Indicators of transport logistics of locomotives of diesel traction on Kattakurgan-Navoi section in operation

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Abstract. The subject of these studies is the assessment of the fuel and energy efficiency of using locomotives of diesel traction in various conditions for organizing the operational activities of railways with the third type of track profile. The purpose of the study: to substantiate the logistic parameters of the main indicators of the transport logistics of freight trains and the transportation work of three-section main (train) freight diesel locomotives of the 3*TE*10*M* series on the real hilly-mountainous section of Kattakurgan - Navoi of the railway line of the Samarkand - Navoi - Bukhara of the Uzbek railway. Research criterion: the value of the kinematic parameters of the movement of freight trains and the parameters of the main indicators of the energy efficiency of the studied diesel locomotives of the 3*TE*10*M* series in quantitative and monetary terms. The author obtained various trajectories of the speed and time of the train, tables, and graphs of logistic kinematic parameters for two types of movement of a freight train with different masses of trains and parameters of the main indicators of the energy efficiency of the studied diesel locomotive for three options for traction calculation on the hilly-mountainous section of Kattakurgan - Navoi of the Uzbek Railway roads. Also, the author compiled the corresponding regression equations for calculating the values of the mentioned logistic parameters, taking into account the dynamics of change and the rate of increase or decrease in the accepted range of fluctuations in the mass of freight trains, and set differentiated standards of consumption of full-scale diesel fuel for each stop of the freight train. The results of the study can be used by specialists in the operation shop of the Bukhara locomotive depot to develop diesel fuel consumption standards for diesel locomotives of the *3TE*10*M* series and substantiate the traction quality of the track profile on the hilly-mountainous railway direction Samarkand - Navoi - Bukhara of the Uzbek railway.

1 Introduction

A general increase in the volume of freight traffic and a reduction in the time of delivery of goods provide an increase in the throughput and carrying capacity of railways, the quantitative and qualitative level of which, in turn, directly depends on the efficiency of

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using traction rolling stock, including for diesel, in operating conditions.

Therefore, the assessment of the fuel and energy efficiency of the use of mainline (train) freight locomotives of diesel traction in a variety of conditions for organizing the operational activities of railways is a timely and urgent task of Joint-Stock Company (JSC) "O'zbekiston temir yo'llari".

This task is implemented by introducing energy-saving technologies for the economical use of fuel and energy resources for train traction by increasing the efficiency of transportation work and the operational reliability of locomotives, taking into account traffic safety along the route of the rolling stock.

Let us consider the results of some studies aimed at studying the traction and energy efficiency of using locomotives, considering the development of recommendations and measures for implementing this efficiency in various operating conditions.

In the study [1], the author proves that the efficiency of electric locomotives under operating conditions is increased by improving the qualitative component of transient processes occurring in their electromagnetic systems.

Recommendations on the economic use of fuel and energy resources for train traction in freight traffic for diesel locomotives and locomotives with hybrid traction are studied in [2-4].

The results of theoretical and experimental studies of the authors of works [5-8] on increasing the wear resistance of 20*GL* structural alloy steel by improving the mechanical properties made it possible to reduce failures due to failure of critical units of locomotives, passenger and freight railway cars under operating conditions.

The authors of studies [9-11] propose various optimization models for railway transport in automatic control systems for traction converters of electric locomotives and the organization of regenerative braking by high-speed passenger trains.

Articles [12-15] present the results of the study of residual stresses, fractography, and metallography, taking into account axial fatigue tests of the electrically conductive material made of the Inconel® 718 alloy, which is based on nickel, with various parameters of electroerosive processing with copper, brass and copper-tungsten electrodes.

The authors of studies [16, 17] propose to increase the operational reliability of a turbojet engine by increasing the fatigue life of the high-pressure turbine blades and disks, taking into account the improvement in the protection of their surface.

In the works of the authors [18, 19], the results of a study of the thermodynamic cycle of a stationary turbojet engine are presented to obtain quantitative indicators and characteristics of the processes of fuel injection and combustion.

Analysis of the results of the presented studies [1-19] indicates a fairly high degree of their scientific and practical significance; however, they do not affect questions about the transport logistics of the transportation process on the hilly - mountainous sections of the railways for the locomotive fleet of JSC "O'zbekiston temir yo'llari" using the main logistics indicators transport energy.

2 Objects and methods of research

Now, the replenishment of the operating fleet of diesel traction locomotives on the Uzbek railway is being implemented through a phased deep modernization of the existing mainline (train) diesel locomotives of the *TE*10*M* series by replacing the 10*D*100 diesel engine with the "new" progressive diesel engine 1A-5*D*49 of the Kolomna Diesel Locomotive Plant [20].

