Logistic indicators of locomotives of diesel traction in Marokand-Kattakurgan section of Uzbek railway

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Abstract. The results of a study on the substantiation of the parameters of the logistical indicators of rail freight traffic implemented by diesel locomotives of the UzTE16 M3 series when moving with stops on the hilly-mountainous section of Marokand-Kattakurgan of the Uzbek railway are presented. The research methodology is a graphical method for solving the differential equation of train movement in the accepted range of changes in the mass of the composition of freight trains as a result of the implementation of which the authors obtained complete and reduced kinematic parameters of the movement of freight trains per one kilometer of the railway track and the parameters of the logistic indicators of the energy efficiency of these diesel locomotives in the form of tabular data, graphical dependencies, as well as regression equations with the subsequent development of nomograms for their calculation. The results of the study can be used by specialists of the Bukhara locomotive depot, which will allow them to develop recommendations for saving diesel fuel by the diesel locomotives under study, considering various conditions for organizing rail transportation of goods.

1 Introduction

At present, «Uzbekiston Temir Yullari» JSC is carrying out widespread intensive electrification of Uzbek railways [1, 2], approximately 90% of the total length of sections of which will already be electrified by 2030 and, in this regard, is actively replenishing the operating fleet of electric traction locomotives due to passenger and freight, passenger and cargo Chinese electric locomotives of the new generation «Uzbekistan».

Moreover, the demand for locomotives of diesel traction does not weaken. Still, it continues to remain at a fairly high level, including, first of all, this applies to three-section mainline (train) freight diesel locomotives of the UzTE M3 series [2], which account for approximately 30 percent of the total operating fleet of locomotives of diesel traction of «Uzbekiston Temir Yullari» JSC. Studies on the justification, analysis, and evaluation of the effectiveness of the use of these diesel locomotives in real operating conditions on sections of the Uzbek railways of different degrees of complexity, taking into account the main indicators of transport

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logistics, are very significant and urgent tasks of the railway industry of Uzbekistan.

In principle, a huge number of studies have been devoted to increasing the efficiency of use and operational reliability of traction rolling stock in the real conditions of the organization of railway transportation of goods and passengers, some of which are presented here—scientists from Uzbekistan [22-25], neighboring [4, 7, 11-15, 18] and non-CIS countries [5, 6, 8-10, 16, 17, 19-21].

Previously, the author [26, 27] analyzed the result of scientific research by scientists from far abroad regarding the transportation work of traction diesel and electric rolling stock under operating conditions, which showed that only a few of them considered the issues of increasing the efficiency of using these locomotives. So, only three works [26] identified and formulated recommendations for reducing the consumption of fuel and energy resources for train traction, intended only for hybrid and, to a lesser extent, diesel traction.

Next, we present an overview of the scientific studies identified in this article.

The method for determining the consumption of diesel fuel according to the curve of the speed of a real trip, which makes it possible to more accurately normalize the traction resources of trains, is described in the study [4].

The authors of [7] show that to improve the operational reliability of electric rolling stock, it is necessary to implement a decision support system for an electric locomotive driver to eliminate failures along the route using an automatic search for optimal solutions without a human factor.

The authors of the article [11] analyze various possibilities of approaches to forecasting based on progressive methods of predictive modeling about the transport industry, and in studies [12, 13], a probabilistic-statistical method of adaptive control management and regulation of electric energy, as well as a system for visual accounting of electricity consumption by electric rolling stock was proposed and tested.

The technique for assessing the energy efficiency of auxiliary equipment of DC electric locomotives and the system for monitoring the consumption of electric energy by electric rolling stock on the traction tracks of locomotive depots are shown in [14,15] taking into account the results of an experimental study on the assessment of dynamic forces [18].

Recommendations for energy saving of passenger traction rolling stock in the Valencia (Spain) metro and on the main railway transport are indicated in [5, 6].

The authors' studies of works [8-10] are devoted to developments in the field of automatic train control for railway transport systems, energy optimization of regenerative braking for high-speed railway systems, and energy-efficient train tracking based on the proposed optimization models.

The problem of minimizing the consumption of electrical energy in the railway network, taking into account the real-time mode, is studied by the authors [16, 17].

The studies of the authors of works [19, 20] are devoted to analyzing dynamic processes of interaction of the wheel of railway vehicles with rails to assess the safety from derailment when driving along curved sections of the track with different curvature radii and turnouts.

The authors of [21] developed an interferometric fiber-optic sensor designed to monitor the load of the railway track and rolling stock running gear under operating conditions and predict the development of faults about places with increased danger to traffic.

