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TRAIN DIESEL TRACTION OPTIMIZATION

SAŽETAK

OPTIMALIZACIJA DIZELSKE VUČE VLAKOVA

U ovom radu se obrađuje simulacija vožnje vlaka primjenom matematičkog modela vožnje, a u cilju dobivanja optimalne vožnje po kriteriju minimalne potrošnje goriva. Dobiveni rezultati simulacijom pokazuju da se može postići značajna ušteda goriva realizacijom optimalne vožnje. Za praktičnu upotrebu dobivenih rezultata predlaže se izrada informatora vožnje. Pritom se navode potrebni sadržaji i oblik informacija koje bi poslužile strojovođi da primjeni predloženi plan vožnje. U radu je provedena simulacija na primjeru dizelske lokomotive serije 2061 u vuči putničkih i teretnih vlakova na konkretnom realnom profilu pruge. Također se daju smjernice za sveobuhvatnu simulaciju vuče i primjenu dobivenih rezultata.

1. INTRODUCTION

Each railway administration takes efforts to perform freight and passenger transport in an as rational manner as possible. In the process, the scope of possible activities is rather large. Most frequently this involves conducting multi-aspected analyses and finding ways for the reduction of transport costs. In the matter of the diesel traction, the consumption of fuel represents a major item in traction costs. Therefore, it is essential to find the appropriate measures for its reduction, one of these being the optimum system of train operation.

In order to find the optimum operation for the completion of evry transport task, it is necessary to conduct comprehensive and thorough research. The obtained results should be integrated into the train operation plan in a precise manner, while the train operator would have to keep to this plan in a strict manner. Automatic traction locomotive operation would be ideal for the implementation of such detailed operation plan.

However, in the present situation the train operator has available the book of the operation plan and other written materials on the specific aspects of the track and method of operation. It is up to the train operator to manage the complete course of operation within the limits of the given plan, governed by his experience and skill. This particular method of operation is, among other things, of impact upon the consumption of fuel.

The basis for the theoretical research in the field of train traction optimization aimed at reaching the best fuel economy, in conjunction with a satisfactory transport time, rests in a valid mathematical traction model. The method of operation defined by this model should serve as the material for the elaboration of adequate instructions designed for the train operator on the economical method of operation. These instructions could represent the so called operation 'informer' and would not have any legal but recommendation status.

2. BASIC TRAIN TRACTION MATHEMATICAL MODEL ASPECTS

The movement of the train is described by a movement equation, while its solution yields the values required. In order for the model to give as precise results as possible, it is necessary to take into consideration all impact values and define them mathematically in an adequate manner. The developed mathematical model of train traction is rather complex and realistically describes the train movement [1,2]. The course of train movement is affected by the forces acting upon it, i.e. the traction force and movement resistance forces. The actual track profile is taken for establishing the track resistance, so that the model eonsequently has to include the length of the train having impact upon these resistance forces.

As a rule, the highest available values originating from the contour of the traction document of the concrete traction vehicle are taken as the traction force. Yet, the fact is that this traction force depends upon the chosen position of the handle for a particular system of operation of the traction vehicle and corresponds to the highest values only when the handle is set in to the highest position. For other positions of the operation system handle, the traction force gets adequately changed. This paper deals with the example of the series 2061 diesel-electric locomotive. It has eight available positions of the operation system handle, and its document is shown in Figure 1.

Individual positions of the operation system handle works the diesel engine control regulating the amount of injected fuel and keeping approximately constant the

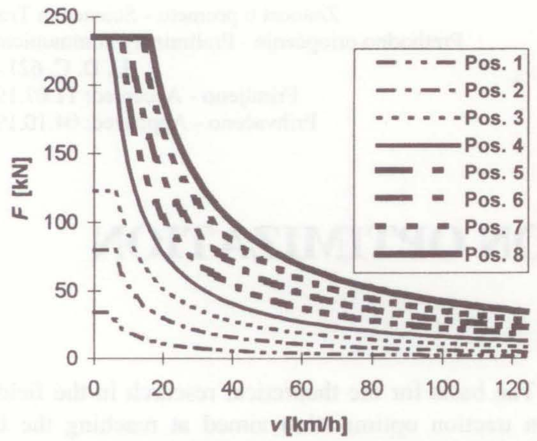


Figure 1 - **Series 2061 locomotive traction for eight positions of the operation system handle.**

revolution speed. To each handle position corresponds a certain speed of revolution of the diesel engine camshaft (Figure 2).