However, approximately seventy percent [21] of all mainline (train) locomotives of diesel traction JSC "O'zbekiston temir yo'llari" still fall on the mainline (train) freight diesel locomotives of the *TE*10*M* series in various sectional designs.

The present studies were carried out for three-section mainline (train) freight diesel locomotives of the 3*TE*10*M* series when driving freight trains with different masses of compositions on the real section of the Kattakurgan – Navoi of the Uzbek railway.

Here, the author relied on the recommendations [22] of the theory of locomotive traction and the algorithm developed him [20] for the implementation of the task, taking into account the initial data, the accepted straightened profile of the path of the specified section of the railway under study, the object and subject of research. And as a research criterion, the author used the logistic parameters of the main indicators of transport logistics - the kinematic parameters of the movement of freight trains and the energy efficiency indicators of the mentioned diesel locomotives in quantitative and monetary terms.

The object of the study is freight trains with different weights of trains, three-section mainline (train) freight diesel locomotives of the 3TE10*M* series, and a straightened track profile of the hilly-mountain railway section Kattakurgan - Navoi "O'zbekiston temir yo'llari" JSC.

The subject of the study is the logistical parameters of the main indicators of transport logistics of the above freight trains and of the 3*TE*10*M* diesel locomotives on the real section Kattakurgan - Navoi of the hilly-mountainous direction Marokand - Navoi of the Uzbek railway.

A characteristic design feature of three-section mainline (train) freight diesel locomotives of the 3TE10*M* series is the use of a unified microprocessor-based system for diesel locomotive automation (*US of DLA*-75-02), an integration of complex locomotive safety device (*CLSD-U*) and a unified control panel (*UCP*), taking into account the changes made to the interface connections and control panels for each section, as well as start-up preparation systems, diesel start-up, and fire alarm systems.

We present the characteristics of the track profile of the given railway section Kattakurgan - Navoi of the hilly-mountainous direction Marokand - Navoi "O'zbekiston temir yo'llari" JSC.

The length of the Kattakurgan-Navoi railway section is 78.75 kilometers. This section, which is an integral part of the real hilly-mountainous section of the Uzbek railway, contains 41 elements, of which twenty-six and thirty-two elements of the railway tracks are characterized by a change in the steepness, respectively, of ascents from +0.14 ‰ to +5.77 ‰ and descents from -0.12 ‰ to -5.37 ‰, and three "sites" - Ziyovuddin and Navoi stations, Sidding No. 33.

The railway section Kattakurgan - Navoi has two intermediate stations (st. Zirabulak and st. Ziyovuddin) and six separate points - sidings (Sidings No. 28, No. 29, No. 30-33), where the limits speed are V^{lim} = 60 km / h (st. Kattakurgan, st. Zirabulak, Siddings No. 28,29) and V^{lim} = 40 km/h (st. Ziyovuddin). The Kattakurgan hauls - Siddings No. 28 has two limits speed of V^{lim} = 80 km/h, and the highest permissible speed of a freight train on the specified section is V^{max} = 90 km/h.

3 Results and their discussion

Table 1 presents the results of a complex (series) of traction calculations to justify the indicators of transport logistics - the kinematic parameters of the movement of freight trains and the parameters of the main indicators of the transportation work of three-section main (train) freight of 3*TE*10*M* diesel locomotives on the Kattakurgan - Navoi section when freight trains move with stops and without stops at intermediate stations and sidings. Here, also, the average and average values of the parameters of the above-mentioned main indicators of transport logistics for two (both) types of traffic are indicated, while the average values were determined (calculated) as arithmetic averages in the range of changes in the composition mass of freight trains accepted by the author, namely: from Q_1 = 2500 t to Q_3 = 3500 t.

Table 1. Parameters of indicators of transport logistics of freight trains and of 3*TE*10*M* diesel locomotives on Kattakurgan - Navoi section of Uzbek railway

