Valuation of the influence of the basic specific resistance to the movement of freight cars on the energy costs of driving a train

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Abstract. The primary specific resistance to the movement of freight wagons is a key parameter for normalizing the time and energy consumption of trains. Although the “Rules of Traction Calculations” calls for dividing wagons into six groups when calculating this resistance, in practice (using the traditional method), appropriate regulations are developed based on the separation of train wagons into two groups (4th and 8th lips). One of the main reasons for this is the inability to account for the unique features of each wagon in a given train. To address this issue, a program was developed for determining the necessary parameters of wagons for traction calculations based on their identification numbers. This software can be accessed through the website https://trainlocomotive.netlife.app/. Using this program, a method for calculating the primary specific resistance to the movement of freight wagons has been developed. Field sheets of freight trains moving through the Uzbekistan Temir Yullari railway station were analyzed. As a result, it was discovered that nearly half of the freight train composition consists of empty wagons, while the proportion of loaded gondola cars and tanks is 23%. The primary specific resistance to the movement of wagons in such a mixed composition is calculated using both traditional and developed methods. The impact of the primary specific resistance on the energy costs of maintaining the train is evaluated. As a result, the feasibility of utilizing the developed method for normalizing electricity consumption based on traction calculations is demonstrated. Key words: Cargo wagons, main specific resistance to movement, train maintenance, energy costs, traction calculations, software.

1 Introduction

In the calculation of the operating costs of railway transport, the movement of locomotives and wagons is considered as one of the main accounting elements. In order to increase the capacity of railway sections and optimize the technical and economic calculations related to the transportation of trains, it is necessary to correctly calculate the movement of the train. Currently, research has been carried out on the technical and economic importance of the
fundamental resistance of wagons to movement, and a number of scientific studies have been conducted to investigate energy consumption issues. For example, in [1], the results of the initial phase of investigating train resistance are presented. Formulas for determining train resistance have been analyzed by researchers in the US and abroad, and factors that cause significant variations in different formulas have been discussed. Various models that take into account atmospheric resistance in determining train resistance have been developed using computer programs that consider various factors. As a result of reducing train resistance, the savings in energy costs have been calculated in detail. The article titled [2], investigates the impact of aerodynamic phenomena on the resistance and fuel consumption of vehicles equipped with diesel engines managed by Romanian railway companies. The study concludes that the resistance characteristics have a direct impact on fuel consumption and that the minimum fuel consumption is achieved with minimal resistance. Furthermore, it was observed that at speeds above 85 km/h, the overall resistance value is significantly reduced.

[3] examines the resistance forces encountered during the propulsion of trains consisting of LE 060 EA 5100kW locomotives and two-level wagons for two different configurations. The results indicate that the resistance of the wagons is dependent on their structure and the number of levels, and that increasing the number of levels also increases the resistance. The study provides valuable insights for optimizing the design and operation of trains for maximum efficiency.

[4] In this monograph it is scientifically proven that the formulas for calculating the resistance to curvature movement used in traction calculations do not express dependence on the design and methods of controlling the rolling stock. As a result, the characteristics of the kinematic resistance to movement were obtained for a number of types of rolling stock.

[5] This study examines the additional tunnel resistance and proposes appropriate resistance coefficients for tunnels with an aerodynamic cross-section of 27 m² to 87 m². Using operational data to estimate the running resistance of trains in a set of Norwegian tunnels, the study suggests coefficients of resistance ranging from 2.4 kg/m to 16.0 kg/m for such tunnels and emphasizes the importance of careful selection of these coefficients.

[6] This scientific article analyzes issues related to energy losses in railway transport and reducing the resistance of wagons to motion. The study focuses on the movement of a partially loaded freight car, and the dependence of the resistance to motion on the curvature is determined based on mathematical modeling. The relationship between the resistance of the motion and the parameters of the track and the lower part of the wagon is established by comparing the motion resistance on straight and curved sections of track.