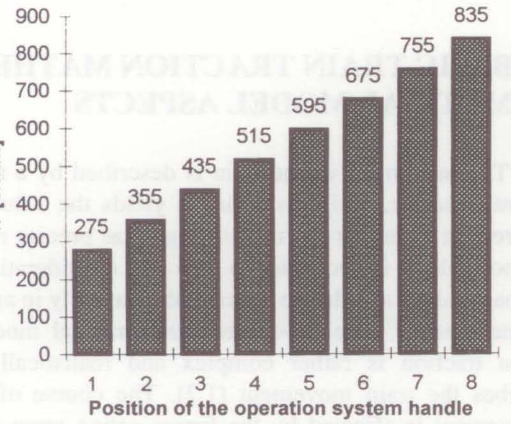


Figure 2 - **Interdependance of the camshaft revolution speed upon the position of the operation system handle.**

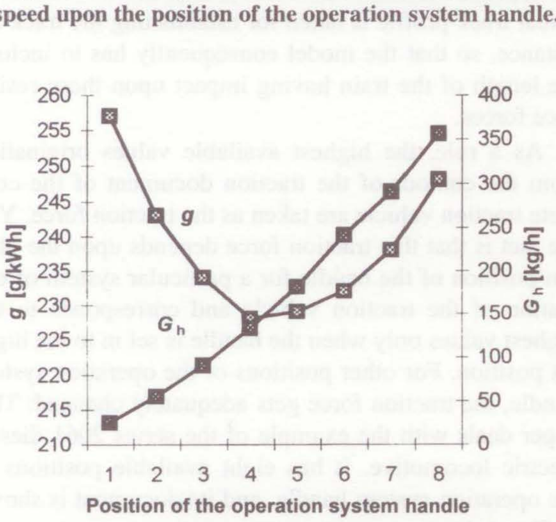


Figure 3 - **Interdependence of the specific and hourly fuel consumption in the diesel engine upon the operation system handle position.**

In order to be able to calculate the consumption of fuel in the mathematical model, it is necessary to know the respective characteristics of the diesel engine. The diesel engine is characterized by different specific consumption of fuel dependant upon the system of operation (Figure 3). The figure shows that the specific fuel consumption is minimum when the operation system handle is in position 4, i.e.5. The same figure shows the hourly consumption of fuel in a diesel engine at full loading.

The mathematical model in the process of operation simulation enables the selection of the operation system handle position through corresponding interactive operation. In this respect, a hybrid computer would be most satisfactory for larger possibilities of simulation. In this example, a digital computer has been used so that consequently the solution enables a programmed interruption of program application offering a new selection of the operation system handle position.

3. FUEL CONSUMPTION OPTIMIZATION

Establishing the minimum consumption of fuel is always carried out within certain given limits. Most frequently this refers to the journey time, highest allowed driving speed, possible sections of slow driving and other elements of the operation plan designed for the train operator. Meeting these requirements involves comprehensive simulations of operation of a given train on a concrete track section.

The mathematical model of train operation simulation calls for meeting the following elements:

A. Train defining elements:

– type (passenger, freight)
– type of train cars (double-axled, four-axled, freight)
– train mass
– train length
– type of traction vehicle.

B. Track defining elements:

– longitudinal track profile data
– stops and signals
– sections of limited speed and slow driving
– highest allowed speed.

Train operation simulation defines all essential values required for an all-inclusive evaluation of the subject operation. Individual values are established in the service of travelled route as an independent variable of differential movement equations. Similarly, the time of journey can be taken as the independent variable.

Picture 4, 5, 6 and 7, furnish the results of simulated operation of a passenger train of 250 ton-mass, 135 m long, formed of four-axled cars, pulled by a series 2061 diesel traction locomotive. The operation is simulated on the track section between Dugo Selo and Ivanić-Grad. The anticipated highest allowed speed is 100 km/h. Figure 4 shows the interdependence of the traction force and driving speed upon the travelled route. The train was started in Dugo Selo by setting the operation system handle in to position 6 for the speed of 100 km/h. The operation continued with the handle in position 4 until the 16.1 km of travelled distance, i.e. until the Ivanić-Grad distant signal. Now the handle was set in to idle position and the train proceeded until the 16.6 km at a pull. Until stopping at Ivanić-Grad the brakes were applied with approximately constant slowing-down, requiring the adequate braking force as indicated in the diagram with a negative traction force. The interdependance of the specific movement resistance in the process of operation is shown in Figure 5, while Figure 6 shows the hourly and total fuel consumption. The total power of the diesel engine used in this run is indicated in Figure 7.

