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STUDY OF THE IMPACT OF PASSENGER TRAIN CONTROL ALGORITHMS ON FUEL CONSUMPTION

Summary. This article examines different control algorithms for passenger trains to reduce fuel consumption. Control algorithms are based on the use of train freewheeling to minimize friction braking and account for the average speed requirements of the traffic schedule. The authors identified the dependencies of the efficiency of the algorithms on the gradients and curves of the track and investigated the patterns of these dependencies. It was determined under which track profile parameters the algorithm is maximally effective. Conclusions are presented on which track profiles the control algorithm saves the most fuel.

1. INTRODUCTION

Passenger trains' fuel consumption could easily be reduced by adjusting their timetables – for example, by reducing the need for braking or by reducing the number of unnecessary accelerations. However, timetables are not made to save fuel but to meet the needs of passengers. Therefore, passenger train timetabling is a delicate area in its own right, which cannot be viewed exclusively through the prism of reducing fuel consumption [1]. Studies have shown that passengers' needs are often at conflict with the goal of reducing fuel consumption. Passengers want stops and require more speed when they don't need them [2]. It is extremely difficult to save fuel if a train is behind schedule. From a fuel-saving point of view, this should not be done (if it can be done), but from a passenger's perspective, the train needs to catch up with the timetable as soon as possible [3]. The dilemma is that passengers do not consider the train's fuel consumption, and train delays cause inconveniences to passengers [4]. As people in the countryside move to the suburbs, some railway stops could be removed. This would contribute to the fuel efficiency of passenger trains. However, there are limits to the removal of stops, depending on the needs of passengers [5].

The interests of the train operator must also be kept in mind. Long journeys lead to operator fatigue. If we compare what is the higher priority between fuel saving (when the journey is slow and long) or the operator's alertness, the question is ambivalent [6]. It should be noted that passenger trains are usually operated on the same infrastructure as freight trains, which means that the timetable for passenger trains must also be coordinated with the timetable for freight trains [7]. Infrastructure features, such as the number of tracks, speed limits, and repair works, also dictate its conditions [8]. Therefore, to reduce the fuel consumption and emissions of passenger trains, researchers must first measure fuel consumption in real time [9] and then look for solutions to reduce it. One of the most commonly used fuel-reduction methods is the use of energy storage devices [10]. It is a technologically advanced field and a promising one. However, the authors of this study believe that too little research has been done on the possibility of saving fuel on passenger trains by adjusting their control algorithm without changing their timetable.

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New electric and electric-battery trains should be put into operation in Lithuania by 2026 [11]. According to the JSC "LTG Link" strategy, they will serve the Vilnius-Klaipėda railway section, which the passenger diesel multiple unit (DMU) PESA 730ML currently serves. The strategy also foresees that passengers will be served on the Vilnius-Turmantas-Vilnius and Vilnius-Ignalina-Vilnius routes from 2026 onwards by more modern and comfortable PESA 730ML trains (Fig. 1) instead of the technologically obsolete DMU DR1A series.

Fig. 1. DMU PESA 730ML used on Lithuanian railways

DMU DR1A have reached the end of their service life and no longer meet passengers' comfort and ergonomic requirements. The strategy estimates that by 2040, the Vilnius-Turmantas-Vilnius and Vilnius-Ignalina-Vilnius routes will cover an average of 657,000 km annually, and the number of passengers will gradually increase from 625,000 to 1.45 million. With the planned use of diesel trains and the need to reduce operating costs and pollution, it is necessary to reduce fuel consumption. The literature on reducing the energy consumption of rolling stock reveals three main groups of approaches: the improvement of railway technology, the development of an optimal train control plan, and the real-time simulation of optimal train control.