[7] In this article, research results are presented on reducing the resistance of the railway track by changing its design, in order to decrease the energy consumption of trains. Based on the continuous monitoring and existing requirements and standards in the field of transportation engineering, several technical solutions have been developed for this purpose. The calculations of the strength and deformation of these technical solutions have also been presented. Based on the obtained information, it is concluded that the proposed design of the railway track meets safety requirements in terms of the resistance to deformation of the track structure.

In the field of train operations, a series of scientific works have been carried out to optimize the movement of trains based on the calculations made by our country's scientists [8-16]. However, in the process of implementing these optimization calculations, the basic principle of considering all types of wagons when calculating the resistance to movement has not been taken into account.

The existing scientific research indicates the need to analyze the impact of various types of cargo wagons on the energy consumption of train management in order to optimize the movement of trains.
2 Automating the process of determining the primary resistance of various types of freight wagons to train movement

“According to the information brochure on the 8-unit system for numbering freight cars, freight cars with a gauge of 1520 mm are classified into 6 types (covered wagons, flatcars, open-top wagons, tank cars, hopper cars, and others) [17]. The “Rules for Calculating Train Operations” that have been produced up to this day were analyzed [18-19]. As a result, it was determined that the parameters necessary for calculating the movement resistance of cars are divided into 6 groups in the car rolling calculations to calculate the basic resistance to train movement of freight cars. In this case, all calculations are performed for 2 types of railway tracks (with and without a ballast) and 2 types of bearings (roller bearings and plain bearings) for freight cars. Investigations were carried out taking into account the cargo parameters in the territory of the Uzbekistan Railways JSC for freight cars with plain tracks and roller bearings. The movement resistance to train movement of freight cars is calculated as follows for the 6 groups mentioned above when the speed (v) is reached:

First group - four-axle open half-car (pv) wagons, the weight of which exceeds the load capacity of six tons per axle (q):

\[ \omega_{a,pv,4}^{rr}(q>6) = 0.53 + \frac{3.6 + 0.08v + 0.00275v^2}{q_{o,pv,4}}, \text{ N/kN} \]  

(1)

Second group - tank wagons with a carrying capacity of more than six tons, designed to be loaded with liquids or gases (sys) that are subject to regulation by weight:

\[ \omega_{a,sys,4}^{rr}(q>6) = 0.642 + \frac{2.925 + 0.0473v + 0.00275v^2}{q_{o,sys,4}}, \text{ N/kN} \]  

(2)

The third group - flatbeds (pl), covered wagons (kr), and other wagons (pr) with a load capacity of more than six tons that can be carried by a single ox:

\[ \omega_{a,pl,kr,pr,4}^{rr}(q>6) = 0.7 + \frac{3 + 0.1v + 0.0025v^2}{q_{o,pl,kr,pr,4}}, \text{ N/kN} \]  

(3)

Fourth group - empty four-axle wagons with a weight capacity less than six tons per axle:

\[ \omega_{a,4}^{rr}(q\leq6) = 1.0 + 0.044 \cdot v + 0.00024 \cdot v^2, \text{ N/kN} \]  

(4)

The fifth group is eight-axle wagons:

\[ \omega_{a,8}^{rr} = 0.7 + \frac{6 + 0.0377v + 0.00214v^2}{q_{o,8}}, \text{ N/kN} \]  

(5)

The sixth group - Refrigerated cars (rf) with a capacity of more than six tons, carrying goods that require cooling during transportation:

\[ \omega_{a,rf}^{rr}(q>6) = 0.68 + \frac{3 + 0.1v + 0.00255v^2}{q_{o,rf}}, \text{ N/kN} \]  

(6)
If a train consists of \(k\) \((k=1\div6)\) groups of cars, the basic braking force of the freight cars in the train is calculated as follows

\[
\omega_{\text{a}}'' = \frac{\omega_{\text{a.pvA}}'' \cdot \sum Q_{\text{br.pvA}}}{} + \frac{\omega_{\text{a.sysA}}'' \cdot \sum Q_{\text{br.sysA}}}{} + \frac{\omega_{\text{a.rfA}}'' \cdot \sum Q_{\text{br.rfA}}}{} + \frac{\omega_{\text{a.mA}}'' \cdot \sum Q_{\text{br.mA}}}{} + \frac{\omega_{\text{a.kaA}}'' \cdot \sum Q_{\text{br.kaA}}}{} + \frac{\omega_{\text{a.kaA}}'' \cdot \sum Q_{\text{br.kaA}}}{}
\]

\[
\sum Q_{\text{br}} N/kN
\]

(7)

here, \(\sum Q_{\text{br}}\) – represents the gross weight of the train.

