Article citation info:
Sawczuk W, Kołodziejski S, Rilo Cañás AM. Determination of the resistance to motion of a cargo train when driving without a drive. Combustion Engines. 0000;XXX(X):xx-xx. https://doi.org/10.19206/CE-184051

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Polish Scientific Society of Combustion Engines

Determination of the resistance to motion of a cargo train when driving without a drive

ARTICLE INFO

Received: 9 August 2023
Revised: 1 February 2024
Accepted: 13 February 2024
Available online: 2 March 2024

The issue related to the motion resistance of a rail vehicle is very important for energy, environmental, and related energy consumption of the vehicle as well as vehicle performance with dynamic points. The latter aspect applies in particular to traction vehicles. The article presents several models of resistance to the movement of a freight train used by various railway authorities, for Polish and foreign rolling stock. The resistance values obtained from the models were verified against the tested freight train carrying aggregate. On the basis of the records from the locomotive recorder, linear models of speed changes over time and coasting paths (without drive) were determined. On the basis of the values obtained from the models of resistance to movement of a freight train, the paths of coasting to stop the train were determined on the basis of the UIC 544-1 card, which were related to the analyzed freight train.

Key words: *movement resistance, driving without the drive engaged, cargo train, operational tests*

1. Introduction

During the progressive movement of a rail vehicle in a gaseous medium (air), it is inseparably accompanied by resistance to motion. In the railway literature, there are many articles presenting empirical models describing the resistance to motion for both passenger and freight trains. These are the quadratic dependencies of the train speed, additionally taking into account the weight, axle load, and aerodynamic resistance while driving. Ultimately, the use of the dependence on train motion resistance is necessary for the calculation of energy consumption in the vehicle design phase as well as for the assessment of energy consumption for traction purposes. The first attempts to measure (measure) resistance to motion were carried out by Stephenson and Wood in 1818, but research in this area was only carried out by Harding and Gooch in 1840. However, these were tests conducted up to the speed of rail vehicles of about 100 km/h. It was only after 1904 that tests were carried out with vehicle speeds exceeding 200 km/h [15].

In the history of railway technology, chronologically, empirical relationships for resistance to motion were developed by Harding and Gooch in 1846, then by Clark in 1855, Barbier in 1898, Frank in 1907, Sanzin in 1908, Schmidt in 1910 in 1911, Leitzmann and von Borries in 1911, Strahl in 1913 and Sachs in 1928 [2]. The dependences on the resistance to motion are based in all cases of their creators on the equation describing the rolling resistance as a square function of speed, generally written as equation (1) [12]:

$$\mathrm{F_{RES}} = \mathrm{A} + \mathrm{B} \cdot \mathrm{v} + \mathrm{C} \cdot \mathrm{v} \tag{1}$$

where: $\mathrm{F_{RES}}$ – resistance force of the rail vehicle motion, v – speed of the rail vehicle, A, B, C – coefficients of resistance to motion.

The naming relationship (1) is the Davis equation, and its coefficients are related to the different components of resistance. The coefficient A is most often associated with the rolling resistance of the wheel on the rail, the coefficient B refers to the mechanical resistance associated with friction in the axial bearings, and the coefficient C is related to the aerodynamic resistance. In the calculations of the FRES movement resistance by various authors, special attention should be paid to the units, as they are given in N, N/t, N/kN, Ib/t. In the case of the train speed, the m/s and km/h units are interchangeable in the motion resistance equations [3, 6].

The resistance to motion of a rail vehicle or train is determined by measuring the consumption of electricity from electric traction at a constant speed. Another method that is more often used is the measurement of the run-down distance after the wagon, locomotive, or wagon train has accelerated from a given speed. Then, the measurement on a given section of the railway line with known track parameters is carried out until the wagon, locomotive, or wagon train stops. The tests related to the determination of the resistance to motion are also carried out, taking into account the aerodynamic resistance. These components of motion resistance tests are most often carried out in wind tunnels on scale models or on real objects [4, 8]. Similar works in the field of vehicle motion resistance are conducted by researchers in their works, e.g., in [9, 21], a methodology for determining motion resistance and aerodynamic resistance for electric vehicles is presented. The works [13, 14] present the movement resistances of an electric locomotive and a proposal to optimize the design of the drive system to reduce these resistances. The work [18, 22] presents the influence of the vehicle's driving route and weather conditions on the vehicle's movement resistance. Works [19, 24] determine the movement resistance of a light rail vehicle due to the wheel structure.

