PRACE NAUKOWE POLITECHNIKI WARSZAWSKIEJ
z. 96 Transport 2013

Anna Yu. Cherniak

State Scientific-Research Center of Ukrainian Railway Transport

OPERATIONAL DEFINITION OF THE POSSIBLE CAUSES OF THE DERAILMENT OF FREIGHT CARS

The manuscript delivered: April 2013

Abstract: The methods of the assessment of the derailment risk on basis of computer experiments with dynamic models of railway rolling stock are presented. Specially designed dynamic models include the necessary parameters that represent the state of rail vehicles in operation. The common set of the factors of derailment is proposed to decompose on the subsets. Any factor of each of the subsets is represented as a Boolean variable, which has an alternative value. The proposed methods can be used for the analysis of propensity of vehicle to derailment by the study of quantitative changes in safety performance.
Keywords: rolling stock, derailment factors, dynamic models

1. INTRODUCTION

On the railways with gauge of 1520 mm the freight train breakdowns are often come from reasons such as design, manufacture and technical maintenance flaws of running gears. Haul freight cars of gauge of 1520 mm are equipped with three-piece trucks model 18-100. In development this truck in the 30's of last century, the prototype was taken American truck type Barber. Bogies of this type have common design drawbacks, namely:

– large unsprung mass;
– instability and incompatibility characteristics of spring suspension;
– low critical hunting speed;
– intensive wear bearing surfaces of center plates;
– increased clearances between the axle boxes and side frames;
– unreliability of the side frames and bolsters;
– one-sided pressure on the brake shoes on wheels;
– small mileage between repairs.

These design drawbacks of trucks along with lack of their maintenance lead to an increased impact on the track and pose a real threat to safety. In connection with the concept of increasing speed on the railway lines of Ukraine one provides for the separation of passenger and freight traffic. Meanwhile, in the present the safety problem remains acutely relevant because of the cases of loss a stability of freight train wagons in fixed tracks.

In recent years DNDC UZ conduct research related to computer simulations, which precede derailment of rolling stock [1]. These studies aim to identify the mechanical factors and to find the most influential factors on the tendency of the rolling stock derailment. The results of this research have formed a technology assessing of the wagon derailment risk.

The main directions of this technology are:

– operational definition of the plausible derailment factors;

– evaluation of derailment risk with characteristics of the technical conditions of the running gears and track quality.

2. THE BASIC COMPUTER MODELS OF DYNAMICS

The theoretical bases of the above technology are the computer models of dynamics of rolling stock as well as the methods of evaluation of derailment risk. Software “Universal Mechanism” was used to creation these models of dynamics of rail vehicles [2].

The model, orientated on estimate of a derailment risk, that here is called the special model of dynamics, include some differences comparing to model of dynamics, which are being developed for other purposes, for example, to select the design the rational parameters of rolling stock, that is called the basic model of dynamics. But in both types of the models of dynamics of railway rolling stock are used the multi-body system approach (MBS) as well as the simulation in the time domain.

Usually the model for each vehicle contains one carbody, two bogie frames and four wheelsets, which are modeled as rigid bodies with six degrees of freedom each. Also axleboxs, beams, rods, wedges, balances, traction engines and transmission components might be included in the model of dynamics as rigid bodies. Thus, for describing the three-piece truck design of freight car we need to consideration the bolster, two side frames and four wedges as rigid bodies.

The mechanical system of rigid bodies is connected by the joints and force components. The characteristics of the suspension of design vehicles are presented by the force elements, which can include stiffness, damping and contact types, what there are the means of software “Universal Mechanism”. Also there is widely used a parameterization of the input parameters.

The basic models reflect the vehicle design features at nominal technical state. According to Ukraine standards in these models are used the track design with a 1520 mm gauge and inclined at 1:20 as well as fixed wheel and rail profiles, for example GOST-9036 and R65. Developed basic models of dynamics of freight cars of different types contain own car bodies without freight.

3. THE SPECIAL MODELS OF DERAILMENT

The main feature of special models, which are developed for estimate of the derailment risk, is the simulation of the parameters and characteristics that reflect the actual technical state of running gears of rolling stock at operation [4]. These models must describe not only the construction features of vehicle, which has probing, but also take into account all of credible factors which provoke a derailment. Consequently the special models of the dynamics of rolling stock, which are oriented on the research of derailments, must take into account the considerably anymore volume of information, to represent all conditions of the event adequately.

