WEB ISSN 2535-0307
SCIENTIFIC PROCEEDINGS XXV INTERNATIONAL SCIENTIFIC-TECHNICAL CONFERENCE "trans&MOTAUTO '17" PRINT ISSN 1313-5031

ASSESSMENT OF RISKS CAUSED BY RAILWAY CAR UNCOUPLING

ОЦЕНКА РИСКОВ ОТЦЕПКИ ЖЕЛЕЗНОДОРОЖНОГО ВАГОНА

Prof. PhD Garbaruk V.V., Prof. PhD Fomenko V.N.
Emperor Alexander I Petersburg State Transport University,Saint-Petersburg, Russia
vmkaf@pgups.ru

Abstract: *Relations are developed estimating risks of in-transit uncoupling of cars caused by technical malfunction depending on the number of cars in a train and haulage distance. The obtained results allow assessing safety level in international transit corridors where each local railway administration shares liability for damage to cargo and railway equipment in the course of transportation through their area of responsibility.*
Keywords: RISK, TRANSPORTATION ROUTE, TRAIN, RAILWAY CAR UNCOUPLING

1. Introduction

Modern approaches to traffic safety ensuring imply introduction of basic security norms. As for passenger transportation, such norms are probabilities of death or injury whereas damage or loss of cargo are relating to freight traffic. Areas for current repair with car uncoupling are intended to remove malfunctions which appear in the car operation in between scheduled repairs or after the car production and before its first normal repair. All defects of cars are to be removed disregarding their cause that may be normal aging of components and units, mistakes in performing loading-unloading and switching operations, violation of rules laid down in corresponding regulations in repairing cars and their components.

In work [1], the probability of a car accident is computed basing on a test sequence. However, the problem to determine the probability of failure of several cars running on a specific route rather than that for a single one has not been posed in that and other works. Similar investigations were performed in paper [2]. The author suggested a computational scheme to estimate the probability of accident proneness of a car. To perform the analysis a tree-like event graph was constructed which decomposed the final state (e.g., derailment of a car) into elementary events such as failure of specific units. In paper [3] the concept of the trouble-free life of car was used, the train safety being treated in such a way that failure of a single car might result in a complete train wreck under fatal circumstances. However, train wreck is a rare event. Other cases are more frequent when a defect is revealed in the course of inspection at the station. In this situation either a slight repair without uncoupling is performed or cars are uncoupled for a more serious repair. In such case risk of delivery delay or cargo damage occurs. The risks of just this kind are of main interest for consignors and insurance agencies: what is the safety level of a car group coursing along the speific route and what is the probability of uncoupling of N cars out of the train. In paper [4] the technique is outlined for estimation of car safety basing on the Markov process theory. In that work the transitions induced by random factors (failures) between states of the car-and-technical-service system have been considered. The state and transition probabilities are computed for a statistically average car, the process being assumed to be ordinary, *i.e.,* excluding that several events occur within short time interval. Thus, like in the abovementioned works, the transition rate of a car to failure state is determined, rather than the probability of uncoupling for the car's extraordinary technical maintenance and repair. The probabilistic estimate of uncoupling of several cars from the same train on a specific route is not discussed by the author either. Some forecast mathematical models have been suggested using correction factors in a number of works [5, 6] investigating the mutual influence of car reliability and performance of repair with uncoupling. The factors take into account the quality of operations with wagons at railway stations, on the one hand, and the influence of trends and seasonality, on the other. However, so far the models mentioned above are isolated from each other and they do not take account the full set of factors causing car uncoupling. For instance, in paper [6] the forecast model predicting the number of car detachments on the supply route is only developed for axle equipment heating.

Freight insurance is a sort of insurance of property which defends cargo against various risks such as incidents in the course of up-, down- and reloading operations, threats arising in cargo transportation *etc.* The insurer can properly estimate the risks related to freight transport if one possesses appropriate information not only on cargo and delivery distance, but also the transport operator. An increase of delivery distance over the nominally fixed average enhances the chance of insurable event. For this reason, insurers allow for specific multiplying factors depending on transport distance. To successfully solve problems arising in insuring cargo it is important that information is available on the number of car detachments occurring during transportation, each detachment being treated as random event with a definite probability.