To calculate the rolling resistance of the wagons in motion, the wagons are divided into two groups, namely, four-axle and eight-axle wagons, in order to perform the current calculations. Their values are determined using formulas (3) and (5), respectively. [20-22]. The main reason for this is the complexity of identifying the contribution of different types of wagons in the composition of the train.

In operation, each freight train consists of different types of wagons and compositions loaded with different types of cargo. These, in turn, form trains with the same number of wagons made up of the same type. This allows for varying energy consumption in the different freight trains composed of similar sets of wagons. To calculate the operating costs for each train composition, the relevant parameters of the wagons in the composition (type, number of axles, length, and weight) and the weight of the cargo (net) must be determined through the calculation of the transport accounts. The parameters of the wagons are identified by their numbers, and the weight of the cargo can be determined based on the natural gauge of the train.

A database of the parameters for all six types of freight wagons was developed based on the "Manual for the Classification of Freight Wagons with 1520 mm Gauge and an 8-digit Numbering System". Using this database, a program was developed to identify the necessary parameters for the calculation of the transport accounts based on the wagon number.

A fragment of the results obtained from using the developed program can be seen in Figure 1. The program developed for the EHM calculates the following parameters in an automated manner based on the 8-digit number and net weight \(q_{n}^k\) of the wagon taken from the natural gauge of the train:

- The total number of wagons in the train composition \(\sum m\);
- The type \(T^k\), number of compartments \(K^k\), length \(l^k\), and weight \(q^k\) of each wagon in the composition.

Based on the provided information, the following calculations can be automated:

The gross weight (brutto) of each wagon in the train composition:

\[
q_{bt}^k = q_{n}^k + q_{t}^k, \text{ t}
\]

(8)

The weight of the load carried by each wagon in the train composition:

\[
q_{o}^k = \frac{q_{br}^k}{K_o^k}, \text{ t/axle}
\]

(9)
The composition.

the natural gauge of the train:

automated manner based on the 8

Figure 1. The program developed for the EHM calculates the following parameters in an

parameters for the calculation of the transport accounts based on the wagon number.

Numbering System

of the train.

through the calculation of the transport accounts. The parameters of the wagons are

number of axles, length, and weight) and the weight of the cargo (net) must be determined

loaded with differen

The weight of the load carried by each wagon in the train composition:

The gross weight (brutto) of each wagon in the train composition

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A fragment of the results obtained from using

A database of the parameters for all six types of freight wagons was developed based on

To calculate the rolling resistance of the wagons in motion, the wagons are divided into

here,

"Manual for the Classification of Freight Wagon

The type

The total number of wagons in the train is calculated as follows

\[ \sum m_{pv,4}^{q>6} = COUNTIFS(q_n^1; q_n^m; >0; K_o^1; K_o^m; =4); \]

The total number of wagons in the second group:

\[ \sum m_{sys,4}^{q>6} = COUNTIFS(q_n^1; q_n^m; >0; K_o^2; K_o^m; =4); \]

The total number of wagons in the third group:

\[ \sum m_{pl,kr,pr,4}^{q>6} = COUNTIFS(q_n^1; q_n^m; >0; K_o^3; K_o^m; =4); \]

The total number of wagons in the forth group:

\[ \sum m_4^{q>6} = COUNTIFS(q_n^1; q_n^m; =0; K_o^1; K_o^m; =4); \]

The total number of wagons in the fifth group:

\[ \sum m_8 = COUNTIFS(K_o^1; K_o^m; =8), \text{wag.} \]