For conventional locomotives with a diesel internal combustion engine, the possibilities of improving the engine control components are being investigated [12]. Chinese researchers proposed an efficient energy management strategy for hybrid trains, taking into account the efficiency of different components [13]. Developing a train control plan that accounts for one or more parameters affecting train movement helps reduce fuel consumption [14]. It takes into account existing constraints such as a timetable, permissible speeds, and the technical characteristics of the rolling stock. Researchers at Gdansk University of Technology tried to reduce energy consumption by building a partial model of the Tripoli railway section [15]. Similar studies were conducted in America [16]. A driver assistance system operates on board a train and provides information based on current parameters on how to keep the train on schedule by selecting the optimal speed and avoiding unnecessary braking [17]. They recalculate the model in real time so that it is always optimal. By studying the basic principles of train control and the dependence of energy consumption on these principles, this knowledge can be applied to driving new sections and managing new rolling stocks, thus reducing fuel consumption.

2. METHODOLOGY OF THE STUDY

The present study consists of two main parts: an experimental journey along the section and a mathematical simulation of the train's movement (a testing of the developed train control methodology). One part of the study consists of an experimental journey on a real section, which, for reasons of national security, is referred to as Section A-J (the specific names of the steep sections are known to the authors). During it, data on fuel consumption on each section is collected and a speed curve is recorded on the safety system cassette, which is later used to compare the data with simulated train runs. The experimental journey was performed on a PESA 730ML passenger train. According to the timetable, MTU departs from Station A and arrives at Station J. The journey stops at nine stations and covers a distance of 147 km. The journey has a routing time of 2.21 hours and a line speed of 62.55 km/h, and a technical time of 2.03 hours and a technical speed of 77.71 km/h. The three-car diesel MTU PESA 730ML has three fuel tanks.

During the experiment, the fuel balances in the main fuel tanks were recorded on arrival at each station, based on readings from the train's main control computer. Calculating the differences between the recorded values yielded the total and average fuel consumption at all intermediate stations. Inter-stop running times corresponding to the technical time were also determined. A mathematical model of the MTU PESA 730ML train movement was used to simulate and evaluate various parameters that vary during the journey in order to develop a new train control methodology (to reduce fuel consumption) [18]. The Simulink module of MATLAB software was used to develop the model. The train model simulates the movement of the train based on the forces acting on it and calculates fuel consumption.

Data validation was performed—the simulation of train movement on the Vilnius–Turmantas section based on data recorded on the safety system cassette during a test run—to verify that the analytical train movement model in MATLAB/Simulink was functioning correctly. The actual speed data is compared with the simulated journey. By adjusting various model parameters, the aim was to ensure that the simulation curve matched the recorded speed values as closely as possible and that the calculated total fuel consumption matched the actual values as closely as possible.

The calculation results are compared with the experimental trip:

- actual fuel consumption – 220 l;
- calculated fuel consumption – 214.03 l;
- difference between fuel consumption and actual consumption – 2.8%.

The calculated fuel consumption differs from the actual consumption by < 3%. Therefore, the model created in the MATLAB/Simulink program can be used to perform simulation runs without conducting experimental tests.

The model is suitable for studying acceleration, deceleration, rolling, and other types of linear motion. The model includes blocks to simulate track gradients and curves, and can investigate the dynamic behavior of trains on specific railway sections, as well as the influence of infrastructure characteristics on the movement and speed of rolling stock (Fig. 2).

3. ANALYSIS OF THE RESULTS

The results of the experimental runs and virtual simulations based on the data from the study of section A-J are shown in Table 1. To assess the effectiveness of the developed train control methodology, it is necessary to compare the fuel consumption in real operation with the cost of the developed methodology. The comparative fuel consumption (l/km) obtained in operation and calculated with the proposed train control algorithm/methodology is shown in Fig. 3.

In Fig. 3, it is not the total fuel cost that needs to be considered (not the height of the bars, which differs due to the difference in the length of the railway sections), but the difference between the cost of operation and the cost of applying the methodology. It is not possible to see any patterns at first glance, and the issue needs to be examined separately and in more detail. Train control techniques not only change fuel consumption, but also the speed and duration of the journey. The percentage changes in fuel consumption, running time, and speed are shown in Fig. 4.

