Logistic indicators of locomotives of diesel traction on high-speed section of the railway

Oleg Ablyalimov*, and *Nikolay* Julenev

Tashkent State Transport University, Tashkent, Uzbekistan

Abstract. The results of a theoretical study evaluating the effectiveness of using Uzbek diesel locomotives of the *UzTE*16*M*3 series during the non-stop movement of freight trains on the hilly-mountainous high-speed section Marokand - Kattakurgan of the Uzbek railway are presented. The reference point for the implementation of this assessment was the mathematical model of the movement of a freight train developed by the authors and the algorithm for performing traction calculations, which are prerequisites for substantiating the numerical values of the parameters of the logistic indicators for the process of railway transportations of goods in real conditions of the organization of operation. The authors obtained the parameters of logistics indicators in the form of numerical tabular values and graphical dependencies, and the corresponding regression equations were proposed to calculate the indicators of transport logistics. The data obtained by the authors can be used by specialists of the locomotive depots "O'zbekiston temir yo'llari" JSC, whose production activities are related to the issues of forecasting and normalizing the consumption of full-scale diesel fuel by diesel locomotives on the hilly-mountainous, of hi high-speed sections of the Uzbek railways.

1 Introduction

At present, the high-speed passenger railway of Uzbekistan, with a total length of 741 km, consisting of three high-speed sections Tashkent - Samarkand, Samarkand - Karshi, and Samarkand - Bukhara, is served by six «Afrosiyob» electric trains and passes through seven regions of the republic, connecting such largest cities like Tashkent, Samarkand, Bukhara, Karshi and Navoi.

In addition, at the indicated high-speed sections of the railway industry of Uzbekistan, passenger and freight rail transportation are carried out by diesel and electric locomotives in various sectional designs.

At the current time, "O'zbekiston temir yo'llari" JSC has actively replenished the operated fleet of the locomotives diesel traction through the implementation of a phased deep modernization of several existing mainline (train) freight diesel locomotives of the *TE*10*M* series by replacing the 10*D*100 diesel engine with a "new" progressive diesel engine 1*A*-5*D*49 PA "Kolomensky Diesel Locomotive Plant" [1].

*Corresponding author: o.ablyalimov@gmail.com

Analysis of the data [2] shows that approximately 52.6 percent of all sections of the operated locomotives of Uzbekistan Temir Yollari JSC are mainline (train) freight locomotives of diesel traction in various sectional designs, while about 30.0 percent are three-section diesel locomotives UzTE16M3 with V-shaped types of diesel.

Research on improving the efficiency of locomotives of electric and diesel traction in real conditions of organizing various types of traffic on high-speed sections of railways is the primary task of the energy efficiency of the mainline traction rolling stock of the locomotive fleet on these sections of railways.

The foregoing is solved with the help of complex measures and recommendations by finding ways and opportunities to implement the mentioned efficiency based on various organizational-technical, constructive, technical, and technological developments.

2 Objects and methods of research

The analysis of scientific studies of scientists from far abroad [3-15], carried out by the author [16, 17] for traction diesel and electric rolling stock, including high-speed ones, indicates that in modern theoretical studies, only a few of them take into account the implementation of one of the components associated with increasing the efficiency of railway transportation of locomotives and of the transportations process of railway transportation of goods.

Indeed, only in works [6,7,15] various technical and design-technological solutions are substantiated and recommended in the practice of operating the locomotive depot - enterprises of the railway network, ensuring, as far as possible, prudent consumption of diesel fuel and electric energy spent on the implementation of rail transportation of goods, primarily by diesel locomotives and hybrid (mixed) traction locomotives.