The article presents several models of motion resistance used by various railway authorities for Polish and foreign rolling stock to calculate the motion resistance of the tested freight train. The obtained values from the calculation of the resistance to motion were verified on the example of a selected freight train carrying aggregate. On the basis of the records from the locomotive recorder, linear models of speed changes over time and the coasting distance without the drive engaged were determined. On the basis of the values obtained from the models of resistance to movement of a freight train, the theoretical distances of the free-wheel drive were determined on the basis of the UIC 544-1 card, which were then referred to the analyzed freight train.

2. Purpose and methodology of research

The aim of the research is to verify selected models of motion resistance on the example of a freight train by determining the coasting distance of the train without drive and without the use of brakes. The test was carried out after starting up to the set speed and measuring the time and distance of driving without drive until stopping.

During the free running of the train from the set speed, the length of the path traveled by the freight train depends on such main factors as rolling resistance, aerodynamics, or load on the train with the transported load [1]. During the tests of a freight train carrying bulk materials, the coasting distance of the train without drive was determined, which was verified analytically (calculated) by determining the rolling resistance of the freight train using various models found in the railway literature. On this basis, on the example of the analyzed freight train, it was determined which of the models of motion resistance with the highest accuracy allows estimating the coasting distance without drive and without using brakes in the train during the tests.

The study was carried out on railway line 275 on the Legnica–Wrocław section. It is a standard-gauge railway line in south-western Poland with a length of 192.658 km, running through the area of the Lower Silesian and Lubuskie Voivodships, connecting Wrocław with Gubinek on the Polish-German border. A section of the railway line on the Legnica–Wrocław section with an inclination of about 0‰ was selected for the study.

3. Research object

The object of the research was a freight train consisting of a 6-axle diesel locomotive BR232 and 35 freight wagons of Eaos and Eamos 426W, 436W, and 437W coal wagons along with their variants. Figure 1 shows the view of the locomotive with the running gear, while Fig. 2 shows the composition of the loaded wagons before the tests.

Table 1. Train (composition) input before testing

No.	Name	Symbol	Value	Unit
1	Gross weight of the composition	m_{wag}	2778.8	[t]
2	Train weight	m_{poc}	2902.7	[t]
3	Train length	l_p	468	[m]
4	Number of wagons	n_{wag}	35	[pcs]
5	Train speed	v	60	[km/h]
6	Number of axles in wagons	n_o	140	[pcs]
7	Number of axles in the trainset	n_p	146	[pcs]
8	Equivalent section of the locomotive	S_{lok}	13.5	[m^2]
9	Equivalent section of wagons	S_{wag}	10	[m^2]
10	Continuous power at start	P_c	1675	[kW]
11	Pulling force at start-up	F_c	294	[kN]

All wagons were loaded with aggregate. In the loaded state, the gross weight of the trainset was 2778.7 t, with the permissible weight of 2800 t.

Fig. 1. View of the BR232 diesel locomotive – a), view of the bogie with the suspension system, power transmission and braking system – b)