Different from the data in Fig. 3, the data in Fig. 4 can be appropriately compared with each other, as they show a percentage change in the values (due to the adaptation of the train control methodology) rather than absolute values. Examining these percentage changes requires the determination of whether there are any patterns and whether these changes correlate with any factors. The first question the researchers asked was whether the percentage reduction in fuel consumption correlates with the percentage change in driving time. A graph of comparative fuel consumption versus driving time is shown in Fig. 5.

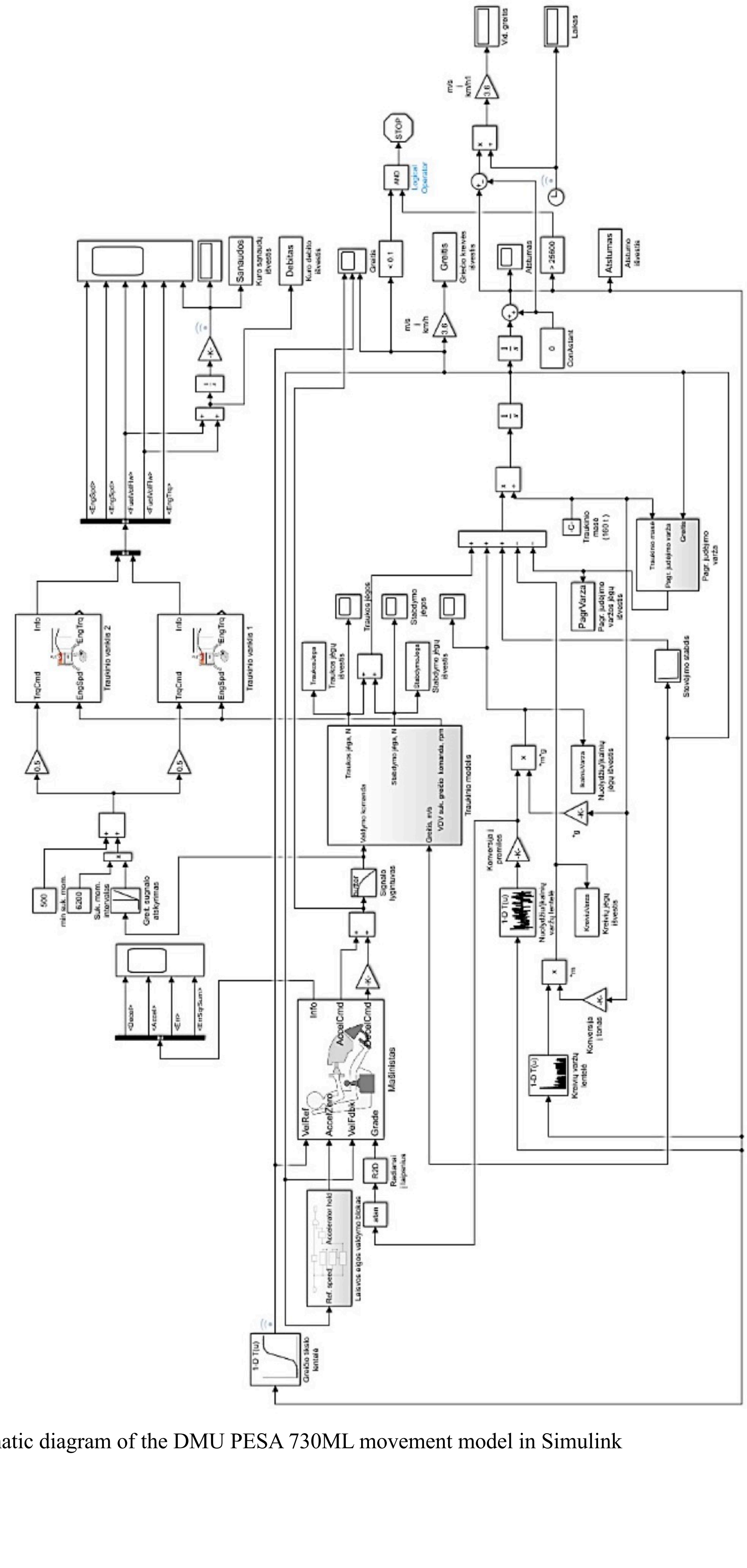

Fig. 2. Schematic diagram of the DMU PESA 730ML movement model in Simulink

Table 1

Experimental running and virtual simulation results

Railway Section	Kilometer	Fuel consumption in real operation, l	Fuel consumption according to the proposed methodology, l	Railway track gradient per mile	Rolling resistance due to road curves, kG/T
A-B	9.2	771	770	0.6	0.43
B-C	16.4	777	786	-0.6	0.24
C-D	34	839	860	-1.2	0.13
D-E	42.1	422	429	0.5	0.15
E-F	68.7	1148	1171	0.9	0.13
F-G	91.7	992	993	0.6	0.34
G-H	116.1	996	1016	-0.1	0.28
H-I	128.4	573	593	-0.8	0.16
I-J	138.8	575	587	-1.1	0.15