The studies of Uzbek scientists [18-20] are devoted to developing new technological methods for smelting and out-of-furnace processing, in particular, improving the process of refining and modifying structural alloyed steel 20GL in a steel-pouring ladle using rare earth metals and solid slag mixtures. Here, the authors show that high manganese steel 20GL is recommended for producing cast critical casting elements that can work with significant requirements for wear and resistance to impact, abrasive, and shock-abrasive variable loads at high specific static pressures. These specified blanks are widely used to produce parts and metal structures intended for railway transport, taking into account their operation in areas with sub-zero temperatures, including quite high ones.

The authors of [18–20] proved that the treatment of this steel, preliminarily deoxidized with aluminum, silicocalcium, and rare earth metals, significantly improves its mechanical properties. In this case, there is a decrease in the content of oxygen and sulfur by reducing the amount of oxide and sulfide inclusions in the metal. Also, introducing rare earth metals allowed the authors to obtain high-manganese steel 20GL with a significantly lower sulfur content, total oxygen, and non-metallic inclusions and provide an almost twofold increase in the level of mechanical properties.

Further, based on the results of studies [18-20], considering thermal hardening, the authors of [21] developed a technological process for producing cast critical elements of automatic coupling devices of locomotives, passenger and freight of railway cars.

In addition, studies [3-15,18-21] are in no way interconnected with the substantiation of the logistics indicators of the transportation process of freight trains and the transportation work of diesel traction locomotives in real operating conditions. It also does not reflect the issues of studying the efficiency of using traction rolling stock, including diesel, on sections of Uzbek railways, including high high-speed ones, considering the degree of complexity of their track profile.

To study the efficiency of using diesel locomotives of diesel traction in various operating conditions on high-speed railway sections, it is possible and necessary to use the main logistical indicators of transport energy - the technical speed of freight trains, the amount and cost of diesel fuel, which is consumed for train tractions. The above should be attributed (added) to the time of movement of a freight train in the study area under different operating modes of the diesel generator set of the diesel locomotive.

The present studies continue the works [1,2] and are devoted to the study of the transportations work of three-section freight diesel locomotives of the *UzTE*16*M*3 when they drive freight trains under real operating conditions of a given (accepted by the authors) of section high-speed railway track Marokand – Kattakurgan of the railway industry of Uzbekistan.

The purpose of this work is to perform numerical calculations to determine the main logistical indicators of transport logistics for the movement of the object of study without stops on the real section of the Uzbek railway in the form of tabular data, graphical dependencies, and regression equations for their calculations in quantitative and monetary terms.

To carry out this study, the author [16] developed an appropriate algorithm for performing traction calculations, for the implementation of which a mathematical model of the movement of a freight train [17] was used as the initial data, which was the object of study, taking into account the subject of study [22].

The object of the study is the Uzbek diesel locomotives of the *UzTE16M3* series with freight trains of different compositions masses, as well as the high-speed section Marokand - Kattakurgan of the Uzbek railway, belonging to the hilly-mountainous profile of the track.

The subject of the study - is the logistical indicators of the non-stop transportation process of freight trains and the efficiency of using the studied locomotives of diesel traction on a high-speed railway section in quantitative and cost (monetary) terms.

The design features, traction, and energy characteristics of the *UzTE*16*M*3 of diesel locomotives are described in detail in [17], and a detailed description of the straightened track profile of the hilly-mountainous, high high-speed section of Marokanda - Kattakurgan is given in the study [22].

3 Results and their discussion

Table 1 shows the indicators of transport logistics during the non-stop movement of freight trains on the hilly-mountainous high-speed section Marokand - Kattakurgan of «Uzbekistan Temir Yollari» JSC.

In the same table, taking into account with studies [23], the average values of the logistic parameters are calculated, calculated for two types of movement of freight trains and transportation work of diesel locomotives *UzTE*16*M*3 on the Marokand - Kattakurgan section for the accepted range of changes in the compositions mass of freight trains.