The total number of wagons in the first group:

\[ \sum m_{rf,4}^{q>6} = COUNTIFS(q_n^1; q_n^m; >0; K_o^1; K_o^m; =4); \]

If the following equation is satisfied, a conclusion is made that all wagons have been analyzed:

\[ \sum m_{pq}^{q>6} = COUNTIFS(q_n^1; q_n^m; >0; K_o^1; K_o^m; =4); \]

\[ T_v^1; T_m^1; =pv; q_o^1; q_o^m; >6, \text{wag.} \]
\[
\sum m = \sum m_{pv, A}^{q>6} + \sum m_{sys, A}^{q>6} + \sum m_{pl, kr, pr, A}^{q>6} + \sum m_4^{q>6} + \sum m_8 + \sum m_{rf, A}^{q>6} \]  
\tag{16}
\]

In this case, calculations are redone using formulas (10)-(15).

The share of the first group of wagons:
\[
D_{pv, A}^{q>6} = \frac{\sum m_{pv, A}^{q>6}}{\sum m} \]  
\tag{17}
\]

The share of the second group of wagons:
\[
D_{sys, A}^{q>6} = \frac{\sum m_{sys, A}^{q>6}}{\sum m} \]  
\tag{18}
\]

The share of the third group of wagons:
\[
D_{pl, kr, pr}^{q>6} = \frac{\sum m_{pl, kr, pr, A}^{q>6}}{\sum m} \]  
\tag{19}
\]

The share of the forth group of wagons:
\[
D_4^{q\leq6} = \frac{\sum m_4^{q\leq6}}{\sum m} \]  
\tag{20}
\]

The share of the fifth group of wagons:
\[
D_8 = \frac{\sum m_8}{\sum m} \]  
\tag{21}
\]

The share of the sixth group of wagons:
\[
D_{rf, A}^{q>6} = \frac{\sum m_{rf, A}^{q>6}}{\sum m} \]  
\tag{22}
\]

If the following equality is satisfied, a conclusion is drawn that all wagons have been analyzed:
\[
D_{pv, A}^{q>6} + D_{sys, A}^{q>6} + D_{pl, kr, pr}^{q>6} + D_4^{q\leq6} + D_8 + D_{rf, A}^{q>6} = 1 \]  
\tag{23}
\]

In this case, calculations were redone based on formulas (10) - (15) in reverse order.

The total weight (gross weight) of the wagons in the first group:
\[
\sum Q_{pv, A}^{q>6} = \text{SUMPRODUCT}\left(\frac{(q_n^{1} \cdot q_n^{m>0}) \cdot (K_o^{1} \cdot K_o^{m=4}) \cdot (T_{t}^{1} \cdot T_{t}^{m=pv}) \cdot (q_o^{1} \cdot q_o^{m>6}) \cdot (q_{br}^{1} \cdot q_{br}^{m})}{(T_{t}^{1} \cdot T_{t}^{m=sys}) \cdot (q_o^{1} \cdot q_o^{m>6}) \cdot (q_{br}^{1} \cdot q_{br}^{m})}\right), \text{t.} \]  
\tag{24}
\]

The total weight (gross weight) of the wagons in the second group:
\[
\sum Q_{sys, A}^{q>6} = \text{SUMPRODUCT}\left(\frac{(q_n^{1} \cdot q_n^{m>0}) \cdot (K_o^{1} \cdot K_o^{m=4}) \cdot (T_{t}^{1} \cdot T_{t}^{m=sys}) \cdot (q_o^{1} \cdot q_o^{m>6}) \cdot (q_{br}^{1} \cdot q_{br}^{m})}{(T_{t}^{1} \cdot T_{t}^{m=pv}) \cdot (q_o^{1} \cdot q_o^{m>6}) \cdot (q_{br}^{1} \cdot q_{br}^{m})}\right), \text{t.} \]  
\tag{25}
\]
The total weight (gross weight) of the wagons in the third group:

\[
\sum Q_{p_l,k,r,p,r,A}^{q>6} = \text{SUMPRODUCT} \left( \left( \frac{q_n^1:q_n^m=0}{(q_n^1:q_n^m=0)^*(K_o^1:K_o^m=4)^*} \right) \left( \frac{q_br^1:q_br^m}{(q_br^1:q_br^m)^*} \right) \right), \text{t.} \tag{26}
\]

