars on stations, and also in running on lines.

The simulation model of a logistic chain of grain delivery is developed on the basis of object-oriented approach and realized in the form of the program complex Nitki.exe, which allows to model process of running of cars with grain from loading stations to harbour unloading station. After the termination of the turnover cycle for cars one fixes the duration of car stay in each of subsystems. Further these data are used for the statistical analysis of transportation process of grain from loading stations to ports.

By means of the developed model were investigated the following options of the organization of the car transportation with grain :

– option 1: grain departure by car sendings;
– option 2: technical routing of grain transportation (on marshalling yard);
– option 3: organization of grain transportations by consignor routes;
– option 4: organization of grain transportations by consignor routes on the basis of the schedule with ensuring the exact departure time of trains due to creation of time reserves;
– option 5: organization of grain transportation by consignor routes on the basis of the schedule with ensuring exact departure time of trains due to rigid rationing of technological operations on stations.

The efficiency assessment of the considered options is executed on the example of logistic system of grain transportation on harbor station Chernomorskaya (Odessa Railways) from the region of stations Nezhin, Nosovka and Bobrovitsy (Jugozapadnaya Railways). Station Nosovka is offered as a station for possible grain loading concentration for this region.

For an efficiency assessment of various options of the organization of grain transportation from loading stations Nezhin, Nosovka, Bobrovitsy to the harbor station Chernomorskaya a series of experiments on simulation model were carried out. The results of simulation of grain transportation show that car sending assure turnover cycle (option 1) 7,8 days that practically correspond to the data from an ASUGP UZ ; technical routing (option 2) reduces the turn-round cycle to 6,9 days. The concentration of freight traffics on the station Nosovka and the organization of consignor routing from this station (option 3) allows to reduce a turnover cycle to 5,7 days. The departure of routes from Nosovka station according to the schedule with preservation of random duration of performance of technological operations and ensuring compliance with the schedule due to time reserves (option 4) is not an effective method of turnover cycle reduction as it increases its duration to 10,4 days. At the same time in the case of assuring the rigid control of time of technological operation performances (option 5) the turnover cycle for cars can be reduced up to three days providing organization of route loading daily.

6. Efficiency assessment of the organization of transportation of grain routes according to the schedule

Domestic and foreign experience in the field of the organization of freight transportation on railway transport shows that one of the effective directions of improvement of transportation process is the technology of the organization of the running of freight trains on the basis of "rigid" train path according to the schedule (Kozachenko, D. et al., 2016). Given the complexity and multivariance of the task of drawing up such a schedule of train traffic, it is advisable to use specialized software developed on the basis of modern mathematical models and algorithms, in particular, heuristic (Jacyna, M., et al., 2017).

In this work, the efficiency assessment of the running of grain trains on the schedule was performed on the example of a logistic grain supply chain from concentration loading stations to one of the large Ukrainian seaports (TIS port, connecting station Chernomorskaya on Odesskaya railway).

On the basis of data from ASUGP UZ were defined the transportation distances from TIS port to loading stations of grain routes, and also the duration of their running both in empty and in the loaded state (Tab. 1) .

Table 1. Transportation distance from port to loading stations of routes and running duration of the route train

Stations of routes' loading	Transportations distance, km	Running duration of the route, h
Pomoshnaya	255	6.14
Koristovka	429	10.34
Zolotonosha-1	442	10,65
Drabovo	480	11,57
Yagotin	552	13,30
Priluki	560	13,49
Romodan	577	13,90
Sula	628	15,13
Reshetilovka	655	15,78
Romny	674	16,24
Toropilovka	790	19,04

On the basis of data about duration of staying of grain routes at stations of loading and unloading, and calculating of the running time of a route between these stations was developed the week schedule of route trains on "rigid" train path (Fig. 4) .

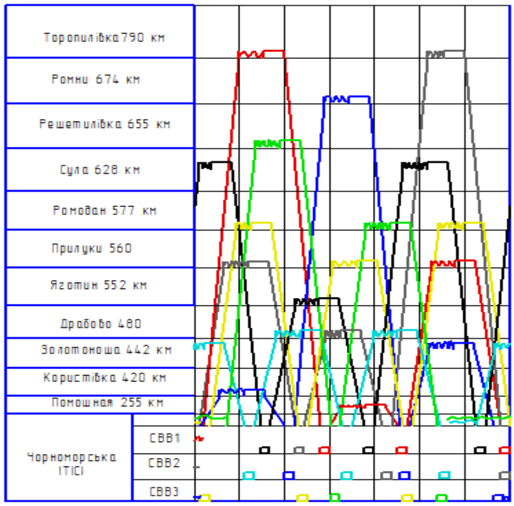

Fig. 4. Diagram of the grain routes

The diagram of service of routes at their running according to the schedule on junction elevators (fig. 4) assumes use of 7 trains for ensuring week volume of transportation. The number of routes, which have to run from concentration stations in a week**:**

$$N_{route} = \frac{N}{m_{wag} \cdot N_{week}}, \tag{18}$$

where N_{route} – total number of cars that are concentrated on loading stations within a year; m_{wag} – number of cars in the route train; N_{week} – number of weeks in a year.