Studies [22-25] are devoted to improving the operational reliability of cast critical elements of automatic coupling devices of locomotives, passenger, and freight railway cars by significantly improving the mechanical properties and increasing the wear resistance of structural alloy steel grade 20GL.
the author shows that these works did not consider the issues of substantiating the main logistical indicators of transport logistics, such as the technical speed and travel time of freight trains at different operating modes of the diesel generator set, the amount of natural diesel fuel consumption for train traction in quantitative and monetary terms, and their impact on the energy efficiency of the use of traction rolling stock, including diesel, on the sections of Uzbek railways, was not assessed, taking into account the degree of complexity their profile railway track. In addition, these studies do not reflect the issues of substantiating the logistics indicators that characterize the stopping process of the movement of freight trains and the transportation work of diesel traction locomotives in real operating conditions.

2 Objects and methods of research

The present research continues the work and is devoted to the study of the conditions of transportation operation of three-section mainline (train) freight diesel locomotives of the UzTE 16M3 series during the movement of freight trains with stops at separate points in real operating conditions on a given (accepted by the authors) real section Marokand–Kattakurgan of the Uzbek Railway.

The purpose of this study is to substantiate the indicators of the transport logistics of the movement of freight trains and the logistics indicators of the transportation work of diesel traction locomotives in quantitative and monetary terms on a real, hilly–mountainous section of the Uzbek Railway.

To implement this study, the authors performed a series of traction and energy calculations based on the corresponding algorithm for performing traction calculations developed by the author, initial data, methods of the theory of locomotive traction, and the object and subject of research.

The object of the study is freight trains with different masses of trains and three-section mainline (train) freight diesel locomotives of the UzTE 16M3 series, as well as the hilly and mountainous section of the Marokand–Kattakurgan of the Uzbek railway.

The subject of the study is the logistic indicators of the transport logistics of the movement of freight trains with the organization of stops at intermediate stations and the main logistic indicators of the energy efficiency of using the diesel locomotives under study on the hilly–mountainous section of the railway in quantitative and cost (monetary) terms.

The design of diesel locomotives of the UzTE 16M3 series, their traction and energy characteristics are covered in [27], and the parameters of the straightened track profile of the hilly–mountainous section of Marokand–Kattakurgan are given in the study.

3 Results and their discussion

The main indicators of the transport logistics of the movement of freight trains and the transportation work of diesel locomotives of the UzTE 16M3 series during the movement of freight trains with stops at the Marokand–Kattakurgan section of the Uzbek railway are shown in Table 1.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>100 km/h</td>
<td>120 km/h</td>
<td>140 km/h</td>
</tr>
<tr>
<td>Travel time</td>
<td>3 hours</td>
<td>4 hours</td>
<td>5 hours</td>
</tr>
</tbody>
</table>

Also, this table shows the average and, taking into account studies [28], the average values of the parameters of the above indicators for two types of traffic (with stops and without stops at intermediate stations), and the latter were calculated as arithmetic averages in the accepted range of changes in the mass of compositions of freight trains.
Table 1. Indicators of transport logistics of diesel locomotives *UzTE* 16 *M*3 on high-speed section Marokand – Kattakurgan, movement with stops option of traction of calculation

<table>
<thead>
<tr>
<th>Q</th>
<th>m</th>
<th>Vt</th>
<th>t tr.</th>
<th>t id,br</th>
</tr>
</thead>
<tbody>
<tr>
<td>53.96</td>
<td>9.87</td>
<td>4.66</td>
<td>5.07</td>
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</tr>
</tbody>
</table>

| L = 8.75 km |
| 3500 | 200 | 5 |
| 9.00 | 4.40 | 5.30 |

| L = 29.00 km |
| 3500 | 200 | 67.00 | 25.97 | 8.36 | 17.61 |
| 3000 | 200 | 67.91 | 25.62 | 8.16 | 17.46 |
| 2500 | 200 | 70.10 | 24.82 | 7.51 | 17.31 |

| Averages values |
| 68.34 | 25.47 | 8.01 | 17.46 |

| L = 24.00 km |
| 3500 | 200 | 59.45 | 24.22 | 6.71 | 17.51 |
| 3000 | 200 | 59.21 | 24.32 | 6.41 | 17.91 |
| 2500 | 200 | 61.25 | 23.51 | 6.07 | 17.44 |