option of traction of calculation	Conditions of the transportation process			Train movement time, min		
	mass of composition Q, t	number of axles m, axles	technical speed of movement V_t, km/h	general, $t_{t\,tr}$	in taction mode t_{tr}	in idling and braking mode, $t_{id,br}$
1	2	3	4	5	6	7
Movement on the hauls of the section without stops						
Kattakurgan – Siding № 28 haul, L = 11.25 km (11.269 km)						
1	2500	200	63.19	10.70	3.60	7.10
2	3000	200	61.47	11.00	3.40	7.60
3	3500	200	63.49	10.65	4.00	6.65
Siding № 28 – Zirabulak haul, L = 16.85 km (17.641 km)						
1	2500	200	71.52	14.80	8.30	6.50
2	3000	200	68.91	15.60	9.55	6.05
3	3500	200	68.73	15.40	10.80	4.60
Zirabulak – Ziyovuddin haul, L = 27.15 km (26.729 km)						
1	2500	200	82.24	19.50	5.90	13.60
2	3000	200	84.41	19.00	5.90	13.10
3	3500	200	81.82	19.60	6.50	13.10
Ziyovuddin – Navoi haul, L = 23.50 km (23.693 km)						
1	2500	200	84.12	16.90	5.25	11.65
2	3000	200	85.12	16.70	5.15	11.55
3	3500	200	84.61	16.80	5.40	11.40
Movement on the Kattakurgan – Navoi section, L = 78.75 km (79.332 km)						
1	2500	200	76.90	61.90	23.05	38.85
2	3000	200	76.40	62.30	24.00	38.30
3	3500	200	76.22	62.45	26.70	35.75
Averages values			76.51	62.22	24.58	37.64
Movement on the hauls of the section with stops						
Kattakurgan – Siding № 28 haul, L = 11.25 km (11.269 km)						
1	2500	200	58.29	11.60	4.80	6.80
2	3000	200	56.82	11.90	4.90	7.00
3	3500	200	58.04	11.65	5.70	5.95
Siding № 28 – Zirabulak haul, L = 16.85 km (17.641 km)						
1	2500	200	68.99	24.80	7.50	17.30
2	3000	200	66.83	25.60	8.15	17.45
3	3500	200	65.93	25.95	8.35	17.60
Zirabulak – Ziyovuddin haul, L = 27.15 km (26.729 km)						
1	2500	200	72.57	22.10	6.40	15.70
2	3000	200	70.34	22.80	6.80	16.00
3	3500	200	69.72	23.00	7.40	15.60

Continuation of table № 1.

Ziyovuddin – Navoi haul, L = 23.50 km (23.693 km)						
1	2500	200	74.44	19.10	7.50	11.60
2	3000	200	69.68	20.40	8.55	11.85
3	3500	200	66.74	21.30	9.50	11.80
Movement on the Kattakurgan – Navoi section, L = 78.75 km (79.332 km)						
1	2500	200	68.49	69.50	26.80	42.70
2	3000	200	65.29	72.90	29.50	43.40
3	3500	200	65.07	73.15	32.70	40.45
Averages values			71.39	67.03	27.12	39.91
Values for two types of movement						
Averaged values on the section Kattakurgan - Navoi, L = 78.75 km (79.332 km)						
1	2500	200	72.69	65.70	24.92	40.8
2	3000	200	70.84	67.60	26.75	40.8
3	3500	200	70.64	67.80	29.70	38.1
Averages values			71.39	67.03	27.12	39.91

Continuation of table № 1.

option of traction of calculation	Diesel fuel costs				
	in quantitative terms			in terms of money	
	general	specific			
	per trip E, kg	of natural fuel e, kg/10^4 tkm brutto	of conditional fuel e_{sp}, kg/10^4 tkm brutto	full $C_{d.f.}$, thousand soums	specific $c_{d.f.}$, thousand soums /km
1	8	9	10	11	12
Movement on the hauls of the section without stops					
Kattakurgan – Siding № 28 haul, L = 11.25 km (11.269 km)					
1	98.814	35.07	50.15	174.94	15.524
2	94.344	27.91	39.91	167.03	14.822
3	108.38	27.48	39.29	191.88	17.027
Siding № 28 – Zirabulak haul, L = 16.85 km (17.641 km)					
1	216.57	49.11	70.22	383.43	21.735
2	247.56	46.78	66.89	438.29	24.845
3	277.40	44.93	64.25	491.12	27.840
Zirabulak – Ziyovuddin haul, L = 27.15 km (26.729 km)					
1	164.18	24.57	35.13	290.67	10.874
2	163.61	20.40	29.18	289.66	10.837
3	178.73	19.10	27.32	316.43	11.838
Ziyovuddin – Navoi haul, L = 23.50 km (23.693 km)					
1	145.58	24.58	35.14	257.74	10.878
2	142.29	20.11	28.76	251.92	10.632
3	149.08	17.98	25.71	263.94	11.140

Continuation of table № 1.

