Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 149 (2019) 288–296

Procedia Computer Science

www.elsevier.com/locate/procedia

ICTE in Transportation and Logistics 2018 (ICTE 2018)

Mathematical model for defining rational constructional technological parameters of marshalling equipment used during gravitational target braking of retarders

Marek Mezitis[a], Vladyslav Panchenko[b], Maksim Kutsenko[c], Artem Maslii[d],*

[a] Dr.sc.ing., Professor, RTU Institute of Transport, 12 Azenes Street, Riga LV-1048, Latvia
[b] Cand. of Techn. Sceinces, Associate Professor, Ukrainian State University of Railway Transport, 7 Feierbakh Square, Kharkiv 61050, Ukraine
[c] Cand. of Techn. Sceinces, Associate Professor, Ukrainian State University of Railway Transport, 7 Feierbakh Square, Kharkiv 61050, Ukraine
[d] Cand. of Techn. Sceinces, Associate Professor, Ukrainian State University of Railway Transport, 7 Feierbakh Square, Kharkiv 61050, Ukraine

Abstract

The article presents the mathematical model for defining rational constructional and technological parameters of marshalling equipment with the application of gravitational target car braking. In contrast to the existing ones, the realization of the given model will allow a complex approach to defining the height and longitudinal profile of the hump yard for applying the technology of gravitational target regulation of car speed. This construction of hump yards is characterized by a special construction of plan and longitudinal profile. The authors believe that it will contribute to reducing operational expenses on compensation of expenditure on damaging cars and freight, electricity, required for regulating the speed of retarders, and to reducing extra costs connected with stock lay-over in the pool waiting for breaking-up.

Peer review under responsibility of the scientific committee of the ICTE in Transportation and Logistics 2018 (ICTE2018).

Keywords: Hump yard; Longitudinal profile; Braking position; Gravitational target car braking

* Corresponding author. Tel.: +371-29169240.
E-mail address: vlad_panchenko@ukr.net

1877-0509
Peer review under responsibility of the scientific committee of the ICTE in Transportation and Logistics 2018 (ICTE2018).
10.1016/j.procs.2019.01.137

1. Introduction

Nowadays the world market of energy resources is characterized by the constant rise in their cost. Consequently, it is obviously necessary to increase the efficiency of every production process. In the railway field, whose main competitor is automobile transport, the problem of searching possibilities to reduce the freight transportation rates is absolutely urgent. It is known that one of the main constituents of the freight transportation rate is the expenses caused by keeping the freight at the railroad yards [1]. Especially it concerns the cost of marshalling process. Most of the hump yards in European countries are equipped with beam pressing retarders that cost around $100.000. Taking into account that amortization expenses, spare details and maintenance of retarders are directly proportional to their cost, pressing need obviously appears to search for possibilities to reduce the prime cost of processing freight car traffic volume at hump yards. Moreover, in most cases cars undergo several processing's at hump yards on their way from exit to receiving stations.

2. Analysis of the previous researches

Nowadays there are a lot of researches aimed at increasing energy efficiency of the marshalling process by rationalizing the profile and the construction plan of a hump yard, developing car retarders, marshalling process automation systems and retarder braking modes [2-7].

Besides, there is an opinion that effectiveness of marshalling process greatly depends on a range of factors that are difficult to take into account by formalization or prognostication [8]. First of all, it concerns technical condition of car retarders, marshalling process automation equipment and condition of car mounted wheels. Furthermore, the so called «human factor» (we mean skill level of operators of retarder positions) also essentially influences the effectiveness of marshalling process and remains to be an area of concern.

The analysis of the abovementioned scientific works allows concluding that so far the problem of formalization or prognostication of the factors referred above has not been solved and remains topical.

The fairly-proved solution to this problem is applying the innovation technology of gravitational target braking of retarders [8]. In the framework of its realization there was suggested a special construction of the longitudinal profile and plan of a hump yard (see Fig.1).

The picture illustrates that in our case a part or the whole section of the switching area (SA) together with the beginning of the marshalling track section up to stock retarder position (SRP) is located on the rise in contrast to the traditional construction of the longitudinal profile of the hump yard with the realization of the interval target braking technology. All the other elements on the section from the hump apex (HA) to the reference point (RP) are located on the slope. Moreover, attention should be paid to the fact that realization of the gravitational target braking technology requires only the stock retarder position, functional purpose of which is the same as while the realization of the interval target braking. The only difference lies in the fact that SRP must be equipped with powerful car retarders.