Table 1. The main indicators of transport logistics on the high-speed section Marokand – Kattakurgan, *UzTE*16*M*3 diesel locomotives

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_{tr}	in action mode t_{tr}	in idling and braking mode, $t_{id,br}$
Movement without stops						
Marokand – Juma haul, L = 8.75 km						
1	3500	200	67.65	8.12	5.31	2.81
2	3000	200	64.26	8.17	4.41	3.76
3	2500	200	67.13	7.82	4.31	3.51
Averages values			665.35	8.04	4.67	3.37
Dzhuma - Nurbulak haul, L = 29.00 km						
1	3500	200	76.75	22.67	5.11	17.56
2	3000	200	77.96	22.32	4.86	17.46
3	2500	200	79.02	22.02	4.56	17.46
Averages values			77.91	22.33	4.84	17.49
Nurbulak – Kattakurgan haul, L = 24.00 km						
1	3500	200	69.83	20.62	4.61	16.01
2	3000	200	67.23	21.42	4.51	16.91
3	2500	200	68.83	20.92	4.26	16.66
Averages values			68.63	29,99	4,46	16,53
Marokand – Kattakurgan section, L = 61.75 km						
1	3500	200	72.07	51.41	15.03	36.38
2	3000	200	71.37	51.91	13.78	38.13
3	2500	200	72.59	51.04	13.41	37.63
Averages values			72.01	51.45	14.07	37.38
Averaged values for two (both) types of movement						
Marokand - Kattakurgan section, L = 61.75 km						
1	3500	200	66.25	55.92	17.68	38.24
2	3000	200	66.77	55.49	16.36	39.13
3	2500	200	68.22	54.31	15.48	38.83
Averages values			67.08	55.24	16.51	38.73

Continuation of table No. 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
Movement without stops					
Marokand – Juma haul, L = 8.75 km					
1	121.98	38.32	54.80	215.96	23.74
2	101.97	37.37	53.44	180.53	19.85
3	99.81	43.90	62.78	176.71	19.43
Averages values	107.92	39.86	57.01	191.07	21.01
Dzhuma - Nurbulak haul, L = 29.00 km					
1	127.62	12.79	18.29	225.94	7.924
2	121.89	14.24	20.38	215.80	7.568
3	115.10	16.15	23.09	203.78	7.147
Averages values	121.54	14.39	20.59	215,17	7,546
Nurbulak – Kattakurgan haul, L = 24.00 km					
1	115.23	13.63	19.49	204.01	8.445
2	113.59	15.67	22.41	201.10	8.325
3	107.75	17.84	25.51	190.76	7.897
Averages values	112.12	15.71	22.47	198.62	8.222
Marokand – Kattakurgan section, L = 61.75 km					
1	364.83	16.87	24.13	645.91	10.457
2	337.45	18.21	26.04	597.44	9.673
3	364.83	16.87	24.13	645.91	10.457
Averages values	341.65	18.66	26.68	604.87	9.793
Averaged values for two (both) types of movement					
Marokand - Kattakurgan section, L = 61.75 km					
1	426.61	19.73	28.22	755.29	12.228
2	397.32	21.44	30.66	703.44	11.389
3	377.29	24.43	34.94	667.98	10.815
Averages values	400.41	21.87	31.27	708.90	11.477

The methodology for evaluating the effectiveness of the studied *UzTE*16*M*3 diesel locomotives carried out in the implementation of rail transportation of different ways and types of cargo in freight movement on a given, high-speed railway section Marokand -

Kattakurgan provided for a comparison between themselves of the average and averaged values of the above-mentioned indicators of transport logistics.