Movement on the Kattakurgan – Navoi section, *L* = 78.75 km (79.332 km)					
1	625.15	31.52	45.07	1106.8	13.951
2	648.46	27.25	38.96	1148.1	14.472
3	713.59	25.70	36.75	1263.4	15.925
	662.4	28.16	40.26	1172.77	14.783
Movement on the hauls of the section with stops					
Kattakurgan – Siding № 28 haul, *L* = 11.25 km (11.269 km)					
1	128.71	45.69	65.33	227.87	20.221
2	131.46	38.88	55.61	232.74	20.653
3	150.42	38.14	54.54	266.31	23.632
	Siding № 28 – Zirabulak haul, *L* = 16.85 km (17.641 km)				
1	208.72	29.28	41.87	369.53	12.959
2	225.27	26.33	37.66	398.83	13.987
3	230.48	23.09	33.02	408.05	14.311
	Zirabulak – Ziyovuddin haul, *L* = 27.15 km (26.729 km)				
1	179.18	26.81	38.34	317.23	11.868
2	189.60	23.64	33.81	335.68	12.558
3	204.26	21.83	31.22	361.63	13.529
Ziyovuddin – Navoi haul, *L* = 23.50 km (23.693 km)					
1	202.22	34.14	48.82	358.02	15.111
2	228.97	32,21	46.06	405.38	17.110
3	252.85	30,49	43.60	447.7	18.894
Movement on the Kattakurgan – Navoi section, *L* = 78.75 km (79.332 km)					
1	724.04	36.51	52.20	1281.9	16.158
2	792.88	33.31	47.64	1403.7	17.947
3	870.15	31.34	44.81	1540.5	19.419
	729.04	30.94	44.24	1290.42	16.819
Values for two types of movement					
Averaged values on the section Kattakurgan - Navoi, *L* = 78.75 km (79.332 km)					
1	674.59	34.01	48.63	1194.35	15.054
2	720.67	30.28	43.30	1275.90	16.209
3	791.87	28.52	40.78	1401.95	17.672
Averages values	729.04	30.94	44.24	1290.73	16.312

The assessment of the energy efficiency of the use of the studied 3*TE*10*M* diesel locomotives is carried out by comparing the average values logistic parameters of the indicated main indicators of transport logistics, obtained with different types of freight train traffic on the real hilly-mountainous section Kattakurgan - Navoi of the Uzbek railway.

From the analysis of the data in Table 1, it can be seen that the movement of freight trains, organized by the mentioned diesel locomotives without stops at intermediate stations and sidings of the Kattakurgan - Navoi section, about a similar movement with stops at them, provides:

- a decrease in the total travel time of the train by 4.81 minutes with an average estimated time per stop of approximately 1.20 minutes and an increase in the technical speed of movement by 5.12 km/h;
- the values of the shares of movement on modes traction at 39.50 percent and idling and braking at 60.50 percent;
- decrease or increase, respectively, of the values of the shares of movement on modes traction, as well as idling and braking, by approximately 0.96 percent;
- reduction of the total (full) and specific consumption of full-scale diesel fuel for train

traction per trip, respectively, on average, by approximately 9.14 and 8.98 percent;

- total (full) and specific consumption of full-scale diesel fuel per stop, respectively, approximately 22.21 kg and 0.927 kg / 10^4 t km gross;
- reduction in the specific consumption of standard diesel fuel for train traction per trip, on average, by approximately 8.96 percent;
- specific consumption of conventional diesel fuel per stop, approximately 1.327 kg / 10^4 t km gross;
- reduction of total and reduced unit monetary costs, respectively, by 117.96 thousand soums (or 9.14 percent) and by 1.529 thousand soums / km (or 9.37 percent).

An analysis of the averaged values of the logistic parameters of the transportation work of freight diesel locomotives $3TE10M$ relative to the same data for a freight train with a unified mass Q_2 = 3000 tons and the number of axles m = 200 axles in the composition showed the following.

1. The average total train travel time is approximately 1.16 h, and a decrease in the mass of the train by ΔQ = 500 t leads to a decrease in the total travel time of the train by approximately 2.81 percent and with an increase in the mass of the train by ΔQ = 500 t there is an increase in this time by 0.296 percent.
2. The technical speed of the train, with a similar change in the mass of the train, tends to increase and decrease, respectively, by 2.57 and 0.282 percent, and, on average, it is approximately 71.39 km/h.
3. The total and specific average consumption of full-scale diesel fuel for train traction is, respectively, 729.04 kg and 30.94 kg/10^4 t km gross (or standard diesel fuel 44.24 kg/10^4 t km gross).
4. Reducing the mass of the composition by approximately 20 percent helps to reduce the total consumption of natural diesel fuel by 6.39 percent; however, the specific consumption of natural diesel fuel increases by 12.32 percent. An increase in the mass of the composition by approximately 20 percent provides an increase in the total and a decrease in the specific consumption of full-scale diesel fuel by 9.88 and 5.81 percent, respectively.
5. Reducing the mass of the composition by approximately 20 percent leads to a decrease and increase in the use of traction modes, as well as idling and braking [23], respectively, by 0.36 percent, and with an increase in the mass of the composition by approximately 20 percent, on the contrary, increase and decrease of these indicators by 4.23 percent.
6. An increase of the composition mass by approximately 20 percent leads to an increase in the total and specific monetary costs per quantity of natural diesel fuel consumed by an average of 9.88 and 9,02 percent, and with a decrease of the composition mass by approximately 20 percent, these indicators decrease by an average of 6.39 and 7,12 percent.