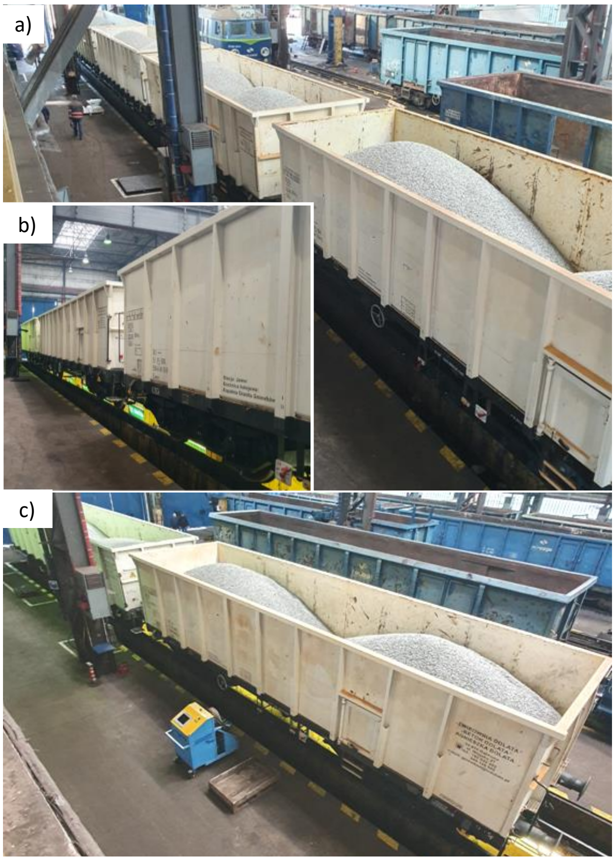

Fig. 2. View of wagons loaded with aggregate before testing

The length of the train was 468 m. Detailed data on the tested train are presented in Table 1. With these train parameters, the travel speed was set to v = 60 km/h.

4. Selected models of train motion resistance

Traffic resistance based on data from the tested freight train was determined on the basis of a number of dependencies for various railways, i.e., Polish, French, German, Czech, and Slovak [2, 3, 10]. No other models were used as for Chinese, Japanese or American railways due to the specificity of the tested train, for which the tests were carried out in the conditions of the European railway infrastructure.

Motion resistance is determined in the conditions of the Polish railway infrastructure, developed by the Railway Science and Technology Centre [3].

$$F_{res} = \left(K + 1.5\frac{v}{10}\right)\cdot m_{wag} + 150\cdot n_o + f\cdot\left(2.5 + n_{wag}\right)\left(\frac{v}{10}\right)^2 \qquad (2)$$

$$F_{res} = 77.98\ \text{kN}$$

where: F_{res} – the value of the movement resistance force in [N], K – bearing type factor, for rolling bearings K = 6.5, v – train speed in [km/h], m_{wag} – weight of wagons in [t], n_o – number of axles in the train, f – train type factor, for freight f = 8, n_{wag} – number of wagons in the train.

The resistance of the whole train, according to relation (2), is 77.98 kN, while the average resistance of one car is 2.17 kN for further calculations of the coast-down distance.

Motion resistance according to Franck's relationship [20].

$$F_{res} = 2.5 + 0.0145\cdot\left(\frac{v^2}{10}\right) + + \frac{0.54}{m_{wag}}\left(1.1\cdot k\cdot S_{lok} + 2 + n_{wag}\cdot q\right)\cdot\left(\frac{v}{10}\right)^2 \qquad (3)$$

$$F_{res} = 3.20\ \frac{N}{kN}$$

where: F_{res} – relative value of the movement resistance force in [N/kN], k – shape coefficient of the locomotive face, for a flat front k = 1, S_{lok} – equivalent section of the locomotive in [m²] (according to Table 1), q – wagon type coefficient, for open wagons loaded with q = 0.32.

The resistance of the whole train according to relation (3) is 3.20 N/kN, which for all wagons will be 87.26 kN, while the average resistance of one wagon will then be 2.42 kN for further calculations.

Movement resistance of French rolling stock according to the UIC standard [3].

$$f_{res} = 9.81\cdot\left(1.25 + \frac{v^2}{6300}\right) = 17.87\ \frac{N}{t} \qquad (4)$$

where: f_{res} – relative value of the movement resistance force in [N/t], v – train speed in [km/h].

The resistance of the whole train according to relation (4) is 51.87 kN, while the average resistance of one wagon will be 1.44 kN.

Train movement resistance according to Czech (ČD) and Slovak railways (ŽSR) [2].

$$f_{res} = A + B\cdot\frac{v}{100} + C\cdot\left(\frac{v}{100}\right)^2 = 2.48\ \frac{N}{kN} \qquad (5)$$

where: f_{res} – relative value of the movement resistance force in [N/kN], A – constant of the basic motion resistance force, for a train with loaded 4-axle freight wagons A = 1.4, B – motion resistance constant, for a freight train B = 0, C – drag coefficient, for a train with loaded 4-axle freight wagons C = 3.

The resistance of the whole train, according to relation (5), is 2.48 N/kN, which for all wagons will be 70.62 kN, while the average resistance of one wagon will then be 1.96 kN for further calculations of the locomotive rundown distance without the drive switched on.