Checking dynamic properties of the longitudinal profile we have found out that the necessary time intervals between cars, which roll down in consecutive order, are ensured by the special construction of the descending part profile and are sufficient to operate switchers from one position to another. Locating some elements of the profile on the rise allows reducing excessive kinetic energy of cars when they enter the section of the stock retarder position (in other words, gravitational effect appears).

To draw a final conclusion as for practicability to apply some marshalling equipment with gravitational target braking of retarders a detailed feasibility study is necessary. Meanwhile, there is a working hypothesis that under the conditions of automation of car processing process the saving rate with progressive total during the calculation period of the analyzed hump yard operation will overtop the saving rate with progressive total during the same period of traditional automated hump yard operation, no matter that capital investments in the means for regulating the speed of car retarders rolling can be preliminary estimated twice as much as while using a hump yard with gravitational target car braking (extra capital investment in automation devices when using a traditionally constructed hump yard can exceed the investment in car retarders).

Moreover, it is expected that it will contribute to reducing the operational expenses on compensation of expenditure on damaging cars and freight (if there are better conditions for improving the quality of regulating the speed of retarders rolling down), electricity, required for this regulating (car retarders can contribute to reducing the air expenditure), and to reducing extra costs connected with stock lay-over in the pool waiting for breaking-up (owing to possible minimization of the hump interval duration at the expense of reducing the volumes of shunting when settling cars at the car yard and if there is no need to eliminate the aftereffects of retarders regaining speed).

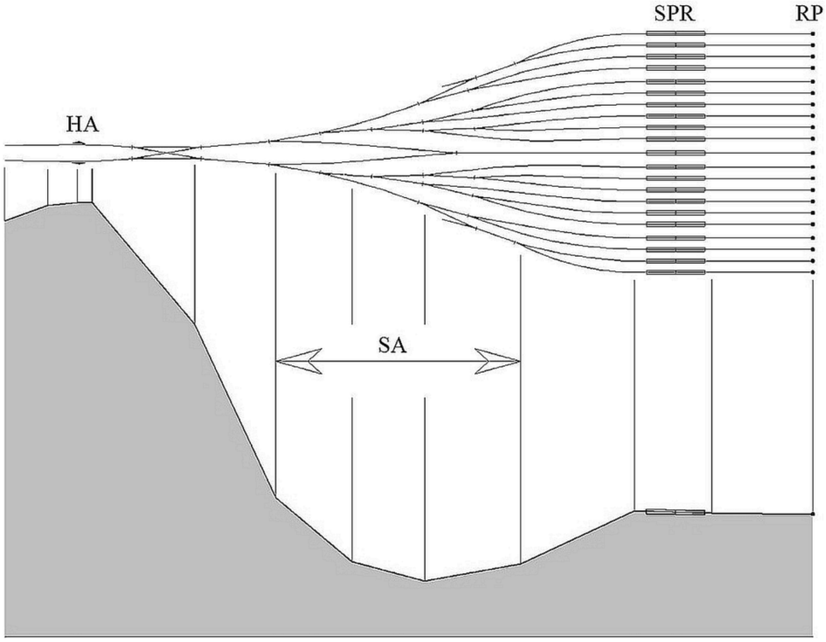

Fig. 1. General view of the longitudinal profile and a hump yard construction plan for realization of the gravitational target car braking technology.

However, nowadays there does not exist a method to get optimal design values of a hump yard with the realization of the gravitational target car braking.

3. The purpose of the article

The aim of the article is to develop a mathematical model for defining optimal structural parameters of hump yards that ensure the realization of the gravitational target car braking and absolute fulfillment of safety conditions as well as reliability of marshalling process.

4. The criterions for optimization

First of all, it is necessary to define the criterion for optimization the structural parameters of hump yards that ensure the realization of the gravitational target braking. It is known that costs of car retarders servicing are among the highest in the marshalling process. Moreover, we have already mentioned their high price. Thus, using less car retarders on a hump yard it is possible to significantly reduce operating costs of marshalling process. So, we suggest choosing the necessary power of the stock retarder position as a criterion for optimization the structural parameters of hump yards.