The total weight (gross weight) of the wagons in the fourth group:

\[
\sum Q_{4}^{q>6} = \text{SUMPRODUCT} \left( \left( \frac{q_n^1:q_n^m=0}{(q_n^1:q_n^m=0)^*(K_o^1:K_o^m=4)^*} \right) \left( q_br^1:q_br^m \right) \right), \text{t.} \tag{27}
\]

The total weight (gross weight) of the wagons in the fifth group:

\[
\sum Q_8 = \text{SUMPRODUCT} \left( \left( K_o^1:K_o^m=8 \right)^* \left( q_br^1:q_br^m \right) \right), \text{t.} \tag{28}
\]

The total weight (gross weight) of the wagons in the sixth group:

\[
\sum Q_{rf,A}^{q>6} = \text{SUMPRODUCT} \left( \left( \frac{q_n^1:q_n^m=0}{(q_n^1:q_n^m=0)^*(K_o^1:K_o^m=4)^*} \right) \left( q_br^1:q_br^m \right) \right), \text{t.} \tag{29}
\]

The gross weight of the train:

\[
Q_{br} = \sum Q_{p_{pv,A}}^{q>6} + \sum Q_{s_{sys,A}}^{q>6} + \sum Q_{p_l,k,r,p,r,A}^{q>6} + \sum Q_4^{q>6} + \sum Q_8 + \sum Q_{rf,A}^{q>6}, \text{t.} \tag{30}
\]

The total number of cargoes carried by the first group of wagons:

\[
\sum K_{p_{pv,A}}^{q>6} = \text{SUMPRODUCT} \left( \left( \frac{q_n^1:q_n^m=0}{(q_n^1:q_n^m=0)^*(K_o^1:K_o^m=4)^*} \right) \left( T_t^1:T_t^m=\text{pv} \right) \right), \tag{31}
\]

The total number of cargoes carried by the second group of wagons:

\[
\sum K_{s_{sys,A}}^{q>6} = \text{SUMPRODUCT} \left( \left( \frac{q_n^1:q_n^m=0}{(q_n^1:q_n^m=0)^*(K_o^1:K_o^m=4)^*} \right) \left( T_t^1:T_t^m=\text{sys} \right) \right), \tag{32}
\]

The total number of cargoes carried by the third group of wagons:

\[
\sum K_{p_{l,k,r,p,r,A}}^{q>6} = \text{SUMPRODUCT} \left( \left( \frac{q_n^1:q_n^m=0}{(q_n^1:q_n^m=0)^*(K_o^1:K_o^m=4)^*} \right) \left( T_t^1:T_t^m=\text{pl, kr, pr} \right) \right), \tag{33}
\]

The total number of cargoes carried by the fourth group of wagons:

\[
\sum K_4^{q>6} = \text{SUMPRODUCT} \left( \left( q_n^1:q_n^m=0 \right)^* \left( K_o^1:K_o^m=4 \right)^* \left( K_o^1:K_o^m \right) \right), \tag{34}
\]

The total number of cargoes carried by the fifth group of wagons:

\[
\sum K_8 = \text{SUMPRODUCT} \left( \left( K_o^1:K_o^m=8 \right)^* \left( K_o^1:K_o^m \right) \right). \tag{35}
\]

The total number of cargoes carried by the sixth group of wagons:
\[ \sum K^q_{rf,A} = \text{SUMPRODUCT} \left( \left( q^1_n : q^m_n > 0 \right) \left( K^1_o : K^m_o = 4 \right) \left( T^1_{t} : T^m_{t}=rf \right) \left( q^1_o : q^m_o > 6 \right) \left( K^1_o : K^m_o \right) \right). \] (36)