Traffic resistance of freight and passenger trains according to French National Railways (SNCF) based on [11].

$$f_{res} = A + B\cdot\frac{v}{100} + C\cdot\left(\frac{v}{100}\right)^2 = 2.10\ \frac{N}{kN} \qquad (6)$$

where: f_{res} – relative value of the movement resistance force in [N/kN], A – constant of the basic motion resistance force, for a loaded freight train, A = 1.2, B – motion resistance constant, for a loaded and empty passenger and freight train, B = 0, C – drag coefficient, for a loaded freight train, C = 2.5.

The resistance of the whole train according to relation (6) is 2.10 N/kN, which for all wagons will be 59.80 kN. On the other hand, the average resistance of one wagon will then be 1.66 kN for the calculation of the coasting distance of the train without propulsion, presented in Chapter 5.

Motion resistance of an express freight train according to DB railways (based on the Strahl relationship) with rolling bearings (homogenous composition) based on [7].

$$f_{res} = 1.0 + 0.0002\cdot v^2 = 1.72\ \frac{N}{kN} \qquad (7)$$

where: f_{res} – relative value of the movement resistance force in [N/kN], v – train speed in [km/h].

The resistance of the whole train according to relation (7) is 2.10 N/kN, which for all wagons will be 48.98 kN. The average resistance of one wagon will then be 1.36 kN.

Train motion resistance according to Strahl's relationship [11].

$$f_{res} = \left[2.0 + 0.1\cdot(0.07 + C_3)\cdot v^2\right]\cdot g = 45.49\ \frac{N}{t} \qquad (8)$$

where: f_{res} – relative value of the movement resistance force in [N/t], C_3 – coefficient depending on the type of train, for fast and freight trains loaded (full) C_3 = 0.025, v – train speed in [m/s], g – gravitational acceleration g = 9.80665 [m/s^2].

The resistance of the whole train according to relation (8) is 45.49 N/t, which for all wagons will be 132.05 kN. The average resistance of one wagon will then be 3.67 kN.

Motion resistance of passenger trains driven by a locomotive according to German railways [7].

$$F_{res} = 3\cdot m_{log}\cdot g + 1.59\cdot S_{lok}\cdot v^2 + 1.5\ \cdot m_{wag}\cdot g + +0.09\cdot m_{poc}\cdot g + 0.0763\cdot\left(n_{wag} + 2\right)\cdot S_{wag}\cdot(v + 4.17)^2 \qquad (9)$$

$$F_{res} = 65301.1\ \text{N}$$

where: F_{res} – the value of the movement resistance force in [N], m_{lok} – weight of the locomotive in [t], m_{wag} – wagon weight in [t], m_{poc} – train mass in [t], S_{lok} – equivalent section of the locomotive in [m²], S_{wag} – equivalent section of wagons in [m²], v – train speed in [m/s], n_{wag} – number of wagons in the train, g – gravitational acceleration g = 9.80665 [m/s^2].

The resistance of the whole train according to relation (9) is 65.30 kN. The average resistance of one wagon will then be 1.81 kN.

Motion resistance used in French railways SNCF for wagons [23].

$$F_{res} = \left[C_1 + \frac{(3.6 \cdot v)^2}{C_2}\right] \cdot m_{poc} \cdot g = 54084.9\ \text{N} \qquad (10)$$

where: F_{res} – the value of the movement resistance force in [N], m_{poc} – train mass in [t], C_1, C_2 – coefficients depending on the type of train, for a heavy freight train, e.g. a coal wagon weighing 80 t, $C_1 = 1$, $C_2 = 4000$, v – train speed in [m/s].

The resistance of the whole train according to relation (10) is 54.08 kN. The average resistance of one wagon will then be 1.50 kN.

Train motion resistance according to the Italian State Railways (FS) based on [3]

$$f_{res} = A + C \cdot \left(\frac{v}{100}\right)^2 = 3.26\ \frac{\text{N}}{\text{kN}} \qquad (11)$$

where: f_{res} – relative value of the movement resistance force in [N/kN], A – constant of the basic motion resistance force, for a train with loaded covered freight wagons, A = 2.50 N/kN, C – motion resistance constant for a train with loaded covered freight wagons, C = 2.12 N/kN, v – train speed in [km/h].