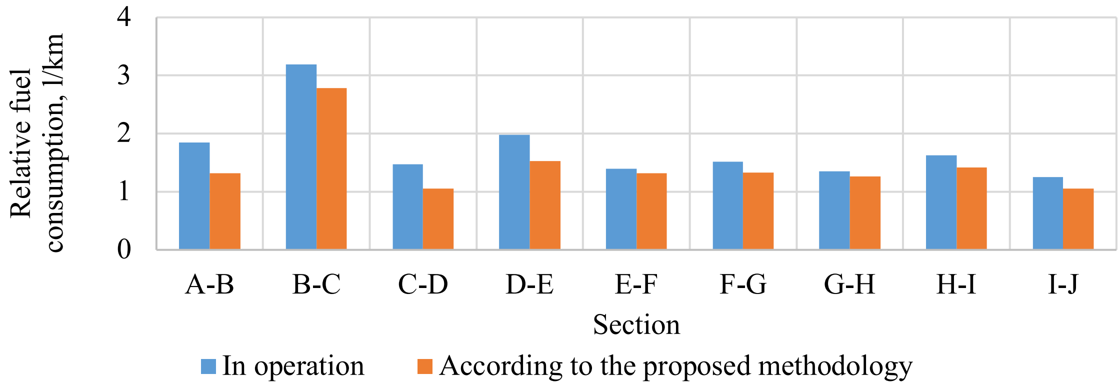

Fig. 3. Passenger train comparative fuel consumption

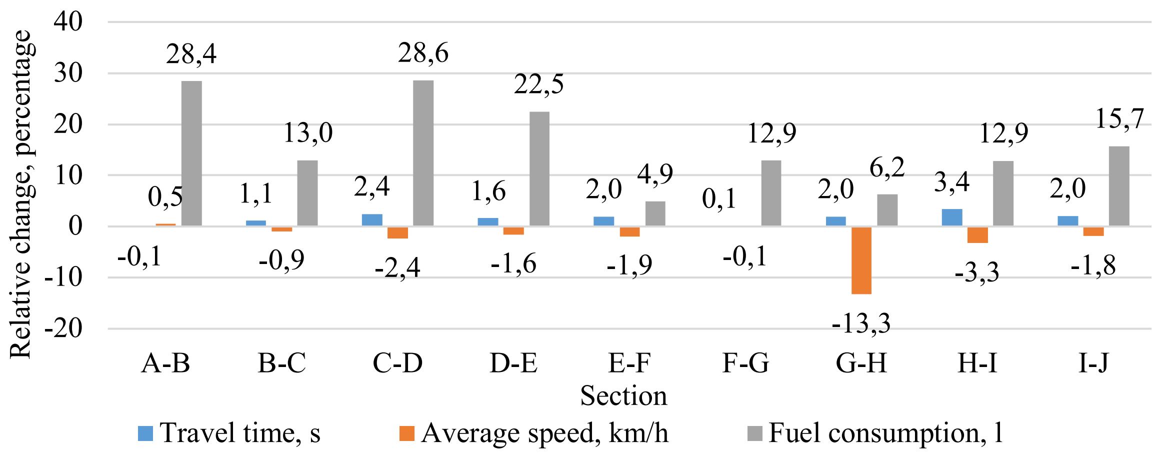

Fig. 4. The percentage changes in fuel consumption, running time, and speed

The data in Fig. 5 show that the average percentage of fuel savings is about 14.5% (in different sections from 5 to 30%). In a similar study by Polish scientists, using a rolling stock control algorithm they developed, fuel consumption savings averaged 12%. [15]. A similar study conducted in America found that up to 25% of fuel can be saved in this way [16].

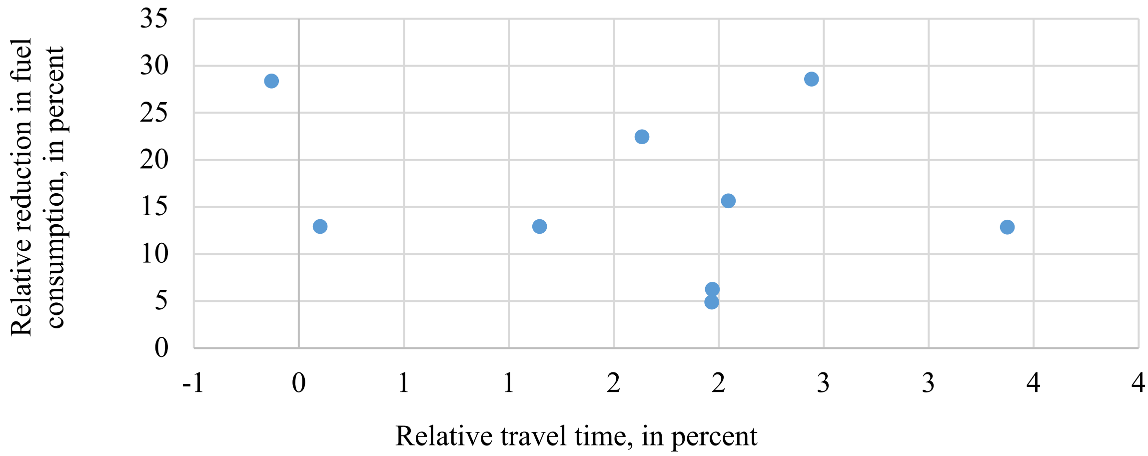

Fig. 5. Comparative fuel consumption and travel time graphs

There was no obvious correlation between the comparative fuel consumption and the change in journey time. On the one hand, this is strange—it would seem that the only way to save fuel is to reduce driving speed. However, it should be noted that during the train's operation and in the simulation of the train's operation according to the developed methodology, the train's timetable was followed, as were the permitted speeds on the sections. This factor may have led to the lack of correlation in the data in Fig. 5. Another area where a correlation can be found is the track profile. The track profile consists of gradients and curves. Fig. 6 shows the percentage change in comparative fuel consumption by gradient.