In the present paper, the risk of failure to make delivery is estimated if there emerges a need to detach one or more wagons for extra repair because of technical malfunction on a specific route.

2. Computation of probability of a single-car uncoupling

Non-failure operating time is often considered in reliability theory to be an exponentially distributed random variable $F(t) = 1 - e^{-\lambda \cdot t}$ (see, for example, GOST 51901.12-2007, Risk management. Method of analysis of failure types and effects). It results from the fact that the probability of non-failure operating of a device within a time interval t does not depend on duration of the preceding failure-free run from its start to the beginning of the time interval under consideration, but it only depends on the duration t [7]. One can adopt exponential distribution also in analyzing in-transit car detachments caused by technical malfunctions with the covered distance L as its argument instead of elapsed time. Distribution function $F(L) = 1 - e^{-\lambda \cdot L}$ allows computing the probability P of a car uncoupling on the route of length L. Prediction of the uncoupling rate λ can be done on the basis of statistical data. A large size of data makes it possible to reliably predict the car-uncoupling rate per 1 wagon-km.

Assuming that a malfunction implying car detachment can appear on any route segment of fixed length with equal probability, calculating the uncoupling probability of a loaded car can be performed by the formula:

(1) $$P_{\cdot} = 1 - e^{-L \cdot \Psi_p \cdot (1-d) \cdot (1 \pm K)},$$

where L is transportation distance;

WEB ISSN 2535-0307
PRINT ISSN 1313-5031

Ψ_p – car-uncoupling rate per 1 wagon-km;

K – seasonal transportation factor;

d – portion of empty cars in current repair.

One can use the following approximate formula for small values of $L{\cdot}\Psi_p$ instead of formula (1):

(2) $$P_{ap} \approx L{\cdot}\Psi_p{\cdot}(1-d){\cdot}(1 \pm K).$$

The car-uncoupling rate per 1 wagon-km Ψ_p is determined by the relation:

$$\Psi_p = \frac{n_p}{\sum\limits_{i=1}^{k} L_i},$$

where k is the number of cars;

$\sum\limits_{i=1}^{k} L_i$ – the total run of all k wagons (km);

n_p – the number of car detachments for current repair.

Known the portion of cars of each type that are in current repair, the value of n_p can be calculated from the data of branch statistical.

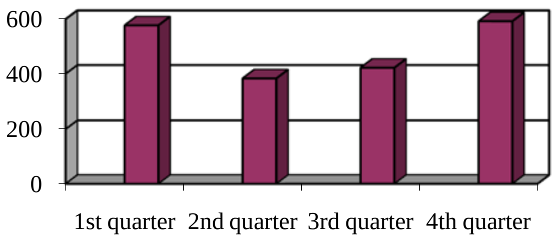

Fig.1 *Number of car detachments by quarters*

The number of car detachments noticeably increases in autumn and winter period. In this work it is suggested to take this fact into account by seasonal transportation factor K. It enters into formulae (1) and (2) with plus sign for the autumn and winter period and with minus sign for the spring and summer one.

In this paper we deal with detachments of loaded wagons only, since the transport operator may suffer a loss in that case. For this reason the factor d is introduced in the formulae to exclude detachments of empty cars from consideration.

3. Risk of a car uncoupling from the train

Let us assume that several identical wagons are combined to one train for cargo transportation. An in-transit uncoupling of any wagon due to its technical malfunction is a random event with the probability which does not depend on the fact if some other wagon went wrong. In other words detachments are considered to be independent events. Let uncoupling probabilities of all wagons have the same value. Suppose N is the number of cars in a wagon batch. Then one has to do with a sequence of independent tests, in each of which a car may be uncoupled because of malfunction occurred in the course of transportation with equal probability. Let us denote by n the number of cars that may be uncoupled. The probability $P(n;\, N)$ that n cars are uncoupled from a batch of N wagons can be calculated by the Bernoulli formula [7]:

(3) $$P(n;N) = C_N^n \cdot P^n \cdot (1-P)^{N-n},$$

where $C_N^n = \dfrac{N!}{n!(N-n)!}$ is the number of combinations consisting of n elements chosen from a set of N elements ($N! = 1{\cdot}2{\cdot}\ldots{\cdot}N$).