The resistance of the whole train according to relation (11) is 3.26 N/kN, which for all wagons will be 92.92 kN. On the other hand, the average resistance of one wagon will then be 2.58 kN for the calculation of the coast-down distance, which is presented in detail in Chapter 5.

A collective list of empirical calculations of freight train motion resistance based on input data for ten models is presented in Table 2.

Table 2. The results of the calculated train motion resistances according to different models

No.	Train resistance model	Value for the train in [kN]	Value for the wagon in [kN]
1	Strahl dependencies	132.05	3.67
2	Italian State Railways (FS)	92.92	2.58
3	Franck dependencies	87.26	2.42
4	The Polish Railway developed by the Railway Science and Technology Centre	77.98	2.17
5	Czech Railways (ČD) and Slovak Railways (ŽSR)	70.62	1.96
6	German Railways for locomotive driven passenger trains	65.30	1.81
7	State Railways (SNCF) freight and passenger trains	59.80	1.66
8	French Railways (SNCF) for wagons	54.08	1.50
9	French rolling stock according to the UIC standard	51.87	1.44
10	DB Deutsche Bahn for express freight trains	48.98	1.36

The values of movement resistance, with separate details for the train and wagon, are presented in Table 2 from the highest to the lowest value. Preliminarily analyzing the data contained in Table 2, it can be unequivocally stated that the dispersion of the results of the train motion resistance according to different models (different countries) is very large. The obtained values ranged from 49 to 132 kN. This proves that despite the same marginal values of the test train being used to calculate the movement resistance, some models with extreme values (max and min) are subject to large errors. This assumes that the models in positions 5, 6 and 7 in the table have similar values and are therefore the most accurate. Verification of the calculation results with the tested test train will allow this statement to be accepted or rejected.

5. Theoretical driving distance without drive

In order to determine the distance covered by the train without drive from the set speed, the relation (12) for the braking distance from the UIC 544-1 card was used [5].

$$s = \frac{t_s}{2} \cdot v + \frac{m_{wag} \cdot v^2}{2 \cdot (F_c + F_{res})} \qquad (12)$$

where: t_s – brake cylinder filling time in [s], v – braking start speed in [km/h], m_{wag} – weight of the wagon with rotating masses in [t], F_c – brake force on the circumference of the wheel, in [kN], F_{res} – rolling resistance of the wagon determined from dependence (2)–(11) in [kN].

From dependence (12), the first part related to the braking force increase time t_s, the braking start speed v and the brake force on the circumference of the wheel F_c from the second part had to be removed. Then, for all methods of train motion resistance, the coasting distance without drive to stop was determined as the product of the average weight of the wagon with rotating masses and the square of the speed, divided by twice the running resistance of the wagon [16]. Finally, the dependence (13) on the coasting of a freight train was obtained.

$$s_w = \frac{m_{wag} \cdot v^2}{2 \cdot F_{res}} \qquad (13)$$

Table 3 shows the driving resistance values for individual methods and the corresponding coasting distances of the wagon to its stop. The values of the coasting distances without drive were ranked from the shortest distance with the greatest resistance to motion, to the longest distance of coasting without drive with the smallest resistance to the movement of the train.

The values of the calculated coasting distances are presented in the table from the smallest to the largest value. Analyzing the obtained and summarized results in Table 3, it is found that the values of the coasting distances without the drive are characterized by a large dispersion. The coasting distance ranges from 3 to 8 km. This is mainly due to the train movement resistance component, the values of which were also obtained with a large dispersion (Table 2). Only in the case of French railways, for three different models of train resistance, the dispersion of the results of the coasting distance was 1 km (max. 7.7 km, min. 6.7 km). The discrepancy in the values of the coasting distances results from the coefficients characterizing the freight wagon adopted for each method of driving resistance and adopted by various railway authorities. Due to the large differences in the values of the calculated coasting distances, with the same initial (boundary) conditions, it is necessary to verify the values obtained from the calculations to the test results of the test train. It will then be possible to indicate the model or group of models that most accurately determines the movement resistance of the train and freight wagon.