Analysis of the data in Table 1 on the average values in kinematic and energy of the main logistics indicators of transport logistics of the above object of study in real operating conditions suggests the following:

- the changes in kinematic (speed movement) and energy (diesel fuel consumption) indicators of transport logistics of the transportation process directly depend on the organization of railway transportation of goods - without stops or with stops of freight trains at intermediate stations of the section and does not depend on the type, content, and structure of the transported cargo;
- an increase in the operating time of a diesel generator set under load provides an increase in diesel fuel consumption along the route, which is reduced (decreases) during operation (operation) of a diesel engine in idling mode;
- with an increase in the composition mass of a freight train, there is an increase in the amount and in the cost of consumed diesel fuel;
- with a decrease in the composition mass of the freight train and the operating time of the diesel locomotive under study in the traction mode, the mechanical work of the forces acting on the freight train decreases;
- the mechanical work of forces on a freight train decreases with an increase in the operating time of the diesel generator set of the diesel locomotive under study in modes idling;
- an increase in the load on the axles of wheel sets of freight trains and the volume of transportation work performed by the studied diesel locomotives will undoubtedly provide an increase in the efficiency of rail transportation, which does not depend on the structure of the transported cargo and of the view of the movement of freight trains;
- each subsequent decrease in a certain fixed number of cars in a freight train contributes to an increase and decrease, respectively, in the specific consumption of diesel fuel and cash costs per trip;
- with a decrease in the mass of freight trains, the total and specific cost of freight rail transportation increases.

Similarly to studies [1, 2, 17], by processing in the Microsoft Excel Office environment the values of the above indicators of the transport logistics of the process of freight trains by the diesel locomotives *UzTE*16*M*3, the authors obtained regression equations for calculating their averaged values for real conditions for organizing freight traffic movement with a sufficient value of the approximation reliability $R^2 = 1.0$ for each i - th mass of the composition Qi of a freight train on the high-speed railway section Marokand - Kattakurgan of the Uzbek railway.

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

$$t_{t\,tr} = -0.37Q_i^2 + 0.68Q_i + 55.59 \quad (1)$$

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

$$t_{tr} = 0.22Q_i^2 - 1.98Q_i + 19.43 \quad (2)$$

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

$$t_{id,br} = -0.6Q_i^2 + 2.7Q_i + 36.12 \quad (3)$$

Technical speed of the train V_t, km/h

$$V_t = 0.72Q_i^2 - 1.69Q_i + 67.75 \quad (4)$$

Total natural diesel fuel consumption per trip E, kg:

$$E = 4.63Q_i^2 - 43.18Q_i + 465.16 \quad (5)$$

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

$$e = 0.64Q_i^2 - 0.21Q_i + 19.3 \quad (6)$$

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

$$e_{sp} = 0.92Q_i^2 - 0.32Q_i + 27.62 \quad (7)$$

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

$$C_{d.f} = 8.195Q_i^2 - 76.435Q_i + 823.53 \quad (8)$$

Specific cash costs $c_т$, thousand soums / km:

$$c_{d.f} = 0.1325Q_i^2 - 1.2365Q_i + 13.322 \quad (9)$$

The analytical dependences (1) - (9) obtained by the authors are in good agreement with the studies [1, 2, 17, 22] and confirm that all the indicated logistic parameters of the indicators of transport logistics of rail transportation of goods, implemented by *UzTE*16*M*3 diesel locomotives on the section of the high-speed railway Marokand - Kattakurgan JSC "Uzbekiston temir yullari", with an increase and decrease in the composition mass of a freight train, change according to a polynomial law.

Table 2 shows the numerical values of the dynamics of the rate of change in the parameters of the studied logistics indicators, depending on the mass of the freight train per each stop of the freight train.

In Table 2, the indicated rates of increase (or decrease) in the values of logistics indicators in quantitative and monetary terms are obtained by dividing the values for the movement of freight trains with stops by the same values for their movement without stops. The averages in said table 2 were calculated as arithmetic average values.