| Averages values |
| 59.97 | 24.02 | 6.40 | 17.62 |

| L = 61.75 km |
| 3500 | 200 | 61.57 | 60.17 | 20.36 | 39.81 |
| 3000 | 200 | 62.25 | 59.52 | 18.96 | 40.56 |
| 2500 | 200 | 63.97 | 57.92 | 17.86 | 40.06 |

| Averages values |
| 62.59 | 59.20 | 19.06 | 40.14 |

Values for two (both) types of movement

| L = 61.75 km |
| 3500 | 200 | 66.22 | 55.95 | 17.70 | 38.25 |
| 3000 | 200 | 66.76 | 55.50 | 16.35 | 39.15 |
| 2500 | 200 | 68.23 | 54.30 | 15.45 | 38.85 |

| Averages values |
| 67.07 | 55.25 | 16.50 | 39.14 |

Averages values on the section Marokand – Kattakurgan, L = 61.75 km
### Continuation of table № 1

<table>
<thead>
<tr>
<th>№</th>
<th>$E_{k3}$</th>
<th>$e_3$</th>
<th>$e_{op}$</th>
<th>$C_{d.l.}$</th>
<th>$G_{v.d.}$</th>
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**Movement on the hauls of the site**

- **Marokand – Juma haul, $L = 8.75 km**
  - $E_{k3}$: 123.29, $e_3$: 38.73, $e_{op}$: 55.38, $C_{d.l.}$: 218.28, $G_{v.d.}$: 24.00
  - $E_{k3}$: 103.25, $e_3$: 37.84, $e_{op}$: 54.11, $C_{d.l.}$: 182.80, $G_{v.d.}$: 20.10
  - $E_{k3}$: 101.05, $e_3$: 44.44, $e_{op}$: 63.55, $C_{d.l.}$: 178.90, $G_{v.d.}$: 19.67
  - $E_{k3}$: 109.20, $e_3$: 40.34, $e_{op}$: 57.68, $C_{d.l.}$: 193.33, $G_{v.d.}$: 21.26

- **Dzhuma - Nurbulak haul, $L = 29.00 km$**
  - $E_{k3}$: 201.27, $e_3$: 20.17, $e_{op}$: 28.84, $C_{d.l.}$: 356.39, $G_{v.d.}$: 12.50
  - $E_{k3}$: 196.64, $e_3$: 22.99, $e_{op}$: 32.87, $C_{d.l.}$: 348.14, $G_{v.d.}$: 12.21
  - $E_{k3}$: 181.81, $e_3$: 25.50, $e_{op}$: 36.46, $C_{d.l.}$: 321.88, $G_{v.d.}$: 11.29
  - $E_{k3}$: 193.24, $e_3$: 22.89, $e_{op}$: 32.72, $C_{d.l.}$: 342.14, $G_{v.d.}$: 12.00

- **Nurbulak – Kattakurgan haul, $L = 24.00 km$**
  - $E_{k3}$: 163.83, $e_3$: 19.38, $e_{op}$: 27.71, $C_{d.l.}$: 290.05, $G_{v.d.}$: 12.00
  - $E_{k3}$: 157.31, $e_3$: 21.70, $e_{op}$: 31.03, $C_{d.l.}$: 278.51, $G_{v.d.}$: 11.53
  - $E_{k3}$: 149.07, $e_3$: 24.68, $e_{op}$: 35.29, $C_{d.l.}$: 263.92, $G_{v.d.}$: 10.92
  - $E_{k3}$: 156.74, $e_3$: 21.92, $e_{op}$: 31.34, $C_{d.l.}$: 277.49, $G_{v.d.}$: 11.48

- **Movement on the section Marokand – Kattakurgan, $L = 61.75 km$**
  - $E_{k3}$: 488.39, $e_3$: 22.59, $e_{op}$: 32.31, $C_{d.l.}$: 864.67, $G_{v.d.}$: 14.00
  - $E_{k3}$: 457.20, $e_3$: 24.67, $e_{op}$: 35.28, $C_{d.l.}$: 809.45, $G_{v.d.}$: 13.10
  - $E_{k3}$: 431.93, $e_3$: 27.97, $e_{op}$: 40.00, $C_{d.l.}$: 764.71, $G_{v.d.}$: 12.38
  - $E_{k3}$: 459.17, $e_3$: 25.08, $e_{op}$: 35.86, $C_{d.l.}$: 812.94, $G_{v.d.}$: 13.16