Table 3. List of coasting distances without drive for different methods of train motion resistance

No.	Train resistance model	Coasting distance without drive [m]
1	Strahl dependencies	3053.04
2	Italian State Railways (FS)	4338.65
3	Franck dependencies	4620.04
4	The Polish Railway developed by the Railway Science and Technology Centre	5169.96
5	Czech Railways (ČD) and Slovak Railways (ŽSR)	5708.82
6	German Railways for locomotive driven passenger trains	6173.75
7	State Railways (SNCF) freight and passenger trains	6741.85
8	French Railways (SNCF) for wagons	7454.07
9	French rolling stock according to the UIC standard	7772.96
10	DB Deutsche Bahn for express freight trains	8231.33

6. Operational tests of a cargo train

In order to verify the values of train motion resistances obtained by various methods (Table 2), the coasting distances obtained in this way without drive (Table 3) were referred to a freight train carrying aggregate. The tested train consisted of a BR232 locomotive and 35 coal wagons, which have already been described in Chapter 3. The tests were carried out on a horizontal section without inclination, the train was accelerated to a speed of 60 km/h and the coasting was started. The data of the tested train for the verification of the train motion resistance models are included in Table 1. The test was carried out at 19.00, the day was cloudy without precipitation, the air temperature was 10°C, the visibility of the air was good. From the recorder of the BR232 locomotive, the speed and time values of the locomotive were read from the moment of acceleration of the train to the speed of 60 km/h and from the moment of stopping. The measurement of the distance traveled was additionally referred to the hectometrical poles placed on the railway line every 100 m.

On the basis of the approximation of the train speed points read from the locomotive recorder over time and travel distance until stopping, the following linear function was determined.

$$v_w = -0.0386 \cdot t_w + 16.67 \qquad (14)$$

$$v_w = -0.033 \cdot s_w + 16.67 \qquad (15)$$

where: v_w – train speed during coasting in [m/s], t_w – rundown time of the train in [s], s_w – distance traveled by the train overrun in [m].

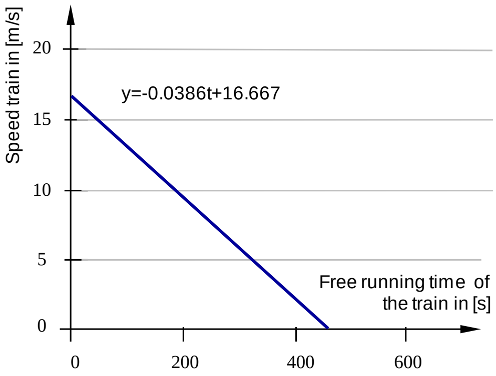

Fig. 3. Dependence of the approximated speed of the train during coasting without drive on the time of travel until stopping

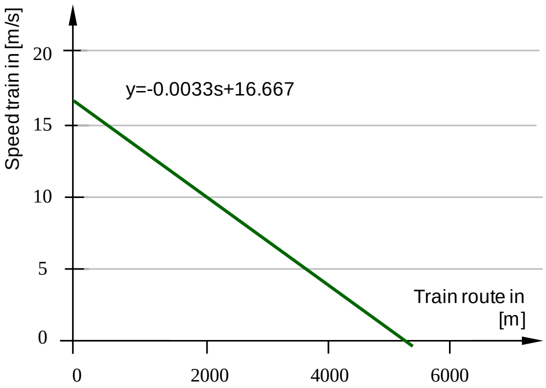

Fig. 4. Dependence of the approximated speed of the train during coasting without the drive on the distance covered until it stops

Based on data from the locomotive recorder of a freight train carrying aggregate with a total weight of 2902.7 t gross, which was accelerated to a speed of 60 km/h on a non-inclined track, the coasting distance traveled without a drive was 5050 m in 7 minutes. and 12 p.

7. Analysis of test results

The value of the coasting distance without the drive of the freight train was related to the theoretical distance determined from dependence (13). Table 4 lists again the values of the coasting distances without drive along with the relative percentage error based on the analyzed models of the motion resistance of a single freight car. The theoretical values of the coasting distances of the train without the drive switched on are listed in the order from the motion resistance model most accurately reflecting the resistance of the tested freight train to the least accurate model.

Analyzing the data contained in Table 4, it is concluded that for the analyzed case of a freight train, the most accurate method of determining the resistance to motion is the method developed for Polish railways. The relative percentage error of the calculated actual coasting distance without the drive compared to the theoretical one was 2.4%. In second place is the method resulting from the Franck dependence of the resistance of the train movement, the error of fitting the theoretical model to the real one was 8.5%. In third place is the method developed for Czech and Slovak railways with a relative percentage error of 13%.