The total number of axles in the train:

\[ \Sigma K_o = \sum K^q_{pv,A} + \sum K^q_{sys,A} + \sum K^q_{pl,pr,A} + \sum K^q_{4} + \sum K^q_{8} + \sum K^q_{rf,A}. \] (37)

The average weight of cargo carried by the first group of wagons:

\[ \bar{q}^q_{o,pv,A} = \frac{\sum q^q_{pv,A}}{\Sigma K^q_{pv,A}}, \text{t/axle.} \] (38)

The average weight of cargo carried by the second group of wagons:

\[ \bar{q}^q_{o,sys,A} = \frac{\sum q^q_{sys,A}}{\Sigma K^q_{sys,A}}, \text{t/axle.} \] (39)

The average weight of cargo carried by the third group of wagons:

\[ \bar{q}^q_{o,pl,pr,A} = \frac{\sum q^q_{pl,pr,A}}{\Sigma K^q_{pl,pr,A}}, \text{t/axle.} \] (40)

The average weight of cargo carried by the fourth group of wagons:

\[ \bar{q}^q_{o,4} = \frac{\sum q^q_{4}}{\Sigma K^q_{4}}, \text{t/axle.} \] (41)

The average weight of cargo carried by the fifth group of wagons:

\[ \bar{q}^q_{o,8} = \frac{\sum q^q_{8}}{\Sigma K^q_{8}}, \text{t/axle.} \] (42)

The average weight of cargo carried by the sixth group of wagons:

\[ \bar{q}^q_{o,rf} = \frac{\sum q^q_{rf,A}}{\Sigma K^q_{rf,A}}, \text{t/axle.} \] (43)

In this way, the parameters necessary for the calculation of the draft of the wagons, including the main resistance to the movement of freight wagons, based on the weight \( q^k_n \) of the cargo and the number of 8-digit wagons taken from the natural section of the train, were identified in an automated way.

The calculation of the draft of freight wagons was carried out [18, 23] in the order indicated in the sources for assessing the impact of the main resistance to movement of freight wagons on energy costs for managing trains.

3 Results and Discussions

The section of railway track from Chukursay to Sariyog'och in Uzbekistan Railways is considered one of the busiest freight corridors. In the course of the investigation, a separate
analysis was carried out of the train traffic, types of wagons, and their condition (loaded or empty) for this section of railway track (Figures 2 and 3).

![Diagram](image1)

- Empty wagons - 48%
- Loaded wagons - 52%

![Diagram](image2)

- Eight-axle wagons - 2%
- Four-axle wagons - 96%

a) Results of observing the condition of the wagons (loaded or empty)

b) Results of the study of wagon axles

**Fig. 2.** The results of studying the composition of trains on the “Chukursay-Saryogoch” railway section.

![Diagram](image3)

- Covered wagons (kr); 17,8
- Tank wagons (sys); 23,9
- Half-open wagons (pv); 22,2
- Refrigerated wagons (rf); 2,3

- Other types of wagons (pr); 30,6
- Flat wagons (pl); 3,2

**Fig. 3.** The results of studying the types of wagons in the composition of trains on the “Chukursay-Saryogoch” railway section.

According to the second figure, it was observed that empty wagons in freight trains on the "Chukursay-Saryogoch" railway section constitute an average of 48% for the middle-sized wagons and 2% for the eight-axle wagons. Due to the small size of the eight-axle wagons, we will investigate the effect of the movement of four-axle freight wagons on the dynamics of the train. However, it was found that there are approximately half-empty wagons in the train composition on the investigated railway section. It is possible to observe the increase in the number of empty wagons in foreign railway systems as well [24].

The above findings indicate the necessity of separately calculating the dynamic resistance of the fourth group of wagons based on formula (4) during movement.

According to Figure 3, on the “Chukursoy-Sariyog’och” railway section, half-open wagons in the freight train consist have an average weight of 22.2%, tank cars have an average weight of 23.9%, and covered wagons have an average weight of 2%. Due to the small weight of covered wagons, it is necessary to calculate the separate solutions of the half-open wagons and tank cars for their movement using the formulas (1) and (2), respectively.