**Values for two (both) types of movement**

- **Averaged values on the section Marokand – Kattakurgan, $L = 61.75 km$**
  - $E_{k3}$: 426.61, $e_3$: 19.73, $e_{op}$: 28.22, $C_{d.l.}$: 755.29, $G_{v.d.}$: 12.22
  - $E_{k3}$: 397.32, $e_3$: 21.44, $e_{op}$: 30.66, $C_{d.l.}$: 703.44, $G_{v.d.}$: 11.39
  - $E_{k3}$: 377.29, $e_3$: 24.43, $e_{op}$: 34.94, $C_{d.l.}$: 667.98, $G_{v.d.}$: 10.81
  - $E_{k3}$: 400.41, $e_3$: 21.87, $e_{op}$: 31.27, $C_{d.l.}$: 708.90, $G_{v.d.}$: 11.47

The methodology for evaluating the effectiveness of the studied $UzTE\, M_3$ 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 average values of the main kinematic and energy indicators of transport logistics of the accepted object of study, taking into account the values for both types of movement in real operating conditions, allows us to draw the following conclusions:

- the magnitude of the change in the speed of movement and consumption of diesel fuel, which are the main indicators of the transport logistics of the transportation process,
depends on the type of movement of freight trains and does not depend on the composition and structure of the transported cargo;

- the amount of diesel fuel consumed by the diesel locomotive under study directly depends on the duration of the diesel generator set under load;

- operation of the diesel engine at idle helps to reduce the amount of diesel fuel consumed by the diesel locomotive under study in the route of the rolling stock;

- the amount and cost of consumed diesel fuel are reduced with a decrease in the mass of the freight train;

- an increase in the mechanical work of forces acting on a freight train occurs with an increase in the operating time of the investigated diesel locomotive in the mode traction and the composition mass of the freight train;

- the mechanical work of forces on freight trains increase with decreases in the operating time of the diesel generator set of the diesel locomotive under study in modes idling;

- improving the efficiency of rail freight transportation directly depends on the increase in the volume of transportation work performed by the studied diesel locomotives and the load on the axles of wheelsets of freight trains and does not depend on the composition and structure of the transported cargo, as well as of the type of freight train traffic;

- each decrease in the number of wagons in a freight train contributes to an increase in the specific consumption of diesel fuel for train traction and a decrease in cash costs for rail transportation of goods;

- the total and specific cost of freight rail transportation increases with an increase in the mass of freight trains.

Similarly to studies \[2,3,27\], by processing in the Microsoft Excel Office environment the values of the above indicators of transport logistics of movement of freight trains by diesel locomotives \(UzTE_{16}M_3\), regression equations were obtained to calculate their values for real conditions organizing of freight traffic with stops with a sufficient value of the approximation reliability \(R^2 = 1.0\) for each \(i\)-th mass of the composition \(Q_i\) of a freight train on the section Marokand-Kattakurgan of the Uzbek railway.

Total train travel time \(t_{tr}, \text{min}\):

\[
t_{tr} = -0.475Q_i^2 + 0.775Q_i + 5.87
\]  

Train travel time in mode traction \(t_{tr}, \text{min}\):

\[
t_{tr} = 0.15Q_i^2 - 1.85Q_i + 22.06
\]  

Train running time at idle and braking modes \(t_{id,br}, \text{min}\):

\[
t_{id,br} = -0.625Q_i^2 + 2.625Q_i + 37.81
\]  

Technical speed of the train \(V_t, \text{km/h}\):

\[
V_t = 0.52Q_i^2 - 0.88Q_i + 61.93
\]  

Total natural diesel fuel consumption per trip \(E, \text{kg}\):

\[
E = 2.96Q_i^2 - 40.07Q_i + 525.5
\]  

Specific consumption of natural diesel fuel \(e, \text{kg} / 10^4 \text{t} \text{km} \text{brutto}\):

\[
e = 0.61Q_i^2 + 0.25Q_i + 21.73
\]  


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

$$e_{sp} = 0.875 Q_{i2} + 0.345 Q_{i4} + 0.3109 (7)$$

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

$$C_{d.f} = 5.24 Q_{i2} - 7.094 Q_{i4} + 930.37 (8)$$

Specific cash costs $c_{d.f}$, thousand soums/km:

$$c_{d.f} = 0.085 Q_{i2} - 1.1515 Q_{i4} - 1.566 (9)$$

Analytical dependencies (1) - (9) are in good agreement with the studies [2, 3, 27, 28] and confirm that the parameters of the main indicators of transport logistics during the movement of the studied diesel locomotives UzTE $M_3$ with stops on section Marokand - Kattakurgan of “O’zbekiston temir yo’llari” JSC with a change in the compositions mass of a freight train are described by a polynomial of the second degree.