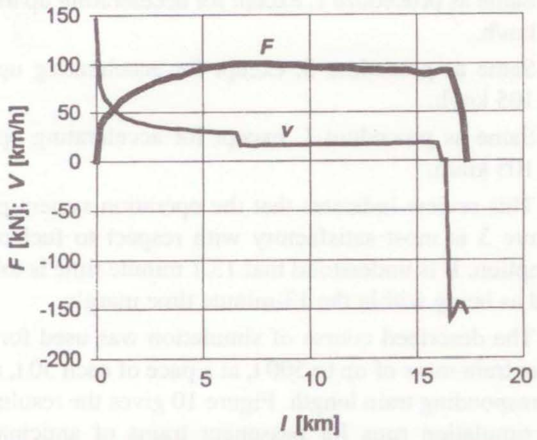


Figure 4 - **Interdependance of the operation speed and traction force upon travelled distance.**

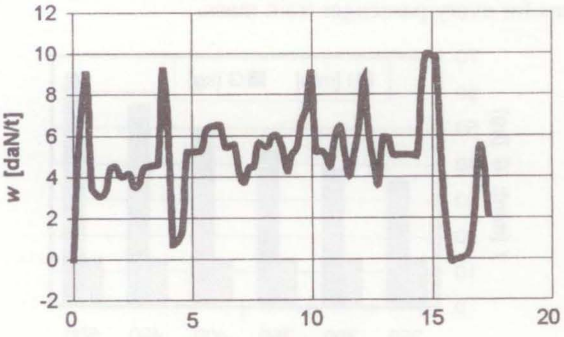


Figure 5 - **Dependance of the specific movement resistance upon travelled distance.**

The simulation of operation involves the possibility of the train running in four basic operation systems:

- acceleration, i.e. the operation with the traction vehicle operation handle set into one active position until reaching the given speed,
- operation at a constant speed, requring a rather variable traction force with regard to such track resistance forces,

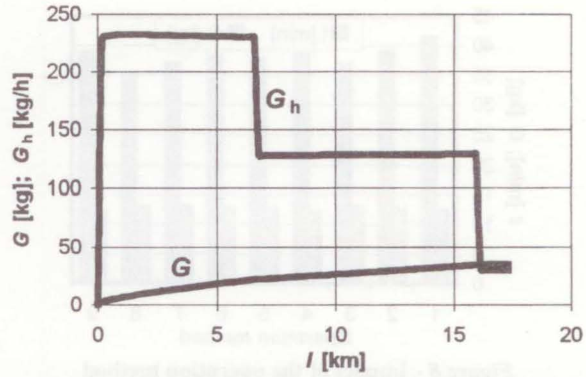


Figure 6 - **Interdependance of the hourly and total fuel consumption upon travelled distance.**

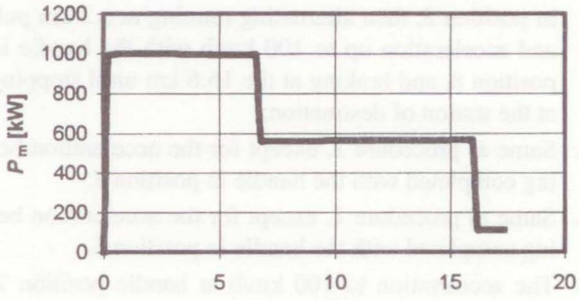


Figure 7 - **Dependance of the diesel engine power upon travelled distance.**

- operation at a pull, i.e. the operation with no active traction force, when the operation system handle is set into neutral position,
- braking with constant deceleration and adequate braking force.