Therefore, the calculation of the movement of loaded wagons in the freight train with a weight distribution of 48% for empty wagons, 23% for loaded half-open wagons and tank cars has been made using the program developed for determining the main resistance (Figure 4).
The calculation of the resistance of freight cars based on movement speed is necessary to calculate the differential expression of the resistance of freight cars based on movement speed for various types of train movements. The calculation of the resistance of freight cars based on movement speed is necessary to evaluate the impact of the resistance of movement on energy costs of train management. The calculations were carried out on a 19 km railway section for the purpose of evaluating energy costs (Table 1) where the electric energy consumption of the train (A) and the movement time (Δt) were calculated for three different movement speeds (Vx).

![Graph showing the calculation results based on the production and conventional methods.](image_url)

**Fig. 4.** Results of calculating the traction resistance of freight wagons in the train composition.

According to Figure 4, it is necessary to calculate the differential expression of the resistance of freight cars based on movement speed for various types of train movements. The calculations were carried out on a 19 km railway section for the purpose of evaluating energy costs (Table 1) where the electric energy consumption of the train (A) and the movement time (Δt) were calculated for three different movement speeds (Vx).

**Table 1.** Results of carrying out weight calculations.

<table>
<thead>
<tr>
<th>Elements of the section</th>
<th>Length, m.</th>
<th>Electric energy consumption (kW-s) and travel time (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vx=38.8 km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conventional method</td>
</tr>
<tr>
<td>1 1000</td>
<td>0</td>
<td>90.8</td>
</tr>
<tr>
<td>2 1000</td>
<td>0</td>
<td>18.3</td>
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<td>3 4000</td>
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<td>0</td>
<td>18.3</td>
</tr>
<tr>
<td>5 1000</td>
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</tr>
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<td>6 1000</td>
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</tr>
<tr>
<td>8 1000</td>
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<td>11 1000</td>
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</tr>
<tr>
<td>12 1000</td>
<td>7.6</td>
<td>103.5</td>
</tr>
<tr>
<td>13 1000</td>
<td>-0.1</td>
<td>17.1</td>
</tr>
<tr>
<td>14 1000</td>
<td>-0.1</td>
<td>15.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>19000</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>
According to Table 1, it can be seen that when the train's speed is 38.8 km/h, 115 kW·s (9.9%) more electric energy is consumed using the developed method compared to the conventional method, while at a speed of 47.7 km/h, 145 kW·s (11.5%) more energy is consumed, and at a speed of 56.2 km/h, 171 kW·s (12.5%) more energy is consumed. Therefore, the developed method is intended to be used for measuring electric energy consumption based on the results of the calculations performed.

4 Conclusion

According to the "Rules for calculating train operations" developed in accordance with the 8-digit numbering system for freight cars with a 1520 mm gauge, freight cars are divided into 6 types (boxcar, platform, half-open car, tank car, hopper car, and others). The rules specify that freight cars should be grouped into 6 sets for the purpose of calculating the main resistance of trains. However, in practice, calculations of the resistance of trains during their movement on the tracks and the consumption of electrical energy are carried out by dividing freight cars into 2 sets (with 4 and 8 axles). The main reason for not taking into account all types of cars and all sets in the calculation of resistance is the absence of an appropriate instrumental means.

In the course of the research, a program was developed to identify the necessary parameters in the calculations of the wagon's movement based on the wagon number. This program was designed to automatically identify the necessary parameters in the calculations of the wagon's movement through the website https://trainlocomotive.netlify.app/. By using this program, the necessity of calculating the energy consumption of the train's primary resistance due to the movement of freight cars was determined. As a result, the program allows for the correct measurement of the travel time and energy consumption of trains based on the differentiated types and conditions (loaded or empty) of the freight cars in the train's composition.

The influence of the specific basic resistance of freight cars on the energy consumption of train movement is estimated. As a result, it is shown that a differentiated accounting of the types and condition of cars in a freight train (loaded or empty) makes it possible to correctly regulate the time of train movement and energy consumption.

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