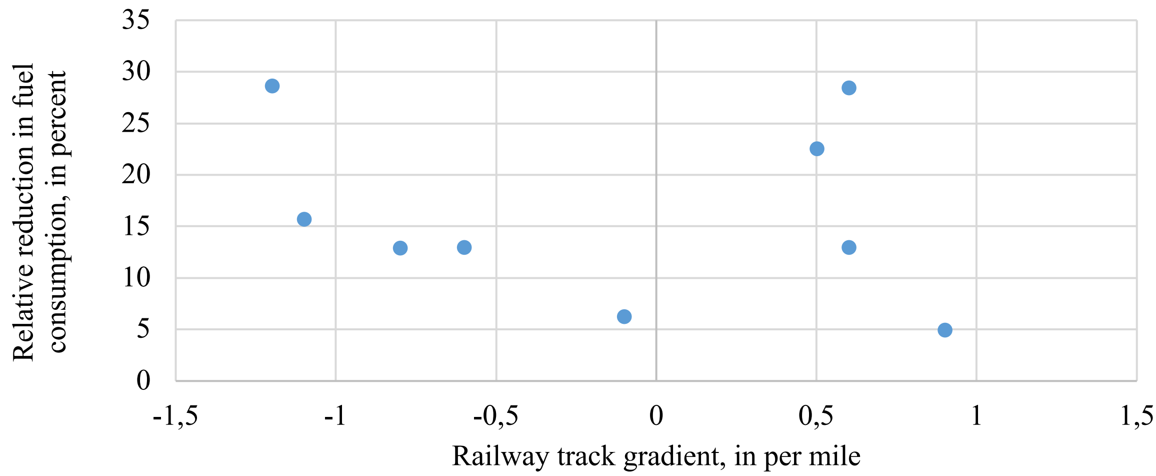

Fig. 6. Percentage change in comparative fuel consumption according to track gradient

At first, it may appear that there is no correlation in the data in Fig. 6. However, by splitting the data set into two parts—a positive gradient and a negative gradient—a correlation can be observed between the gradient of the track and the percentage change in comparative fuel consumption in each of these parts. The correlation is most obvious when the track gradient is negative. To fully assess the effect of the track profile, the rolling resistance generated by the road curves must also be considered. The percentage variation of the comparative fuel consumption according to the resistance of the track curves is shown in Fig. 7.

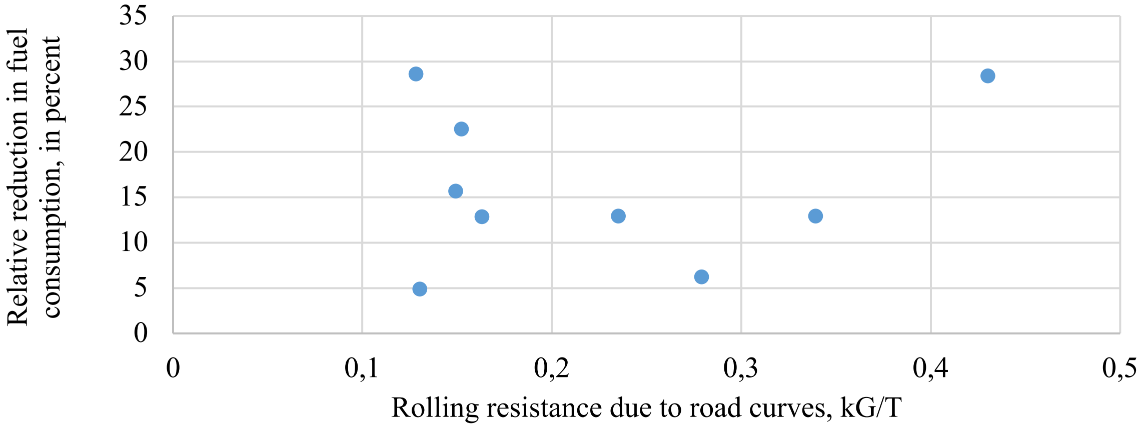

Fig. 7. Percentage change in comparative fuel consumption according to the resistance of track curves

Based on the data in Fig. 7, it is not possible to definitively confirm or deny the correlation. Up to a value of 0.3 for the resistance of the track curve, a correlation can be seen: as the resistance of the curve decreases, the percentage fuel saving increases. When the resistance of the track curve exceeds 0.3, the percentage fuel economy does not fit into this correlation. According to the results, the resistance created by the track's curve is not the only factor contributing to fuel consumption savings. Therefore, at this stage of the study, nothing is excluded, and further analysis is required. It is important to determine how the percentage fuel saving depends on the total resistance: the gradient of the track and the resistance of the curve. This dependence is shown in Fig. 8.