The number of cars which are involved in route transportations on concentration station in a year:

$$n_{route} = N_{route} \cdot m_{wag} \cdot N_{week} \tag{19}$$

The number of cars that are not involved in route transportation and involve in car sendings:

$$n_{cs} = n - n_{route}, \tag{20}$$

The corresponding values of numerical characteristics of grain freight transportation by routes and car sending are presented in Tab. 2.

Available stock at routing transportations according to the schedule:

$n^{м}_{p}=N_{sost}\cdot m_{wag}\cdot k_{res}$ (21)

where:

k_{res} – the reserve coefficient of available stock (k_{res}=1,04).

$n^{м}_{p}$=7·52·1,04=379 wag.

Table 2. Definition of number of grain routes

Station	Total amount, wag	N_{toute}	n_{route}, wag	n_{cs}, vag
Pomoshnaya	3248	1	2704	544
Koristovka	3580	1	2704	876
Zolotonosha-1	5480	2	5408	72
Drabovo	8897	3	8112	785
Yagotin	3323	1	2704	619
Priluki	8496	3	8112	384
Romodan	8143	3	8112	31
Sula	6112	2	5408	704
Reshetilovka	3425	1	2704	721
Romny	3420	1	2704	716
Toropilovka	6152	2	5408	744

The turnroung cycle for car sending between TIS port and concentration stations was calculated on the basis of the developed simulation model and is presented in tab. 3.

Table 3. Turns of car sendings grain freights

Stations	Turnover of the car sending, days.
Pomoshnaya	6,62
Koristovka	6,66
Zolotonosha-1	6,45
Drabovo	4,92
Yagotin	7,34
Priluki	7,20
Romodan	7,52
Sula	4,26
Reshetilovka	8,16
Romny	6,72
Toropilovka	5,78

Available stock of cars at car sending of grain freights:

$$n_{n}^{p}=\frac{\sum_{j}^{k} n_{cs,j}\cdot\Theta_{j}}{N_{week}}\cdot k_{res} \quad (22)$$

where Θj – a turnover cycle of car sending on *j-th* station (tab. 3).

Thus, $n^{p}_{r}=786$ wag.

The average turnover cycle of grain freights for routing according to the schedule (fig. 3) makes 2,85 days, and at car sendings (tab. 3) – 6,51 days. The economy of wagon fleet at using of a routing of grain freights transportations makes:

$$\Delta n_{p}=n_{p}^{п}-n_{p}^{м} \quad (23)$$

$$n_{\mathrm{p}}^{\mathrm{econ}}=(786-379)=407\ wag.$$

Δn_{p}=786 – 379 = 407 wag.

In terms of money (considering the cost of one car for grain transportation that costs 50 thousands USD) the economy could be about 20 million USD.

7. Conclusions

1. The organization of consignor routing of railway grain transportation requires formation of a network of junction elevators for a concentration of grain loading. Transportation of grain from linear to junction elevators can be carried out by road transport.
2. On the basis of the developed technique were allocated 24 concentration regions for possible grain loading that cover 70 stations on Ukrainian railways. This approach provides minimal additional expenses and assures consignor routing at a level of 110 thousand wag. in a year (consignor routing of grain provides more than 7 MT, i.e. about 16% of export value).
3. It is useful to make an assessment of technical and economic indicators of a logistic supply chain of grain from loading stations to ports on the basis of a simulation model, which is the powerful instrument for modeling of the difficult dynamic systems.
4. The results obtained on simulation model showed that consignor routing allows to reduce a car turnover in the considered logistic delivery chain by 27%, and application of the diagram of consignor routes according to the schedule allows to reduce a car turnover by 62%, in comparison with transportation by car sending. Thus, as shown the calculations for one of the directions of grain transportation for export, the available stock of grain-carriers could be reduced twicely, thereby allowing to cut logistic delivery expenses of the Ukrainian grain through seaports to the world markets.

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