The quantity and power of car retarders at a hump yard is determined by the requirements of the set technological modes of work (which are mostly characterized by breaking-up design speed), safety conditions for gravity shunting, reliability demands and durability of the technological system regulating car speed that is designed (taking into account further automation of marshalling process) and depends on the hump yard height, quantity of groups of tracks and quantity of tracks in these groups, the structure of car traffic volume under processing, etc. (1).

Total required power of the gravitation breaking gear, kJ/kN, en-route of the rolling down car with good rolling qualities from the hump apex to the beginning of the stock retarder position, is defined using the formula (1).

$$H_{\mathrm{SRP}} = k_m (H_h + h_0 - h_\omega - h_{pr}), \tag{1}$$

where H_h – the height of the hump yard, m;

h_0 – specific energy of the car, which corresponds to the accepted speed of splitting up of the train V_0, kJ/kN;

$$h_0 = V_0^2 / 2 \cdot g^{/}, \tag{2}$$

h_ω – specific energy that is lost in the movement (under favourable weather conditions for a car rolling down) on the section from the hump apex to the end of the last retarder of the stock retarder position, kJ/kN;

$$h_\omega = 10^{-3} [(\omega_0 \pm \omega_{cв}) l + V_{SRP}^2 (0,56 \cdot n_{SRP} + 0,23 \cdot \sum \alpha_{SRP})], \tag{3}$$

ω_0 – the main specific free axle resistance with good running qualities (taken 0,5 N/kN);

ω_{aw} – specific air and wind resistance caused by moving a four-axle car weighing 981kN with favourable rated wind, kJ/kN;

l – distance from the hump apex to the end of the SRP, m;

V_{SRP} – mean value of the traverse speed of the wagon with good driving qualities on the mentioned section, m/s;

$n_{SRP}, \sum \alpha_{SRP}$ – respectively, the number of point switches and rotation angular sum en-route the car to the low-resistant track from the hump apex to the end of the SRP;

h_{pr} – profile height of the section from the end of the last retarder of the stock retarder position to the reference point, m;

$$h_{pr} = 10^{-3} i_{cn} \Delta l_{cn}, \tag{4}$$

i_{cn} – the average track gradient from the the end of the last retarder of the stock retarder position to the project reference point, ‰;

Δl_{cn} – from the the end of the last retarder of the stock retarder position to the project reference point, m;

k_m – magnification factor for minimum calculated power of the stock retarder position.

Thus, having analyzed the abovementioned and components in (1) we can claim that value H_{SRP} is directly proportional to the height of the hump, as the other components in (1) are either constant for a particular hump neck, or also directly depend on H_h. We know that

$$H_h = \sum_{j=1}^{n} L_j i_j , \tag{5}$$

where L_j, i_j – the length of the hump profile and gradient of its n-part respectively.

Thereby, in the final accounting, value H_{SRP} depends on the gradient values of the certain parts of hump yard profile, as their length is constant. So, in order to define the optimal required power of the stock retarder position of the hump yard it is necessary to define the optimal values of its profile elements gradient.

It is known that under weather conditions favorable for rolling

$$H_{SRP} = k_m((\sum_{j=1}^{n} L_j i_j + \Delta L_{mt} i_{mt}) \cdot 10^{-3} + \frac{V_0^2}{2 \cdot g^/} - (\omega_0 L_{HA-SRP} + V_{av(HA-SRP)}^2 (0{,}56 n_{HA-SRP} + \\ + 0{,}23 \sum \alpha_{HA-SRP})) \cdot 10^{-3} - (\Delta L_{mt} i_{mt}) \cdot 10^{-3}) \to H_{SRP(\min)}, \quad (6)$$

where n – the number of the elements of the slope profile (from the HP to the beginning of the SRP).

As every element of the profile consists of the technological elements we can state

$$V_{av(HA-SRP)}^2 (0{,}56 n_{HA-SRP} + 0{,}23 \sum \alpha_{HA-SRP}) = \sum_{i=1}^{m} (0{,}56 n_i + 0{,}23 \sum \alpha_i) V_{av(i)}^2, \quad (7)$$

where m – the number of technological elements.

Values $V_0, g^/, \omega_0, L_j, n_i, \sum \alpha_i$ for $j = 1,..., n$ and $i = 1,..., m$ are constant.