Adhering to the experimental design concepts and based on empirical data which obtained from the analysis of the technical conditions of railway vehicles using modern measuring devices, in the models separately is formed the set of the special parameters and the characteristics. Thus constructed models allow to search reasons and to set the alert limits of technical condition parameters of railway vehicles and the track quality.
For example, it was found out at research in relation to freight carriages of derailment tie-up not only with the construction but also with operational features of carriages. Therefore computer models of dynamics which are attracted to investigation of derailment risk must give possibility to take account of the operating changes of the certain geometrical parameters of details and knots and provide varying these parameters. In addition the plays, clearances and gaps in vertical, lateral and longitudinal directions of suspensions elements due to the wear, the changes of friction or damping coefficients, the contact stiffnesses and other characteristics must be take into consideration as the parameters and characteristics of special models [4]. In addition in these models the dynamics of freight wagons shall be described actual profiles of worn wheels. It is also possible to change the parameters of inertia of the body and the position of its center of mass due to different weight of freights.

The degree of working out in detail of special models from separate units of rolling stock or all units of the train also directly depends on the circumstances of event of derailment, that in different cases differ. Therefore for research and establishment of reasons of derailment it is expedient more in detail to represent all of features of car which left the tracks first. The complete models of the train dynamics are developed in a spatial setting for all units with a detailed presentation of the three or five cars with the car that derailed first.

A characteristic feature of the technology of computer simulation to investigate the derailment risk is the support of significant amount of computing research options because of a necessity to represent the circumstances of accidents adequately. Thanks to modern development of computer technology, these features do not cause complications.

The database of computer basic models of the dynamics of locomotives and railway cars, which operate on the railways of Ukraine, was created and is continuing to supplementing. Today, a number of special models of the main line locomotives and of the freight cars have developed. The availability of basic and special models in the database allows to creating the full computer models of dynamics of train on the principle of assembly.

4. THE DECOMPOSITION OF THE SET OF DERAILMENT FACTORS

Proposed technology of the assessment a derailment risk, besides adequate special models of the dynamics, is based on well-focused computer experiment. To form the plan of computer experiment is proposed to use the decomposition of the set of factors of the event of breach of safety in four subsets $F = F_1 \cup F_2 \cup F_3 \cup F_4$, which are separated from each other in meaning. These subsets are: technical conditions of the vehicles, the track quality, scheme of train formation and mode of train conducting.

Also to form a computer experiment plan it is offered, to represent any factor of every subset as a Boolean variable, that takes on alternative values: 1 - is an actual "value" and 0 - is the nominal "value" or “value” which as assumed improves safety conditions.

The first subset F_1 consists of factors, which reflect the technical conditions of the vehicle, which has derailment first. Thus, in the special models of dynamics of freight wagons to present the technical conditions of carts take account of such factors (fig.1):

– wagon wheel diameters and defects of rolling wheel profiles,
– draw downs of suspension springs,
– clearances in side bearings,
– wear of center plate, clearances in box guides, overvaluation of wedges.

In the second subset F_2 factors which indicate the state of quality of track are identified. Here the actual “values” are data obtained by the track recording vehicle at last passage and the alternative “values” are data corresponded to satisfactory state of track are used. In addition the surfaces of rails on the left and right sides at known information about the worn surfaces of the rails in the area of derailment may be used.

In the third subset F_3 contain factors that characterize the scheme of train formation, including the number of units in the train and the freight load of each wagon in train. Here the logical variables are used to generate options regarding the loads of wagons. As alternative options are considered combinations of empty and loaded cars, that preceded and followed by the car which had derailment first.

In the fourth subset F_4 the variables which reflect parameters of operation mode of train running at the site of the derailment, are included. The full subset of logical variables, that traction or brake modes represent, allows designing the computer experiment with several scenarios of the train running, including the transitional modes of motion. If there was a derailment of over run, the fourth subset is reduced to one element, which is parameterized by the running speed. In this case, the subset F_4 contains one element and computer experiment form by two values: the actual running speed and the alternative value of speed, which is less than actual value.

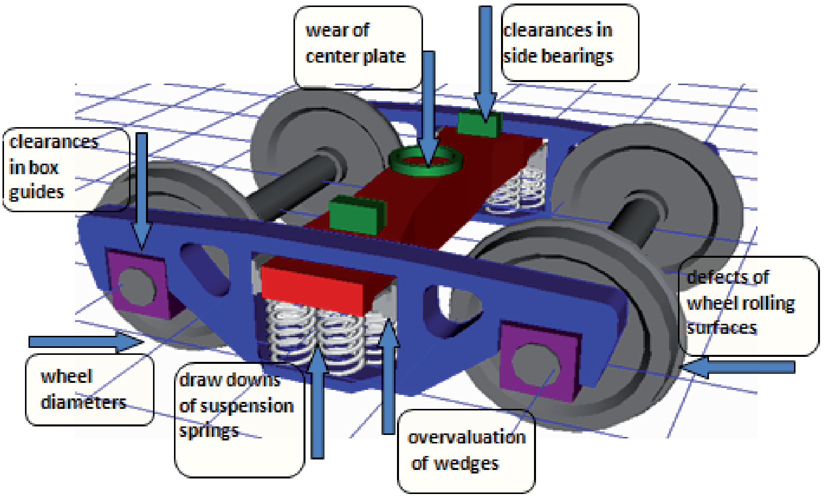

Fig. 1. The factors of the technical conditions of trucks (model 18-100)
in special model of freight car dynamics