Based on the *Microsoft Excel Office* environment, the author obtained analytical expressions (regression equations) designed to calculate the average values of the parameters mentioned above of the main indicators of transport logistics for real conditions for organizing freight traffic on a given (accepted) real railway section Kattakurgan - Navoi, implemented by three-section main lines (train) freight diesel locomotives of the $3TE10M$ series of any i - th mass of the composition Q_i of a freight train with a sufficient value of the approximation reliability R^2 = 1.0 (the necessary reliability condition is $R^2 \geq 0.8$). Here the factor (indicator) Q_i = 1, 2, 3 is a variant of a series (complex) of traction calculation.

Total train travel time $t_{t\,tr}$, min:

$$t_{t\,tr} = -0.85Q_i^2+4.454Q_i+62.10 \qquad (1)$$

Train travel time in mode traction t_{tr}, min:

$$t_{tr} = 0.56Q_i^2 + 0.15Q_i + 24.21 \quad (2)$$

Train running time at idle and braking modes $t_{id.,br}$, min:

$$t_{id,br} = -1.41Q_i^2 + 4.3Q_i + 37.889 \quad (3)$$

Technical speed of the train V_t, km/h

$$V_t = 0.8254Q_i^2 - 4.325Q_i + 76.19 \quad (4)$$

Total natural diesel fuel consumption per trip E, kg:

$$E = 2.96Q_i^2 - 40.07Q_i + 525.5 \quad (5)$$

Specific consumption of natural diesel fuel e, kg / 10^4 t km brutto:

$$e = 0.985Q_i^2 - 6.685Q_i + 39.75 \quad (6)$$

Specific consumption of conventional diesel fuel $e_{sp,}$ kg / 10^4 t km brutto:

$$e_{sp} = 1.405Q_i^2 - 9.545Q_i + 56.77 \quad (7)$$

Total cash costs $C_{d.f}$, thousand soums:

$$C_{d.f} = 22.25Q_i^2 + 14.8Q_i + 1157.37 \quad (8)$$

Specific cash costs c_{t}, thousand soums / km:

$$c_{d.f} = 0.154Q_i^2 + 0.693Q_i + 14.207 \quad (9)$$

Table 2 shows the values of the kinematic parameters of the movement of freight trains and of the parameters of energy efficiency of the use of three-section mainline (train) freight diesel locomotives 3*TE*10*M*, obtained in the form of distributed values on each specific of one stop of an intermediate separate point (station or siding).

The lower part of the table shows the rates of change (increase or decrease) of the indicated values obtained by the author within the accepted differentiation by the value ΔQ = 500 tons of mass of trains (from Q_1 = 2500 tons to Q_3 = 3500 tons) of a freight train on the investigated section Kattakurgan - Navoi directions Samarkand - Navoi - Bukhara in quantitative and monetary terms. Moreover, the calculated average values are the arithmetic mean magnitudes.

In Table 2, the negative sign (minus) characterizes only a decrease in the technical movement speed of a freight train in the process of increasing the mass of its composition and nothing more; that is, this sign indicates (means) only a decrease the mentioned speed and does not affect the values of its absolute magnitude.

Table 2. Dynamics of parameters of main indicators of transport logistics of freight trains and diesel locomotives 3TE10M on section Kattakurgan - Navoi, L = 78.75 km

option of traction of calculation	Conditions of the transportation process		Kinematic motion parameters of freight train on the one stop			
	mass of composition Q,t	number of axles in composition m, axles	Speed motions	Train movement time, min/stop		
			technical speed ΔV_t, km/h:stop	general, $\Delta t_{t\ vr}$	in taction mode, Δt_{tr}	in idling and braking mode, $t_{id,br}$
1	2	3	4	5	6	7
Efficiency indicators of the 3*TE*10*M* diesel locomotives per one stop of a freight train						
1	2500	200	-2.102	1.900	0.937	0.963
2	3000	200	-2.777	2.650	1.375	1.275
3	3500	200	-2.787	2.675	1.500	1.175
Averages values			-2.555	2.408	1.271	1.137
The rate of change in the values of the parameters of efficiency of use, of investigated diesel locomotives						
1	2500	200	0.891	1.123	1.163	1.099
2	3000	200	0.854	1.170	1.229	1.133
3	3500	200	0.853	1.171	1.225	1.131
Averages values			0.866	1.155	1.206	1.121

Continuation of table № 1.