Let

$$\begin{aligned} & k_m = A, \\ & \frac{V_0^2}{2 \cdot g^/} - L_{HA-SRP} \omega_0 \cdot 10^{-3} = B, \\ & (0{,}56 \cdot n_i + 0{,}23 \cdot \sum \alpha_i) \cdot 10^{-3} = C_i, \end{aligned} \quad (8)$$

then

$$H_{SRP} = A(\sum_{j=1}^{n} (L_j i_j) \cdot 10^{-3} + B + \sum_{i=1}^{m} C_i V_{av(i)}^2) \to H_{SRP(\min)}. \quad (9)$$

The average speed of the car rolling down on i technological element is

$$V_{av(i)} = \frac{V_i^/ + V_{i-1}}{2}, \quad (10)$$

where $V_i^/$ – the car speed at the end of the i element at a first approximation (calculating $V_i^/$ we take into consideration only the specific resistances that do not depend on the average rolling speed on the technological element: the main ($\omega_{0(i)}$), caused by snow and hoarfrost ($\omega_{sh(i)}$) and braking ($\omega_{b(i)}$)), m/s.

$$V_i^/ = \sqrt{V_{i-1}^2 + 2 \cdot g^/ L_i (i_i - \omega_{0(i)} - \omega_{sh(i)} - \omega_{b(i)}) \cdot 10^{-3}}, \quad (11)$$

where L_i, i_i – the length and gradients of the *i* technological element respectively.

Since H_{SRP} is defined under conditions favourable for rolling, $\omega_{sh(i)} = 0$ and $\omega_{b(i)} = 0$.

Thus,

$$V_i^{/} = \sqrt{V_{i-1}^2 + 2 \cdot g^{/} L_i (i_i - \omega_{0(i)}) \cdot 10^{-3}}, \tag{12}$$

where V_{i-1} –speed at the end of $i-1$ element at a second approximation (taking into account $\omega_{sc(i-1)}$ and $\omega_{b(i-1)}$)

Consequently, the speed at the end of the first element

$$V_1 = \sqrt{V_0^2 + 2 \cdot g^{/} L_1 (i_1 - \omega_0 - \omega_{sc(1)} - \omega_{b(1)}) \cdot 10^{-3}}, \tag{13}$$

at the end of the second one

$$\begin{aligned} V_2 &= \sqrt{V_1^2 + 2 \cdot g^{/} L_2 (i_2 - \omega_0 - \omega_{sc(2)} - \omega_{b(2)}) \cdot 10^{-3}} = \\ &= \sqrt{V_0^2 + 2 \cdot g^{/} L_1 (i_1 - \omega_0 - \omega_{sc(1)} - \omega_{b(1)}) \cdot 10^{-3} + 2 \cdot g^{/} L_2 (i_2 - \omega_0 - \omega_{sc(2)} - \omega_{b(2)}) \cdot 10^{-3}}, \end{aligned} \tag{14}$$

at the end of the m-element

$$\begin{aligned} V_m &= \sqrt{\begin{aligned} &V_0^2 + 2 \cdot g^{/} L_1 (i_1 - \omega_0 - \omega_{sc(1)} - \omega_{b(1)}) \cdot 10^{-3} + 2 \cdot g^{/} L_2 (i_2 - \omega_0 - \\ &\omega_{sc(2)} - \omega_{b(2)}) \cdot 10^{-3} + \ldots + 2 \cdot g^{/} L_m (i_m - \omega_0 - \omega_{sc(m)} - \omega_{b(m)}) \cdot 10^{-3} \end{aligned}} = \\ &= \sqrt{V_0^2 + 2 \cdot g^{/} \cdot 10^{-3} \sum_{y=1}^{m} L_y (i_y - \omega_0 - \omega_{sc(y)} - \omega_{b(y)})}. \end{aligned} \tag{15}$$

Consequently, the speed at the beginning of $i-1$ element

$$V_{i-1} = \sqrt{V_0^2 + 2 \cdot g^{/} \cdot 10^{-3} \sum_{y=1}^{i-1} L_y (i_y - \omega_0 - \omega_{sc(y)} - \omega_{b(y)})}. \tag{16}$$

It is known that the average rolling speed on the technological element is essentially different from the actual average speed [1]

$$V_{av}^{a} = \frac{V_{beg} + \sum_{i=1}^{Z} \sqrt{V_{beg}^2 + 2 \cdot g^{/} L_i (i_i - \omega_0) / (1000 \cdot Z)}}{Z+1}, \tag{17}$$

where Z – the number of elementary sections, on which the technological element is subdivided (calculating V_{av}^{a}, the length of the elementary section is taken 0.5 m, that is $L/Z = 0{,}5$).