The most probable number of cars $m(AB)$ that may be uncoupled due to in-transit failure detection on the route between points A and B is determined by the following formula

(4) $$m(AB) = N{\cdot}P = L{\cdot}N{\cdot}\Psi_p{\cdot}(1-d)\cdot(1 \pm K),$$

suppose that $N{\cdot}P$ is an integer. Otherwise the most probable number of uncoupled cars $m(AB)$ is obtained from the following two-sided inequality

$$N{\cdot}P + P - 1 \le m(AB) \le N{\cdot}P + P.$$

Let us consider a specific example of probability computation for an in-transit car detachment caused by technical failure. Here are source data to make calculations: L = 9882 km; N = 50 cars; Ψ_p = 0,00003741; d = 0,78; K = 0,162. The transportation is assumed to be carried out in spring and summer period. The probability P of a car detachment due to in-transit detection of a technical malfunction is approximately found by formula (2)

$$P_{pr} \approx 9882{\cdot}0{,}00003741{\cdot}(1-0{,}78){\cdot}(1-0{,}162) \approx 0{,}068.$$

A more precise value of P is obtained via formula (1)

$$P = 1 - e^{-0{,}068} = 0{,}066.$$

The most probable value of the number of cars uncoupled on the route between points A and B $m(AB)$ is got from the following two-sided inequality

$$3{,}4 + 0{,}066 - 1 \le m(AB) \le 3{,}4 + 0{,}066.$$

The integer $m(AB)$ = 3 obeys this inequality. The probability of a detachment of three cars from a fifty car batch is computed by formula (3) with n = 3:

$$P(3;50) = C_{50}^3 \cdot P^3 \cdot (1-p)^{50-3} = 50{\cdot}0{,}066^3{\cdot}(1-0{,}066)^{47} \approx 0{,}228.$$

The risk that one, two or no car at all will be uncoupled can be found by formula (3) too:

$$P(1;\,50) = C_{50}^1 \cdot P^1 \cdot (1-P)^{50-1} \approx 0{,}117.$$

$$P(2;\,50) = C_{50}^2 \cdot P^2 \cdot (1-P)^{50-2} \approx 0{,}202.$$

$$P(0;\,50) = (1-P)^{50} \approx 0{,}033\,.$$

The probability of detachment of an arbitrary number of wagons can be calculated similarly. Fig.2 illustrates the behavior of the car detachment probabilities.

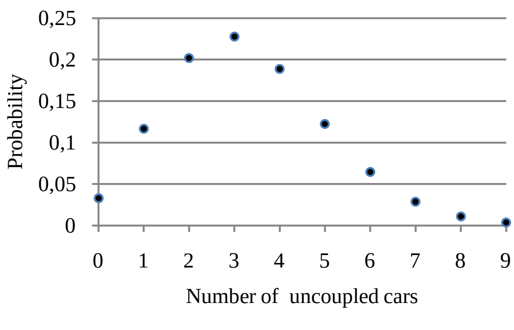

Fig.2 *Probability of uncoupling of various numbers of cars from a car batch.*

The risk that one, two or no car at all will be uncoupled can be found by formula (3) too:

$$P(1;\,50) = C_{50}^1 \cdot P^1 \cdot (1-P)^{50-1} \approx 0{,}117.\cdot$$

$$P(2;\,50) = C_N^2 \cdot P^2 \cdot (1-P)^{50-2} \approx 0{,}202.$$

$$P(0;\,50) = (1-P)^{50} \approx 0{,}033\,.$$

YEAR I, VOLUME 2, P.P. 128-131 (2017)

WEB ISSN 2535-0307
PRINT ISSN 1313-5031

The probability of detachment of an arbitrary number of wagons can be calculated similarly. Fig.2 illustrates the behavior of the car detachment probabilities. Another important way to describe the risks is the interval estimation of the number of cars uncoupled for a specified confidence level P_{conf}. It is possible to state with a degree of reliability P_{conf} that the number of cars uncoupled cannot exceed the value n_{max}. The maximum value of car detachments n_{max} is determined by the system of inequalities

$$\begin{cases} P\left(n > n_{max}\right) \le 1 - P_{conf} \\ P\left(n > n_{max} - 1\right) > 1 - P_{conf}. \end{cases}$$

For instance, we get $n_{max} = 8$ as the maximum number of uncouplings at confidence level $P_{conf} = 0{,}99$ in the example given above. Fig.3 demonstrates results of calculations of the maximum number of cars detached are shown at various confidence levels.