Quantitative and cost indicators of energy efficiency				
consumption diesel fuel in quantitative terms			consumption diesel fuel in cash costs	
general	specific			
per trip ΔE, kg/stop	of natural fuel Δe×10, kg/10^4 tkm brutto:stop	of conditional fuel Δe_{sp}×10, kg/10^4 tkm brutto:stop	full $\Delta C_{d.f}$, thousand soums /stop	specific $\Delta c_{d.f\,T}$×10, thousand soums /km:stop
8	9	10	11	12
Efficiency indicators of the 3*TE*10*M* diesel locomotives per one stop of a freight train				
24.722	12.47	17.82	43.775	5.52
36.105	15.15	21.70	63.900	7.56
39.140	14.10	20.15	69.275	8.73
33.322	13.91	19.89	58.983	7.27
The rate of change in the values of the parameters of efficiency of use, of investigated diesel locomotives				
1.158	1.158	1.158	1.158	1.158
1.223	1.223	1.223	1.223	1.223
1.213	1.213	1.213	1.213	1.213
1.165	1.165	1.165	1.165	1.165

Fig. 1 and Fig. 2 show, obtained by the author, the dynamics of the main indicators of the transport logistics of freight trains with different masses of trains and the efficiency of the transportation work of diesel locomotives 3*TE*10*M* in the organization of railway transportation of goods on the hilly-mountainous by section of Kattakurgan - Navoi "Uzbekiston temir yullari" JSC depending on the mass of the freight trains. The numerical values of these logistic indicators are reduced values, that is, such values, which are evenly distributed along the entire length of the studied section of the railway and fall on each kilometer of the railway track.

In these figures, along the abscissa axis, the values of the mass of the composition of freight trains are plotted in the accepted (given) range of their fluctuations from Q_1 = 2500 t to Q_3 = 3500 t, and along the ordinate axis, the parameters of logistic indicators have the following designations: ΔV_t – technical speed of movement, km/h:stop·km; train running time, min/stop·km - general $\Delta t_{t\ tr}$, in traction mode Δt_{tr}, in idling and braking mode $\Delta t_{id\ br}$ (Figure 1) и diesel fuel of consumption - per trip ΔE, kg/stop·km; natural Δe and conditional Δe_{sp}, kg/10^4 t km brutto:stop·km; cash outlays - fulls $\Delta C_{d\ f}$, thousand soums /stop·km and specific $\Delta c_{cd\ f}$, thousand soums /km:stop thousand soums /km:stop (Figure 2).

For greater clarity and better illustration of the diagrams in Fig. 1, the magnitude of the travel time of a freight train in the mode traction is increased by 1.5 times, and in Fig. 2, values of total ΔE, specific Δe and conditional Δe_{sp} diesel fuel consumption are increased by 1.5 times, 2 times and 4 times, respectively.

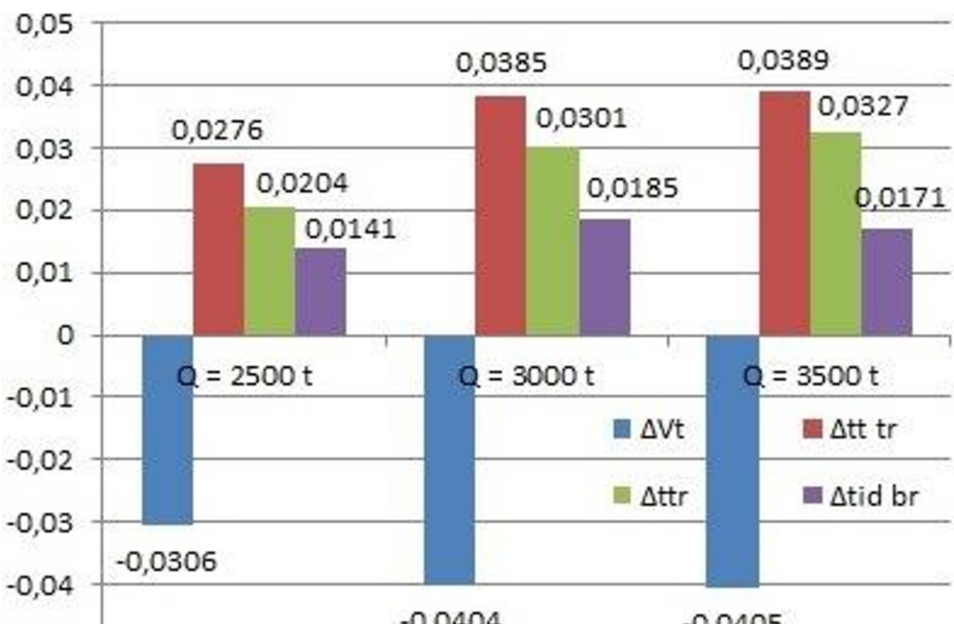

Fig. 1. Diagram of indicators of transport logistics of movement of freight train on section Kattakurgan – Navoi