The average speed on the technological element is defined using the following formula:

$$V_{av(i)} = k_i V_{c(i)}^{/} \tag{18}$$

where $V_{c(i)}^{/}$ – the speed at a first approximation in the middle of the technological element

$$V_{c(i)}^{/} = \sqrt{V_{i-1}^2 + g^{/} L_i (i_i - \omega_0) \cdot 10^{-3}}\ , \tag{19}$$

k_i – correction factor.

We suggest defining the correction factor on the assumption of the equality of calculating errors for the average speed on technological elements, one of which is of infinitesimal length, that is why V_{av} on the given element can be taken as equal to V_{beg} , the second is 30 m long and is located on the gradient 50‰, consequently

$$V_{beg} - kV_{beg} = kV_c^{/} - V_{av}^{\phi}\,. \tag{20}$$

From the received equality

$$k = \frac{V_{beg} + V_{av}^{\phi}}{V_{beg} + V_c^{/}}\,. \tag{21}$$

The correction factor by different V_{beg} , showed that it can be set as an exponential function

$$k = -0{,}0576191 \cdot e^{-0{,}5710201 \cdot V_{beg}} + 0{,}9966873. \tag{22}$$

Inserting (18) in (9), we get

$$H_{SRP} = A(\sum_{j=1}^{n}(L_j i_j)\cdot 10^{-3} + B + \sum_{i=1}^{m} C_i k_i^2 (V_{i-1}^2 g^{/} L_i (i_i - \omega_0)\cdot 10^{-3}) \rightarrow H_{SRP(\min)}\,, \tag{23}$$

where

$$\begin{aligned} V_{i-1}^2 &= V_0^2 + 2\cdot g^{/}\cdot 10^{-3}\sum_{y=1}^{i-1}(L_y(i_y - \omega_0) - (0{,}56\cdot n_{s(y)} + 0{,}23\sum \alpha_y)k_y^2 \times \\ &\times (V_{y-1}^2 + g^{/} L_y (i_y - \omega_0)\cdot 10^{-3} - 1000\cdot h_{h(y)}) \end{aligned}\,. \tag{24}$$

Let

$$\begin{aligned} &C_i k_i^2 = D_i\,, \\ &V_{i-1}^2 - g^{/} L_i \omega_0 \cdot 10^{-3} = E_i\,, \\ &g^{/} L_i \cdot 10^{-3} = F_i\,, \\ &L_j / 1000 = G_j\,. \end{aligned} \tag{25}$$

Then

$$H_{SRP} = A(\sum_{j=1}^{n} G_j i_j + B + \sum_{i=1}^{m} D_i (E_i + F_i i_i)) \to H_{SRP(\min)}\,, \tag{26}$$

or

$$\begin{aligned} &H_{SRP} = A(B + ((G_1 i_1) + D_1(E_1 + F_1 i_1)) + ((G_2 i_2) + D_2(E_2 + F_2 i_2)) + \ldots + \\ &+ ((G_n i_n) + D_n(E_n + F_n i_n))) \to H_{SRP(\min)} \end{aligned}. \tag{27}$$

As every profile element consists of several technological elements, we can indicate:

$$\begin{aligned} &I_1 = i_j \text{, where } j = 1,\ldots,Z_1 \\ &I_2 = i_j \text{,where } j = Z+1,\ldots,Z_2 \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ &I_x = i_j \text{, where } j = Z_{x-1}+1,\ldots,Z_x\,. \end{aligned} \tag{28}$$

Here x - number of profile elements of the rolling part of the marshalling equipment, and $Z_1, Z_2, \ldots, Z_x$ - number of the last technological element of the first, second, x profile element respectively.