Studies of the optimum operation involve numerous running simulations for all operation sections and all types of the train mass, in order to get a full review of the most satisfactory runs under the established conditions [3]. For a single track section and one train type and mass the operation is simulated in a number of variants. In the process, individual operation systems are combined with running with different positions of the operation system handle, that may be selected in different segments of operation. The number of possible simulations is rather high. Certain experience is needed in order to have the number of required simulations reduced to an acceptable level, as well as to reduce the required time. With given starting operation conditions it is necessary to use in the process of simulation as many as possible positions of the traction vehicle operation system handle requiring minimum specific fuel consumption. For the chosen traction vehicle this involves position 4 and 5.

Figure 8 and 9 show the example of one shortened simulation of operation of the passenger train of 250 t, 135 m long, on the already mentioned section.

In Figure 8 individual operation methods involve as follows:

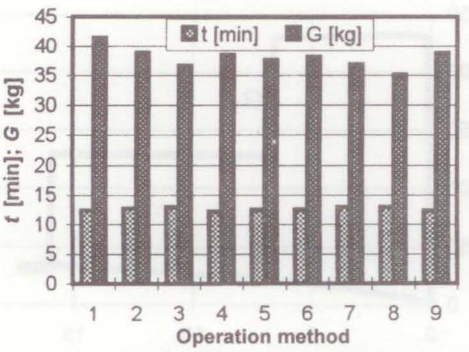


Figure 8 - **Impact of the operation method upon the operation time.**

1. Train acceleration up to 100 km/h with the handle set in position 8, then alternating running at a 2 km pull and acceleration up to 100 km/h with the handle in position 8, and braking at the 16.6 km until stopping at the station of destination;
2. Same as procedure 1, except for the acceleration being completed with the handle in position 7.
3. Same as procedure 1, except for the acceleration being completed with the handle in position 6.
4. The acceleration to 100 km/h at handle position 7, continuation of operation at a constant speed, braking until the 16.6 km.
5. Same as procedure 4, except for the acceleration being completed with the nadle in position 6.
6. Accelerating up to 100 km/h at handle position 7, running at a pull for 2 km, accelerating up to 100 km/h at handle position 5, running at a pull, braking until the 16.6 km.
7. Same as procedure 6, except for accelerating from the start at handle position 6.
8. Accelerating up to 100 km/h at handle position 6, continuing at handle position 4 until the 16.1 km, running at a pull until reaching the 16.6 km, braking until coming to a stop.
9. Same as procedure 8, except for continuing the run at handle position 5.

If the given time of operation of up to 13 minutes and the highest allowed speed of 100 km/h are required, the most satisfactory run appears to be the one described in procedure 8. This run, performed in given time yields the minimum fuel consumption of 35.1 kg.

In Figure 9, individual operation methods involve the following:

1. Acceleration up to 100 km/h at handle position 8, continuing until the 16.1 km at handle position 4, running until the 16.6 km at a pull, braking until coming to a stop.
2. Same as procedure 1, except for continuing at handle position 5.
3. Same as procedure 1, except for accelerating at handle position 7.

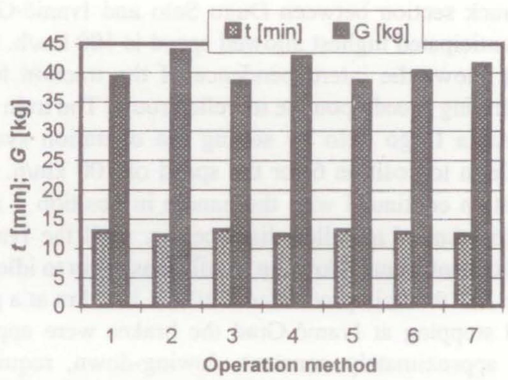


Figure 9 - **The impact of the operation method upon the time of run and fuel consumption for the passenger train of 300 t mass.**

4. Same as procedure 3, except for continuing at handle position 5.
5. Same as procedure 1, except for accelerating up to 95 km/h.
6. Same as procedure 3, except for accelerating up to 105 km/h.
7. Same as procedure 1, except for accelerating up to 105 km/h.

This review indicates that the operation system procedure 3 is most satisfactory with respect to fuel consumption. It is understood that 13.1 minute time is tolerated as being within the 13-minute time margin.

The described course of simulation was used for all other train mass of up to 500 t, at a pace of each 50 t, and corresponding train length. Figure 10 gives the results of all simulation runs for passenger trains of anticipated mass and length on the subject section. The figure shows the run times and total fuel consumption for optimum runs for every passenger train mass.