The components of each subset may have an effect on the risk of derailment and therefore an analysis of the potential consequences on their differences must be made. This analysis shall assess the significance influence of the differences of factors on the derailment propensity. Used decomposition allows, first, to do structuring factors, and, secondly, at the event of certain circumstances of the derailment reduce the number of subsets or the number of components in each subset, in order to reduce the common number of calculated variants in the computer experiment. That allows a results interpretation do easier.

5. THE METHODS OF THE ASSESSMENT OF DERAILMENT RISK

For the first direction, which this research actually began from, source of input data, which the search of significant derailment factors is based on, is the specified event of derailment. Here the information from internal investigation of the derailment is used. For the second direction, by an information source, to execute the search of influential factors, as the specified event of the derailment so and a typical mode of operation (straight, curve, turn or switch) are possible.

The primary important index of derailment safety for running of the railway vehicles for 1520 mm track gauge is coefficient of supply of stability η from climbing of wheel flange on a rail head that like to the inverted derailment quotient *Y/Q* for 1435 mm track gauge [3, 5]. For the passenger rolling stock the minimum permissible value of this coefficient is [η] = 1,6; for conventional freight rolling stock – [η] = 1,3. Also the choice of the other indexes for conducting of researches is possible.

Within the proposed concept of assessment of significance of the derailment risk factors are designed three methods:

– the method of the prompt investigation of derailment (DIP);

– the method of determining the cause of derailment (DCD);

– the method of weighing the risk factors significances of derailment (DSF).

These methods are recommended to use in the case when the mechanical causes of derailment are disputable or are not obvious. Also these methods may be to use for analysis of the rail vehicle propensity to derailment by the study of quantitative changes of the indexes of a safety. This make possible to forecast the origin of problems (derailment), requiring immediate interference, even if general losses from factors did not yet attain a critical level. At these methods the output indexes of the safety of each simulation run of the dynamic behavior of a rail vehicle or train are analyzed to extracting the extreme values.

According to the first method (DIP), the multi-factors regression of minimum values of coefficient of supply of stability η is constructed. In mathematical sense the method is formulated as a choice of factors of computer experiment, establishment of their levels and intervals of varying, the construction of plan of experiment and the execution by the simulation the behaviors of dynamics system on changing of factors. Then the minimum value η determined at each simulation run and the coefficients of regression characterize influence of factors on the derailment risk of the system. Constructed as a result of the method the multiple regressions function can not only determine the significance of the influence factors on the possible event of the derailment, but also to establish the factor level, above which the criterion is violated safety [6]. Thus, the boundaries of an acceptable level of safety are defined. Some results of the regression analysis in relation to the technical state of gondola car are shown in fig. 2.

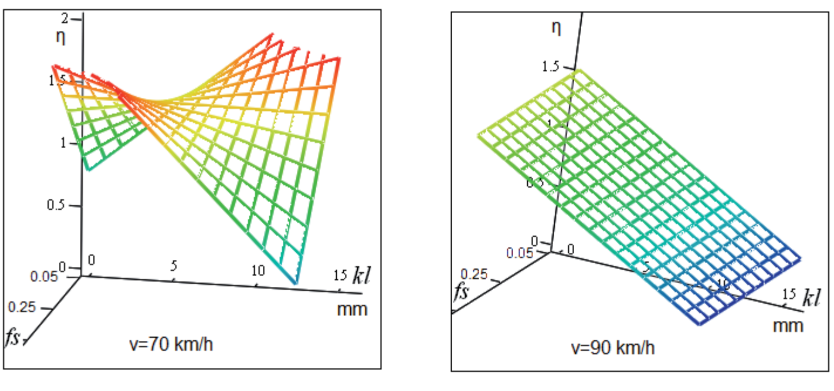

Fig. 2. Coefficient of supply of stability η as function in terms of wedge overvaluation (*kl)* and friction coefficient (*fs)* (car)

In the second and third method the result of each simulation run is represented as Boolean variable: 1 – if the event of derailment takes place (the minimum value η is less than the limit value), and 0 – in the opposite case. In the second method (DCD) the causes of derailment are established on the base of the logical concluding by the construction of the minimal disjunction form.