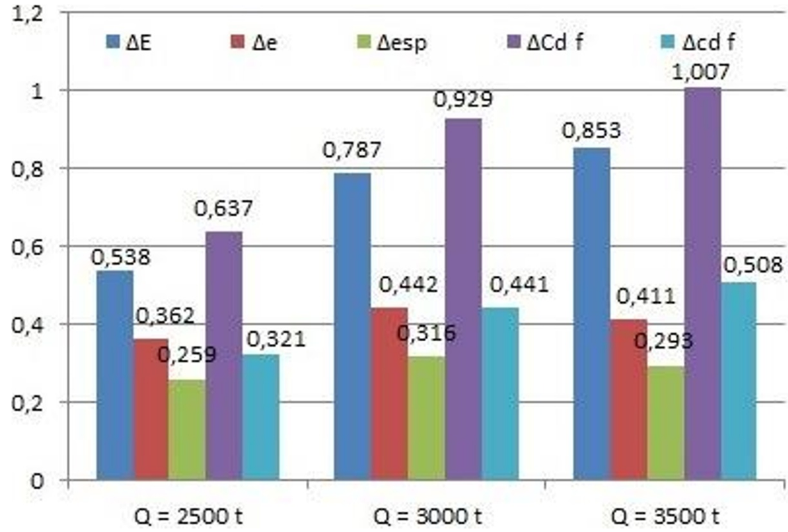

Fig. 2. Diagram of logistic indicators of energy efficiency of 3*TE*10*M* diesel locomotives on section Kattakurgan – Navoi

Graphical dependences of the rate of change (increase or decrease) of the values of logistic parameters of the indicators of transport logistics of the movement of freight trains and the energy efficiency of the use of the studied diesel locomotives 3*TE*10*M* on the Kattakurgan - Navoi section are shown in fig. 3, where are the following designations: ΔV_t – technical speed of movement, km/h:stop·km; train running time, min/stop·km - general $\Delta t_{t\ tr}$, in traction mode Δt_{tr}, in idling and braking mode $\Delta t_{id\ br}$, and also ΔE – quantitative and cost parameters of the energy efficiency of the studied diesel locomotives, kg/stop·km.
For a more compact image and a qualitative illustration of the graphical dependencies presented in Fig. 3, the value of the quantitative and cost parameters of the energy efficiency of the studied diesel locomotives ΔE was reduced by 1.2 times.

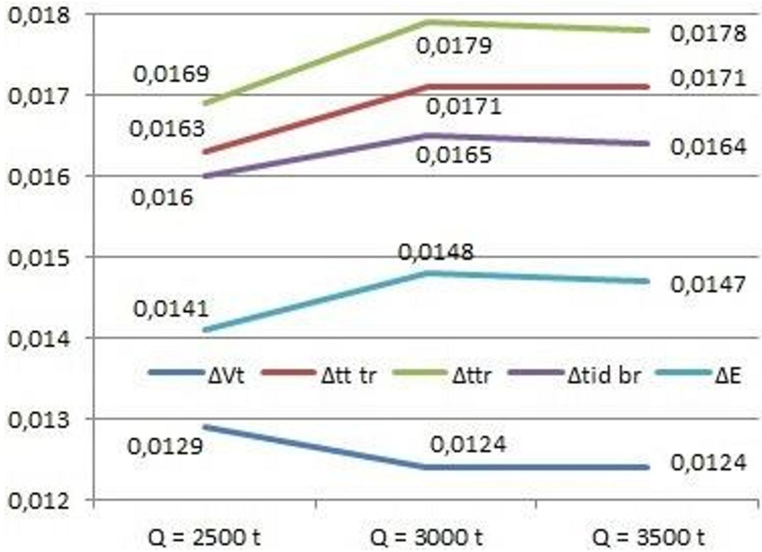

Fig. 3. Rate of changes in the parameters of the efficiency of transport logistics of diesel locomotives of the 3*TE*10*M* on the section Kattakurgan – Navoi