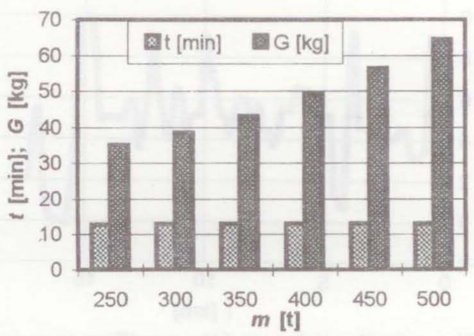


Figure 10 - **Dependance of the run time and fuel consumption upon the passenger train mass for optimum operation system procedures.**

Analogue run simulations in the same section of the route were completed for trains of the mass range of between 400 and 800 t, and corresponding train length. Optimum run was established for each mass, i.e. defined the operation system procedure in given time with least fuel consumption. In the procedure the maximum allowed speed of 80 km/h was anticipated. The results of these simulations are shown in Figure 11. The figure shows the fuel consumption and run times for each train mass with optimum operation system procedure.

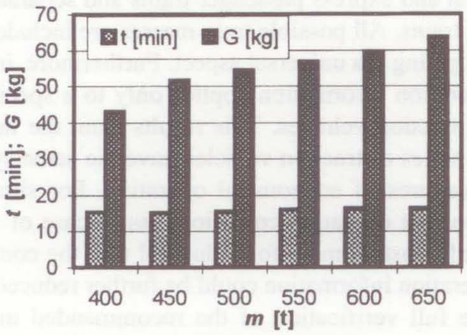
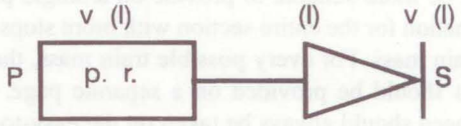


Figure 11 - **Dependance of run times and fuel consumption upon freight train mass for optimum operation system procedures.**

The results of completed simulations should be given a corresponding written form in order to be of use to the operator as instructions for optimum operation. It would be convenient to call these instructions 'the operation information' having the status of recommendations, with no legal binding. [4]. They should have the same format as all other written material designed for the operator for the completion of operation procedures. The arrangement of operation information must in the first place meet the requirement of easy-to-follow material; in this manner the operation information would be accepted by the operator as a useful material. The recommended symbols and descriptions of the operation system procedures have the following from:



The above marks have the following meaning:

P - departure stop

S - the next stop

p.r. - the operation system handle position

V (L) - speed, i.e. the travelled distance requiring keeping the mentioned handle position, i.e. the indicated system procedure.

The square indicates the operation with active traction; the horizontal line means the operation at a pull; the triangle with 'k' mark means braking and the vertical line means stopping.

Figure 12 shows the example of possible content of one operation information page for economical operation in the before mentioned section for the passenger train of predictable mass characteristics. Here the train masses are given for every 50 t. As the case may be, this step may also be different.

If the traction force is affected by the set electric heating of passenger trains, the operation information