Thus, the objective function is as follows:

$$\begin{aligned} &H_{bmg} = A(B + (\sum_{j=1}^{Z_1} (G_j I_1 + D_j(E_j + F_j I_1)) + \sum_{j=Z_1+1}^{Z_2} (G_j I_2 + D_j(E_j + F_j I_2)) + \ldots + \\ &+ \sum_{j=Z_{x-1}+1}^{Z_x} (G_j I_x + D_j(E_j + F_j I_x)))) \to H_{bmg(\min)} \end{aligned}. \tag{29}$$

Minimization of the objective function is necessary by non-linear restriction-equalities:

$$\begin{aligned} &D_1 = f_{D_1}(V_0), E_1 = f_{E_1}(V_0) \\ &D_2 = f_{D2}(V_0, i_1), E_2 = f_{E_2}(V_0, i_1) \\ &D_3 = f_{D3}(V_0, i_1, i_2), E_3 = f_{E_3}(V_0, i_1, i_2) \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ &D_{Z_x} = f_{D_{Z_x}}(V_0, i_1, i_2, \ldots, i_{Z_{x-1}}), E_{Z_x} = f_{E_{Z_x}}(V_0, i_1, i_2, \ldots, i_{Z_{x-1}})\,, \end{aligned} \tag{30}$$

linear restriction-equalities:

$$\begin{cases} L_{run} = L_{calc} \\ H_{b(WG)}^{SRP} = 0 \\ V_{out}^{SRP} = 1,4 \end{cases}, \quad (31)$$

linear restriction-inequalities:

$$\begin{cases} -50 \le I_1 \le 50 \\ \dots\dots\dots\dots\dots\dots \\ -50 \le I_x \le 50 \\ I_1 - I_2 \le 25 \\ H_b^{SRP} \le n_y h_{ret} \\ V_{in}^{SRP} \le V_{in(\max)}^{SRP} \\ T_0 \le T_0^{\max} \end{cases}. \quad (32)$$

5. Conclusion

The problem researched in the article is an optimization problem with restrictions. It is impossible to turn this problem into the unconditional extreme problem [9]. Therefore, further researches are required to find a method, which will allow defining the minimum value H_{SRP} with the minimal enumeration of possible values $I_1, I_2, ..., I_x$. The solution of this problem will contribute to deciding the question of the integrated design of the height and longitudinal profile of hump yards to realize the gravitational target car braking technology with the minimally required power of the stock retarder position. In its turn, it will allow adjusting power inputs, which accompany the marshalling process, in accordance with the rate of yard operation.

References

[1] Berestov, I. V., Ohar, O. M., Akhiiezer, O. B., Kutsenko, M. Yu. (2009) "On the question of developing methods of complex calculation of optimal design parameters of sorting slides." *Eastern-European Journal of Enterprise Technologies* **2/3 (38)**: 56-60.
[2] Bobrovskyi, V. Y., Kolesnyk, A. Y., Dorosh, A. S. (2011) "Improving the design of the plan track downhill fillers." *Transport Systems and Transportation Technologies: Collection of Scientific Works of Dnepropetrovsk National University of Railway Transport named after Academician Lazaryan* **1**: 27-33.
[3] Mamaev, E. A. (2016) "The Variant of Design Development Decision and Technological Process of Hump Sorting Complexes." *International Journal of Applied Engineering Research* **11**: 11515-11524.
[4] Bessonenko, S. A. (2008) "Optimization the main parameters of hump yards." *Improving Railway Field Operation: Collection of Scientific Works*: 4-25.
[5] Kobzev, V. A. (2004) "Condition and prospects of developing brake hump technologies." *Automation, Connection, Informatics* **11**: 2 – 5.
[6] Shabelnikov, A. N. (2005) "Developing theories and methods of control automation of complex processes at railway yards." *Doctoral Thesis*: 344.
[7] Bobrovskyi, V. Y., Kozachenko, D. N., Bozhko, P. N, et.al. (2010) "Optimization of cut braking modes at hump yards." *Monograph*. Dnepropetrovsk.
[8] Ohar, O. M., Taratushka, K. V. (2015) "Research of efficiency of application of technology of gravitational-targeted inhibition of cuts." *Transport Systems and Transportation Technologies: Collection of Scientific Works of Dnepropetrovsk National University of Railway Transport named after Academician Lazaryan* **9**: 49–56.
[9] Hemdy, A. Taha. (2007) *Introduction to operation research*. Saint Petersburg.