The least accurate model of motion resistance turned out to be the DB method for German railways for express freight trains. With this method, the calculated coasting distance without the drive switched on in relation to the actual distance of the tested freight train, the error was 63%.

Table 4. Comparison of the theoretical and actual coasting distance of a freight train for different motion resistance models

No.	Train resistance model	Coasting distance without drive [m]	Difference [m]	Error [%]
1	The Polish Railway developed by the Railway Science and Technology Centre	5169.96	119.36	2.36
2	Franck dependencies	4620.04	430.56	8.52
3	Czech Railways (ČD) and Slovak Railways (ŽSR)	5708.82	658.22	13.03
4	Italian State Railways (FS)	4338.65	711.95	14.10
5	German Railways for locomotive driven passenger trains	6173.75	1123.15	22.24
6	State Railways (SNCF) freight and passenger trains	6741.85	1691.25	33.49
7	Strahl dependencies	3053.04	1997.56	39.55
8	French Railways (SNCF) for wagons	7454.07	2403.47	47.59
9	French rolling stock according to the UIC standard	7772.96	2722.36	53.90
10	DB Deutsche Bahn for express freight trains	8231.33	3180.73	62.98
The actual coasting distance of the tested train			5050.6 [m]	

Fig. 5. View of the last wagon after the tests: a) the railway inspector conducts a simplified test of the braking system operation, b) the railway inspector evaluates the technical condition of the wagon

After the tests of the coasting distance without the locomotive drive turned on, the stopped freight train was checked by the railway inspector, as shown in Fig. 5. The pressure in the main conduit was checked on the last car, and the condition of all cars (from the last to the locomotive) was visually assessed, in accordance with procedure contained in [17] and the train was dispatched to its further scheduled route.

The authors of the article are aware that the results of calculations and tests on one freight train are insufficient and tests should be carried out on a larger number of freight trains of different weights and for different coasting speeds. However, due to the extensive organizational preparation of such studies, it is complex and costly. It also requires a lot of involvement of the carrier to be willing to carry out such coasting tests during scheduled railway traffic.

8. Conclusions

On the basis of the tests carried out on a freight train and the calculations of train motion resistance, it was found that:

a) The methods of determining the coasting distance based on the weight of the train, speeds and models of driving resistance can be verified with high accuracy on the basis of operational tests of the train

b) On the example of the analyzed freight train, the most accurate method of determining the resistance of the train movement is the method for the Polish rolling stock and the method used by the Czech and Slovak railways. The relative percentage error for both methods when determining the theoretical coast-down distance and comparing it to the real driving distance without the drive was 2.4 and 8.5%, respectively

c) The literature presents a lot of models describing the train motion resistance, both for traction vehicles (locomotives) and trains. Verification of 10 models presented in the article showed that the relative percentage error is in the range of 2.4–63%

d) The high inaccuracy of matching models of motion resistance to real conditions is evidenced by the values of model coefficients and model variables. In some cases of the models, the coefficients for a freight wagon took into account only the case of covered wagons, and not, as for coal wagons, with an open roof.

Acknowledgements

The investigations were carried out within the Implementation Doctorate Program of the Ministry of Education and Science realized in the years 2021–2025.

Nomenclature

DB	Deutsche Bahn AG
ČD	České dráhy
FS	Ferrovie dello Stato Italiane
SNCF	Société nationale des chemins de fer français
UIC	Union Internationale des Chemins de fer
ŽSR	Železnice Slovenskej republiky
f_{res}	relative value of the movement resistance force
F_{res}	the value of the movement resistance force
F_c	brake force on the circumference of the wheel
m_{lok}	weight of the locomotive
m_{poc}	train mass
m_{wag}	weight of wagons
n_o	number of axles in the train
n_{wag}	number of wagons in the train
s_w	distance traveled by the train overrun
S_{lok}	equivalent section of the locomotive
S_{wag}	equivalent section of wagons
t_s	brake cylinder filling time

t_w rundown time of the train
v train speed
v_w train speed during coasting

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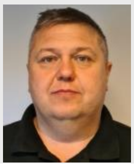

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