Table 2. Indicators of transport logistics of freight trains on the hilly – mountainous section Marokand - Kattakurgan, section length L = 61.75 km

option of traction of calculation	Conditions of the transportation process		Indicators of transport logistics for one freight train stop			
			Kinematic indicators			
	mass Q,t	number of axles m, axles	movement speed	movement time, min/stop		
			technical speed ΔV_t, km/h:stop	general, $\Delta t_{t\ tr}$	in action mode, Δt_{tr}	in idling and braking mode, $t_{id.br}$
1	2	3	4	5	6	7
The rate of change in the values of indicators of transport logistics of the *UzTE*16*M*3 diesel locomotives						
1	2500	200	0.891	1.14	1.36	1.06
2	3000	200	0.867	1.15	1.38	1.07
3	3500	200	0.861	1.16	1.36	1.08
Averages values			0.873	1.15	1.38	1.07

Continuation of table No. 2.

option of traction of calculation	Indicators of transport logistics for one freight train stop				
	Quantitative and cost indicators				
	consumption diesel fuel in quantitative terms			consumption diesel fuel in cash costs	
	general	specific			
	per trip ΔE, kg/stop	of natural fuel $\Delta e \times 10$, kg/10^4 tkm brutto:stop	of conditional fuel $\Delta e_{sp} \times 10$, kg/10^4 tkm brutto:stop	full ΔC_{df}, thousand soums /stop	specific $\Delta c_{df_T} \times 10$, thousand soums /km:stop
	8	9	10	11	12
The rate of change in the values of indicators of transport logistics of the *UzTE*16*M*3 diesel locomotives					
1	1.33	1.33	1.33	1.33	1.33
2	1.35	1.35	1.35	1.35	1.35
3	1.33	1.33	1.33	1.33	1.33
Averages values	1.34	1.34	1.34	1.34	1.34

Diagrams of the rate of change (increase or decrease) in the values of the logistic indicators of the transportation process associated with the rail transportation of goods on the hilly-mountainous section of Marokand - Kattakurgan with a change in the mass of the freight train by value ΔQ = 500 tons, taking into account studies [23], is shown in fig. 1.

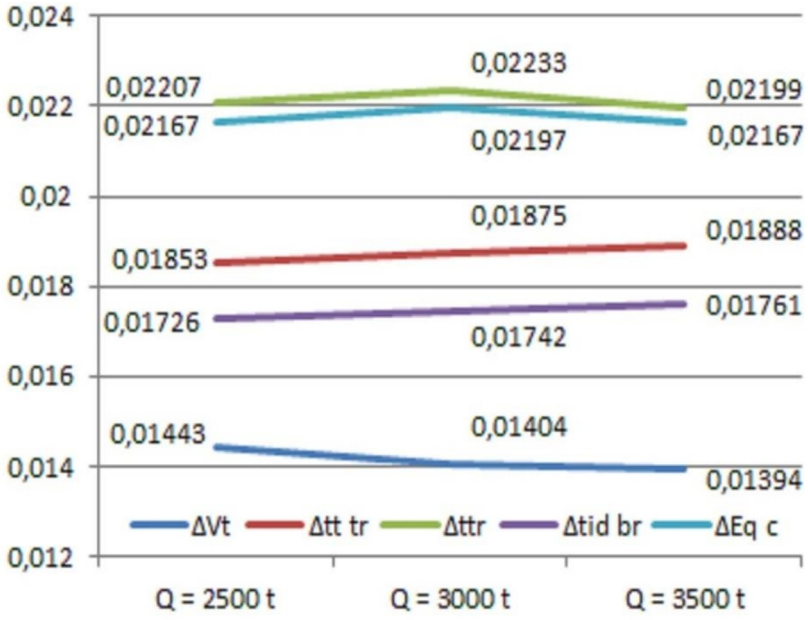

Fig. 1. The rate of change in the values of indicators of transportation logistics for the diesel locomotives *UzTE*16*M*3 series on the high-speed section Marokand – Kattakurgan

On fig. 1, the following symbols are adopted: ΔV_t is technical speed of movement (km/h:stop km); train running time is total $\Delta t_{t\ tr}$, in mode traction Δt_{tr} and in idle mode, braking $\Delta t_{id,br}$ (min/stop km) and E_{qc} is quantitative and cost parameters of logistic indicators of energy efficiency of the diesel locomotives (kg/stop km).