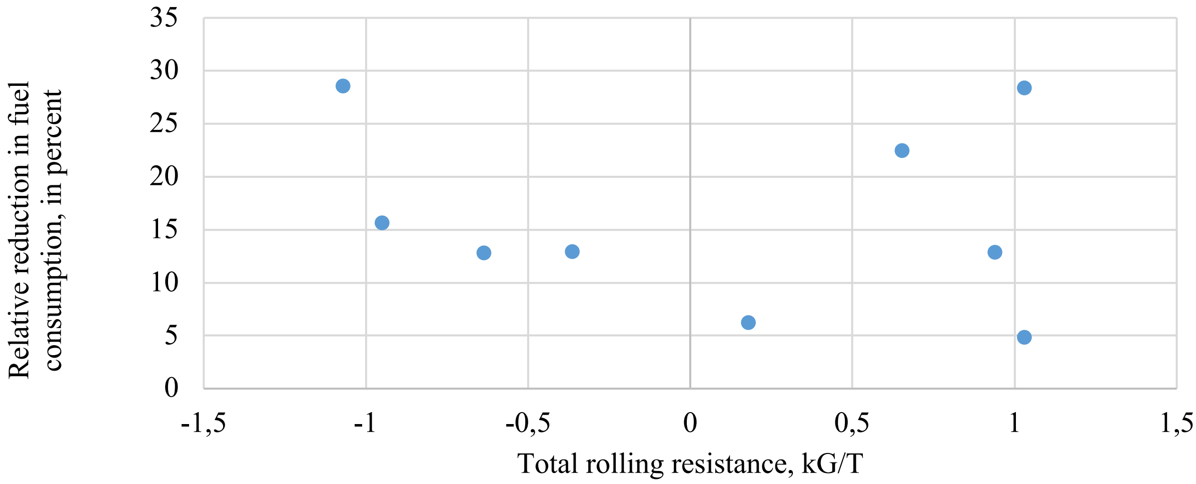

Fig. 8. Percentage fuel saving dependence on the total resistance of the track

The data in Fig. 8 are the result of a pairwise summing of the data in Figs. 6 and 7. The trend in Fig. 8, therefore, is similar to the trend in Fig. 6. However, one important difference between the tendencies in Figs. 6 and 8 does exist. Where the total resistance of the track is negative (the train is rolling downhill), the tendency in both figures is the same: more gradient – easier to roll – more savings, whether there are curves or not (note that extremely small radius curves were not considered). However, in the case of a train going uphill (where the track resistance is positive), fuel savings correlate well with the gradient of the track, but resistance distorts this correlation due to the curves.

The results show that the algorithm does not perform equally well for different track profiles, and this needs to be taken into account when applying the algorithm. The algorithm is especially useful in mountainous areas, where slopes and uphill sections are common. Even a 1 per mile of track gradient significantly increases the efficiency of the algorithm at the cost of the train's free rolling performance. It should also be borne in mind that this study was conducted within the existing train schedule. If the train schedule could be adjusted, even better fuel savings could be achieved by using the free rolling of DMUs.

Based on the results, it is possible to adopt the fuel-saving DMU control algorithm to different railway sections and different DMU series.

CONCLUSIONS

Adjusting the control scheme (algorithm) of a passenger train can reduce fuel consumption without disrupting the train's schedule. The average fuel savings for the entire journey (from Station A to Station J) is approximately 14.5%.

The study followed the train timetable and speed limits on the sections, and there was no obvious correlation between the comparative fuel consumption and the change in journey time.

An analysis of the dependence of fuel savings on resistance shows that where the train is rolling downhill (the total resistance is negative), the tendency is for a higher incline – easier to roll – more savings, and the resistance created by the curves of the track is not a major factor in this case.

In the case of positive resistance, fuel savings correlate well with track gradient, but the resistance of track curves distorts this correlation.

Based on the results, it is possible to efficiently adopt the fuel-saving DMU control algorithm to different railway sections and different DMU series.

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