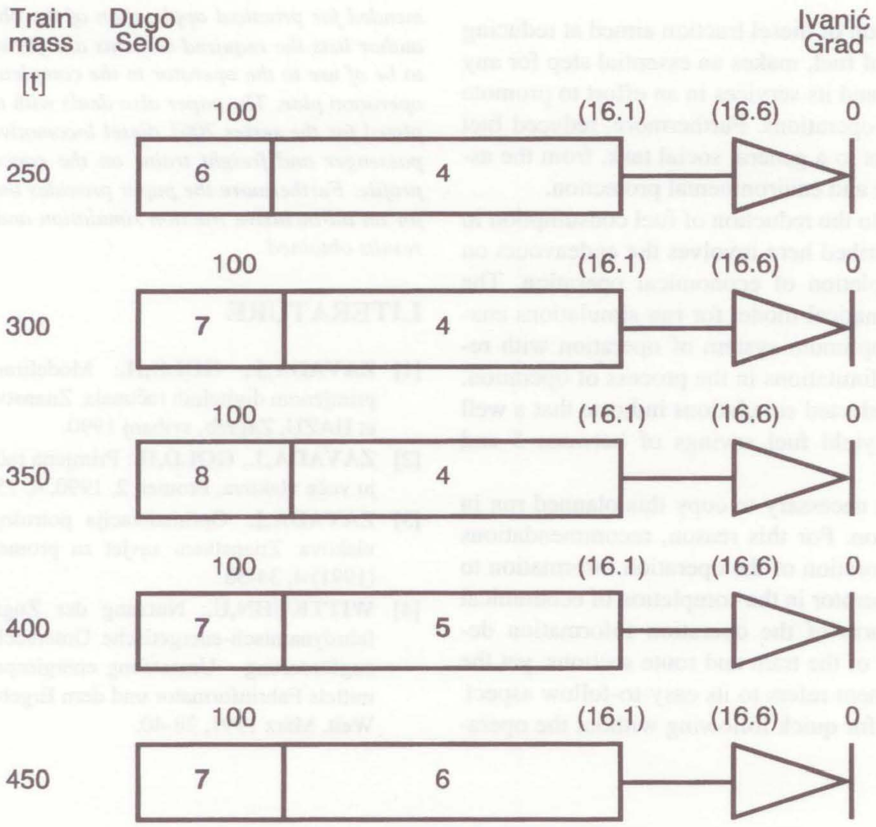


Figure 12 - **Anticipated aspect of one operation information page.**

should offer also this variant of economical operation. The shown method of information provision is suitable for through passenger trains. For local passenger trains it would be more suitable to provide on a single page the information for the entire section with more stops but for one train mass. For every possible train mass, the information should be provided on a separate page. In any case, heed should always be taken on the easy-to-follow aspect of provided information for economical operation. The operation information should be elaborated for each series of traction vehicles separately. The operation information shall present in a precise manner the operation mode, i.e. the position of the operation system handle at every moment of operation. If the operator follows the recommended operation mode from the operation information, this will guarantee minimum fuel consumption of the traction vehicle in normal external conditions.

The operation information for freight trains is provided in a similar way. The mass range is larger, frequently with a step of 100 t, yet in case of multiple traction it is convenient to provide the information for every 50 t. In case of the application of multiple traction (traction provided by several vehicles in the train), the operation information for a single traction vehicle may be used, yet the mass of the entire train with multiple-traction is devided with the number of traction vehicles.

4. CONCLUSION

The optimization of diesel traction aimed at reducing the consumption of fuel, makes an essential step for any railway company and its services in an effort to promote more economical operations. Furthermore, reduced fuel consumption refers to a general social task, from the aspect of energy use and environmental protection.

The approach to the reduction of fuel consumption in train traction described here involves the endeavours on finding and completion of economical operation. The developed mathematical model for run simulations enables finding the optimum system of operation with regard to the given limitations in the process of operation. The results of conducted simulations indicate that a well planned run can yield fuel savings of between 5 and 10%.

However, it is necessary to copy this planned run in the actual operation. For this reason, recommendations are given for elaboration of the operation information to be of use to the operator in the completion of economical operation. The form of the operation information depends on the type of the train and route sections, yet the principal requirement refers to its easy-to-follow aspect. This is important for quick following without the operator being hindered in the performance of other procedures/activities essential for safety.

The operation information is elaborated separately for local and express passenger trains and separately for freight trains. All possible train masses are included, to a degree giving it a universal aspect. Furthermore, individual operation information applies only to a specific series of traction vehicles. This results from the fact that not all series of traction vehicles have the same systems or procedures of economical operation. For simplified and constant operation conditions, as in case of freight trains of constant mass for industrial use, the content of the operation information could be further reduced.

The full verification of the recommended methods and the obtained results would be reached by means of measurement in actual operation. For this reasons the habitual operation methods adopted by the operator should be compared with the ones obtained through the simulation referring to the optimum runs per criterion of minimum fuel consumption for the same operation time and the same limitations in the process of operation.

SUMMARY

The paper deals with simulated train runs by application of a mathematical operation model, aimed at reaching the optimum operation per the criterion of minimum fuel consumption. The results obtained in the process of simulation indicate that substantial savings of fuel can be reached by completion of optimum run. The elaboration of operation information is recommended for practical application of the obtained results. The author lists the required contents and form(at) of information to be of use to the operator in the completion of the proposed operation plan. The paper also deals with the simulation completed for the series 2061 diesel locomotive in the traction of passenger and freight trains on the concrete realistic track profile. Furthermore the paper provides the recommendations for an all-inclusive traction simulation and application of the results obtained.

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