The kinematic parameters of the transport logistics of the movement of a freight train with stops at intermediate separate points and the logistic indicators of the efficiency of the transportation work of three-section mainline (train) diesel locomotives UzTE $M_3$ with a specific uniform distribution of their values for each stop at an intermediate station are given in Table 2.

In Table 2 the negative sign (minus) predetermines only the reduction (decrease) in the technical speed of movement of the freight train in the process of decreasing the mass of composition of the train and nothing more; that is, this sign characterizes only a decrease in the value of the main indicator of the mentioned transportation work and does not affect the absolute values of the technical speed of movement. The averages in said Table 2 were calculated as arithmetic average values.

Table 2. Main indicators of transport logistics of freight trains on section Marokand - Kattakurgan, section length $L = 61.75$ km option of traction of calculation

<table>
<thead>
<tr>
<th>Conditions of the transportation process</th>
<th>Kinematic motion parameters of freight train on the one stop</th>
<th>mass of composition $Q_i$, t</th>
<th>number of axles in composition $m$, axles</th>
<th>Speed motions</th>
<th>Train movement time, min/stop</th>
<th>technical speed $\Delta V_t$, km/h:stop</th>
<th>general, $\Delta t_{tr}$ in traction mode, $\Delta t_{id}$ in idling and braking mode, $\Delta t_{br}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Q_i$</td>
<td>$UzTE M$</td>
<td>$m$</td>
<td>$\Delta V_t$</td>
<td>$\Delta t_{tr}$</td>
<td>$\Delta t_{id}$</td>
<td>$\Delta t_{br}$</td>
</tr>
<tr>
<td>1</td>
<td>3500</td>
<td>200</td>
<td>3.500</td>
<td>2.920</td>
<td>1.777</td>
<td>1.143</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>200</td>
<td>3.040</td>
<td>2.537</td>
<td>1.727</td>
<td>0.810</td>
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<tr>
<td>3</td>
<td>2500</td>
<td>200</td>
<td>2.873</td>
<td>2.293</td>
<td>1.450</td>
<td>0.810</td>
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</tbody>
</table>

Averages values

<table>
<thead>
<tr>
<th>$Q_i$</th>
<th>$UzTE M$</th>
<th>$m$</th>
<th>$\Delta V_t$</th>
<th>$\Delta t_{tr}$</th>
<th>$\Delta t_{id}$</th>
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Continuation of table № 2

<table>
<thead>
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<th>№</th>
<th>Quantitative and cost indicators of energy efficiency consumption diesel fuel in quantitative terms</th>
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<tbody>
<tr>
<td></td>
<td>per trip $\Delta E$, kg/stop</td>
<td>of conditional fuel $\Delta e_{sp}$, kg/104tkm brutto</td>
</tr>
<tr>
<td>2</td>
<td>41.187</td>
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<td>3</td>
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<td>4</td>
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Fig. 1 and Fig. 2 show the dynamics of changes in the indicators of transport logistics of the movement of a freight train with different masses of trains and energy efficiency of the use of diesel locomotives UzTE M3 on the hilly-mountainous section Marokand-Kattakurgan of the Samarkand-Navoi-Bukhara railway line of “O'zbekiston temir yo’llari” JSC depending on the load on the axles of the wheel sets of the train, taking into account its reduction.

The above parameters of logistic indicators were determined for one stop of a freight train; however, for a more “visual” image in Fig. 2, the values of the total and specific consumption of full-scale diesel fuel, as well as of the reduced cash costs, were increased, respectively, by two, four and one and a half times.

Using the Microsoft Excel Office environment, the authors obtained regression equations to calculate the dynamics of the parameters of transport logistics indicators of the efficiency of using the studied diesel locomotives UzTE M3 per one stop of a freight train of any i-th mass of the composition $Q_i$ with a sufficient value of approximation reliability $R^2 = 1.0$. Here the factor (indicator) $Q_i = 1, 2, 3$ is a variant of traction calculations.
Fig. 1. Indicators of transport logistics of movement of freight train on section Marokand-Kattakurgan:

- $\Delta V_t$ is technical speed of movement;
- $\Delta t_{tr}$, in traction mode;
- $\Delta t_{id br}$, in idling and braking mode.