Analysis data table 2 and diagrams of the rate of increase - decrease of the logistic indicators of the efficiency of diesel locomotives 3TE10M on the Kattakurgan - Navoi section allow the author to affirmatively state the following.
1. An increase in the mass of a freight train indicates:
- the rate of change of the parameters mentioned above is the same for all quantitative and cost energy indicators of efficiency of use and does not depend on their type or type, taking into account the increase in the range from 1.158 to 1.213 units;
- a decrease in the technical speed V_t of a freight train occurs at a rate of decrease, the value of which varies from 0.891 (Q_1 = 2500 t) to 0.853 (Q_3 = 3500 t) units;
- the average values of the rate of increase in the time of the movement of freight trains for different modes of operation of the power plants of the studied diesel locomotives range from 1.206 (traction mode) units to 1.121 (idling and braking mode) units, and for the total time of train movement along the section they are 1,155 units.
2. Reducing the mass of a freight train provides:
- the same growth rates of the mentioned parameter values for all types (types) of quantitative and cost energy indicators of efficiency of use, as in the case of an increase in the mass of a freight train, with a reduction interval from 1.213 to 1.158 units, and for the mass of the composition Q_2 = 3000 tons, the increase is 1.223 units;
- an increase in the technical speed V_t of a freight train with a rate of increase, the value of which ranges from 0.853 (Q_3 = 3500 t) to 0.891 (Q_1 = 2500 t) units;
- the rate of change in the time of the movement of freight trains in the modes of traction, idling, and braking and the total time of movement of the train along the studied section for the mass of the train Q_1 = 2500 tons decreases, respectively, by 5.06, 2.83 and 4.10 percent;
- the rate of change in the time of the movement of freight trains in the modes of idling, braking, and traction for the mass of the train Q_2 = 3000 tons increases by 0.33 and 0.18 percent, except the total time of movement of the train along the studied section, the indicated rate of change of which decreases by only 0.08 percent.
The dynamics of the average of logistic parameters of the main indicators of the efficiency of the use of the studied 3*TE*10*M* diesel locomotives on the hilly-mountainous section of Kattakurgan - Navoi of the Uzbek railway, depending on the change in the mass of the freight train, is described by polynomials of the second degree.
For each, one stop of a freight train, the following data are obtained:
- the value of the total and specific consumption of full-scale diesel fuel is, respectively, 24.72 kg and 1.25 kg/10^4 t km gross (Q_1 = 2500 t), 36.18 kg and 1.51 kg/10^4 t km gross (Q_2 = 3000 t) and 39.14 kg and 1.41 kg/10^4 t km gross (Q_3 = 3500 t);
- the rate of increase (decrease) of the mentioned costs of diesel fuel with each successive increase in the mass of the composition by a fixed value ΔQ = 500 t changes approximately 1.46 (0.121) times - from Q_1 = 2500 t to Q_2 = 3000 t and 1.08 (0.934) times - from Q_2 = 3000 tons to Q_3 = 3500 tons;
- the average value of the total (full) and specific consumption of full-scale diesel fuel for train traction per one kilometer of the railway track is, respectively, 0.314 kg/km and 0.158 kg/10^4 t km gross: km (Q_1 = 2500 t); 0.459 kg/km and 0.192 kg/10^4 t km gross: km (Q_2 = 3000 t); 0.497 kg/km and 0.179 kg/10^4 t km gross: km (Q_3 = 3500 t).

4 Conclusions

1. As a result of modeling the transportation process and performing traction calculations, the author obtained various trajectories of the speed and travel time of the train, which made it possible to substantiate the logistical parameters of the main indicators of transport logistics for freight trains and diesel locomotives 3*TE*10*M* on a real, hilly-mountainous section of the Uzbek railway.

2. Logistic indicators of the movement of freight trains with different masses of trains and the transportation work of the studied diesel locomotives $3TE10M$ on the real, hilly-mountainous section of Kattakurgan - Navoi of the Uzbek railway were obtained in the form of tabular data and of graphical dependencies.
3. It is proved that the obtained regression equations and the dynamics of changes in the values of the logistic parameters of the main indicators of the transport logistics of the transportation process, depending on the mass of the freight train, are described by a second degree polynomial.
4. Are substantiated of the values of the rate of increase or decrease of the logistic parameters of the indicators of transport logistics of the movement of freight trains and the energy efficiency of the studied of diesel locomotives $3TE10M$ on the Kattakurgan - Navoi section of the Uzbek railway.
5. The numerical values of the differentiated rate of full and specific consumption of full-scale diesel fuel for each freight train stop for the accepted range of changes in the mass of the train are established.
6. The results of the study obtained by the author are recommended for practical use by specialists in the locomotive complex to substantiate the traction quality of the track profile of hilly-mountain railway sections, including Uzbek ones.

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