In third method (DSF) the significance of the influence factors to the accident is established on the basis of statistical inference by calculating the conditional probability by the Bayesian approach. The estimation of meaningfulness risk for every factor is offered as a difference of conditional probabilities at presence and absence of this factor, if the derailment is detected at simulation.

The outputs of computer experiment, expressed as binary numbers, are used to calculate value q_0, that is the probability of occurrences of the derailment event Z, value p_0, that is the probability of occurrences of the opposite event $\overline{Z}$ (the derailment has not happed), and values q_i^+, q_i^-, p_i^+, p_i^-, which are conditional probabilities:

$q_i^+ = P(Z|F_i)$ and $q_i^- = P(Z|\overline{F_i})$ – the conditional probabilities of event Z at factor presence F_i and at factor absence $\overline{F_i}$;

$p_i^+ = P(\overline{Z}|F_i)$ and $p_i^- = P(\overline{Z}|\overline{F_i})$ – the conditional probabilities of event $\overline{Z}$ at factor presence F_i and at factor absence $\overline{F_i}$.

The significance of the impact of derailment risk factors calculate as the difference of conditional probabilities at presence factor $P(F_i|Z)$ and at absence factor $P(\overline{F_i}|Z)$ by using the formula:

$$R_i = P(F_i|Z) - P(\overline{F_i}|Z) = \frac{q_0 \cdot q_i^+}{q_0 \cdot q_i^+ + p_0 \cdot p_i^+} - \frac{q_0 \cdot q_i^-}{q_0 \cdot q_i^- + p_0 \cdot p_i^-}.$$

After that, positive values R_i put in decreasing order. The factor F_m, corresponding to the maximum value R_m, produces the maximum derailment risk, whereas the factor F_k with $R_k = 0$ has no effect to the derailment.

6. CONCLUSIONS

1. The concept assessment of rolling stock derailment risk, which combines the identification of mechanical risks with the technology of computer simulation of rolling stock dynamics, is proposed.
2. The special models of rail vehicles dynamics, which oriented for risk assessment of derailment, together with an adequate introduction of the design features of the vehicle,

represent the full range of characteristics of the technical conditions of the rolling stock units.

3. The common set of the factors of derailment are proposed to decompose on four subsets:
   – subset of factors, that represent the technical state of the rolling stock;
   – subset of factors, that identify the state of quality track at the area of derailment;
   – subset of factors, that characterize the scheme of forming a train;
   – subset of factors, that correspond to mode of running train.
4. Three methods are recommended to use for analysis to the proneness to derailment by the study of quantitative changes of the indexes of a safety.

References

1. Diomin Yu., Cherniak A.: Dynamics of empty car and safety of the train. Railway Transport of Ukraine, 2007, No.3, pp. 50-52.
2. Pogorelov D.: Simulation of Rail Vehicle Dynamics with Universal Mechanism Software. Rail vehicle dynamics and associated problems. Gliwice: Silesian University of Technology, 2005, pp. 13-58.
3. Chudzikiewicz A., Opala M.: Application of computer simulation methods for running safety assessment of railway vehicles in example of freight cars. Applied Mechanics and Materials, 2008, vol. 9, pp. 61-69.
4. Cherniak A.: The use of computer modeling to determine the probable causes of the derailment of freight cars. Railway Transport of Ukraine, 2009, No.3, pp. 49-52.
5. Norms for analysis and design of railway wagons MPS 1520 mm (non-self). GosNIIV-VNIIZhT, Moscow, 1996.
6. Cherniak A.: Computer model for operational determining of probable causes of the derailment of freight cars. Journal of East-Ukrainian National University named by Vladimir Dahl, Lugansk, 2010, No5 (147), pp. 40-46.

OPERACYJNA DEFINICJA MOŻLIWYCH PRZYCZYN WYKOLEJENIA WAGONÓW TOWAROWYCH

Streszczenie: Prezentowane metody oceny ryzyka wykolejenia taboru na podstawie eksperymentów komputerowych z pomocą modeli dynamicznych. Specjalnie zaprojektowane modele dynamiczne zawierają niezbędne parametry, które przedstawiają stan pojazdów kolejowych w eksploatacji. Wspólny zestaw czynników wykolejenia zaproponowano rozkładać na podzbiory. Każdy czynnik, z każdej z podgrup jest reprezentowany jako zmienna typu Boolean, która ma alternatywną wartość. Proponowane metody mogą być wykorzystane do analizy tendencji taboru do wykolejenia się przez badanie ilościowe zmiany poziomu bezpieczeństwa.
Słowa kluczowe: tabor kolejowy, czynniki wykolejenia, modele dynamiczne