Fig. 2. Logistic indicators of energy efficiency of UzTE16M diesel locomotives on section Marokand-Kattakurgan:

- Diesel fuel consumption per trip $\Delta E$,
- Natural $\Delta e$,
- Conditional $\Delta e_{sp}$;
- Cash outlays full $\Delta C_d f$ and specific $\Delta c_d f$. 

https://doi.org/10.1051/e3sconf/202341003034
\[ \Delta t_{tr} = -0.0018 Q_i^2 + 0.0044 Q_i + 0.0262 \] (11)

Train running time at idle and braking modes
\[ \Delta t_{id.,br} = 0.0026 Q_i^2 - 0.0131 Q_i + 0.029 \] (12)

Technical speed of the train
\[ \Delta V_t = -0.0024 Q_i^2 + 0.0147 Q_i - 0.069 \] (13)

Total natural diesel fuel consumption per trip
\[ \Delta E = -0.036 Q_i^2 + 0.068 Q_i + 1.302 \] (14)

Specific consumption of natural diesel fuel
\[ \Delta e = -0.0138 Q_i^2 + 0.201 Q_i + 1.048 \] (15)

Specific consumption of conventional diesel fuel
\[ \Delta e_{sp} = -0.0073 Q_i^2 + 0.1078 Q_i + 0.561 \] (16)

Total cash costs
\[ \Delta C_{d.f} = -0.0318 Q_i^2 + 0.0589 Q_i + 1.1538 \] (17)

Specific cash costs
\[ \Delta c_{d.f} = -0.0515 Q_i^2 + 0.0955 Q_i + 1.868 \] (18)

It can be seen that the dynamics of the kinematic and energy parameters of the logistic indicators of the efficiency of using the studied UzTE 16M diesel locomotives for one stop of a freight train with different composition masses, as well as the regression equations (1) - (9), are described by a polynomial of the second degree.

In addition, for one stop of a freight train at an intermediate station, a siding, or a separate point, we have the following data:
- the value of the total and specific consumption of natural diesel fuel is, respectively, 36.423 kg and 2.357 kg/104 t km gross (\( Q_1 = 2500 \) t), 39.917 kg and 2.153 kg/104 t km gross (\( Q_2 = 3000 \) t) and 41.187 kg and 1.907 kg/104 t km gross (\( Q_3 = 3500 \) t);
- 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 approximately 2.33 kg/km and 0.151 kg/104 t km gross: km (\( Q_1 = 2500 \) t); 2.47 kg/km and 0.133 kg/104 t km gross: km (\( Q_2 = 3000 \) t) and 2.64 kg/km and 0.122 kg/104 t km gross: km (\( Q_3 = 3500 \) t).
- the average value of the reduced cash costs (expenses) for train traction per one kilometer of the railway track is approximately 4.128 thousand soums/km (\( Q_1 = 2500 \) tons).
4.369 thousand soums/km ($Q_2 = 3000$ t) and 4.667 thousand soums/km ($Q_3 = 3500$ t).

The results obtained by the authors of this stage of the research showed a fairly high convergence and are in good agreement with the research data [2, 3, 27, 28, etc.]; therefore, they can be used in assessing the fuel-energy efficiency of locomotives of diesel traction on real hilly-mountainous sections of the railway track.

4 Conclusion

1. As a result of the modernization of the diesel generator set of diesel locomotives UzTE16M3 by replacing the diesel engine 10D100 of diesel locomotives 3TE10M with diesel 5D49, taking into account new auxiliary diesel systems, were obtained traction and energy characteristics and traction properties of these modernized locomotives of a higher level and quality, ensuring their normal operation on sections of the Uzbek railways of varying degrees of difficulty, including hilly-mountainous.

2. Within the range of changes in the mass of the freight train composition accepted by the authors with a constant number of axles in the composition, the logistic indicators of the movement of freight trains and the transportation work of the investigated diesel locomotives UzTE16M3 along the route on the real, hilly-mountainous section Marokand-Kattakurgan of the Uzbek railway were obtained.

3. It is proved that the dynamics of changes in the above logistic indicators depending on the composition mass of the freight train is described by a polynomial of the second degree, and the regression equations obtained by the authors to determine their numerical values will allow us to correct systemic measures and identify further ways to economically use full-scale diesel fuel for train traction for linear enterprises of the locomotive complex "Uzbekistan temir yo'llari" JSC.

4. The research results obtained by the authors are recommended for practical use by specialists in the locomotive economy related to the issues of substantiating differentiated consumption rates of fuel and energy resources for train traction.

References


29. FORM-2023