An analysis of the data in Table 2 and diagrams of growth rates - a decrease in the logistic indicators of the movement of the studied freight trains and diesel locomotives on the high-speed section of Marokand - Kattakurgan (Fig. 1) allow the authors to state the following.

1. An increase in the composition mass of a freight train indicates:

- the rate of change in energy efficiency for all quantitative and cost (monetary) indicators of transport logistics of the studied diesel locomotives is a constant value and does not depend on their view or type, with an increase in the range from 1.338 to 1.357. units;
- with a decrease in the technical speed *V*t of movement, the value of the growth rate coefficient also decreases from 0.889 (Q_1 = 2500 t) units. up to 0.859 (Q_3 = 3500 t) units.;
- coefficients for increasing the time of movement of freight trains and the operation of the diesel generator set of the studied diesel locomotives with V-shaped diesel engines in traction and idling modes are, respectively, 1.367 units and 1.076 units, and for the time movement of the train as a whole over the section they are 1.156 units.

2. Reducing the composition mass of a freight train provides:

- the same (constant) values of the growth rate of the mentioned parameter values for all types (view) of quantitative and costs parameters of the energy efficiency of diesel locomotives with V-shaped diesel engines, as well as for the case of increasing the compositions mass of the freight train, with a decreasing interval of 1.338 units;
- an increase in the technical speed V_t of a freight train with a rate of increase, the value of which ranges from 0.861 (Q_3 = 3500 t) to 0.891 (Q_1 = 2500 t) units;
- decrease in the rate of change in time of movement on the modes general movement time and idling of the freight train, on average, respectively, is 0.95 and 0.97 percent, except for the mode traction, the decrease of which is approximately 1.16 percent for Q_1 = 2500 t and an increase of 1.55 percent for Q_2 = 3000 t.
- reduced cash costs (expenses) for train traction per one kilometer of the railway track is approximately 3.6 thousand soums/km (Q_1 = 2500 tons); 3.8 thousand soums/km (Q_2 = 3000 t) and 4.08 thousand soums/km (Q_3 = 3500 t).

The results obtained by the authors showed a fairly high convergence and are in good agreement with research data [1-2, 17, 23, and others]; therefore, they can be recommended to specialists for assessing and predicting the consumption of diesel fuel for traction trains by diesel locomotives on real hilly-mountainous, high-speed sections of the railway track.

4 Conclusion

Diesel locomotives of «Uzbekiston Temir Yullari» JSC *UzTE*16*M*3 series have significant design differences from three-section diesel locomotives of the 3*TE*10*M* series due to the deep modernization of the converter part, control system, and diesel generator sets by replacing the 10*D*100 diesel engine with the diesel 5*D*49, which, of course, has a very positive effect on their traction and energy characteristics and parameters.

1. The study results will help correct the existing regime maps for driving freight trains, which will save the amount of natural diesel fuel consumed in each trip and help increase the technical speed of such trains on hilly-mountainous of the high high-speed sections of Uzbek railways.

2. Obtained by the authors of the indicators of transport logistics of freight trains and logistic fuel and energy efficiency parameters of the diesel locomotives with V-shaped

diesel engines, taking into account the regression equations to determine their values, will allow developing systemic (complex) measures and outline further ways for the economic consumption of full-scale diesel fuel on the traction of trains for enterprises of the locomotive economy of the Uzbek Railway

In addition, the research results obtained by the authors for mainline (train) three-sections of the *UzTE*16*M*3 series of freight diesel locomotives, which are quite successfully operated on a given, hilly-mountainous, high-speed railway section Marokand - Kattakurgan and which can be used in the practice work of the specialists of the locomotives depot operation shop Bukhara "Uzbekistan temir yullari" JSC.

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