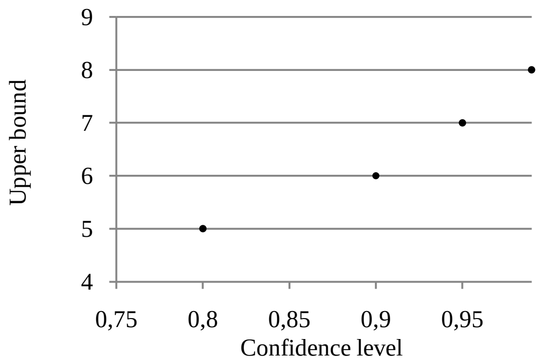

Fig.3 *Interval estimation of car detachment risk.*

4. Car detachments at variable length of the route

The probability P_L of a car uncoupling in case of a technical malfunction detection for variable route length is as follows

$$P_L = 1 - e^{-L \cdot 0{,}00003741\,(1-\;0{,}78)\,(1-\;0{,}162)} =$$
$$= 1 - e^{-L \cdot 0{,}0000069} \approx L \cdot 0{,}0000069\,.$$

The probability that a car will not be uncoupled is equal

$$Q_L = 1 - P_L = e^{-L \cdot 0{,}0000069}.$$

If there are N cars in the train, then the probability of no detachments is computed by multiplication theorem [7] for independent events

$$P_L(0; N) = Q_L{}^N = e^{-N \cdot L \cdot 0{,}0000069}.$$

Figure 4 demonstrates how the probability of uncoupling of at least one car depends on transportation distance for various numbers of cars in the train.

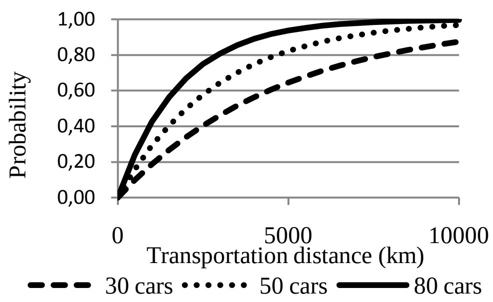

Fig.4 *Risk of uncoupling of at least one car for various transportation route lengths and numbers of cars in the wagon batch.*

The probability of at least one uncoupling, i.e., that of an opposite event, depends on the transportation distance. The expression giving the probability of uncoupling of at least one car which depends on the number of cars in the batch and the transportation distance is as follows:

$$P_L(n > 0) = 1 - P_L(0; N) = 1 - e^{-N \cdot L \cdot 0{,}0000069}.$$

If we assume that the train consists of N cars the calculation of the probability of uncoupling of just one car can be carried out by means of the Bernoulli formula [7]:

$$P_L(1; N) = C_N^1 \cdot P_L \cdot Q_L{}^{N-1} =$$
$$= N \cdot \left(1 - e^{-L \cdot 0{,}0000069}\right) \cdot e^{-(N-1) \cdot L \cdot 0{,}0000069}.$$

Then the formula for computing the probability that two or more cars will be uncoupled on the route due to technical malfunction has the form:

$$P(n > 1) = 1 - P_L(0; N) - P_L(1; N)$$

Fig.5 demonstrates the results are presented for the probability of detachment of one or two cars from a 50 wagon batch, as well as that of no uncoupling at all.

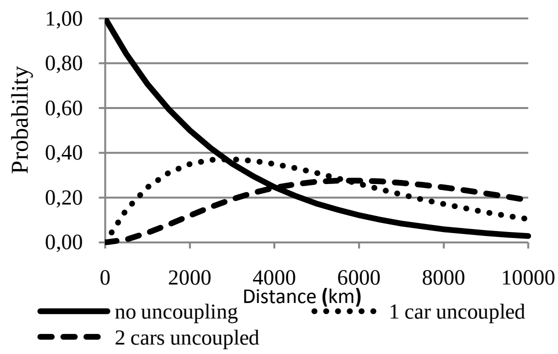

Fig.5.*Detachment risk on various routes for a batch of 50 wagons*

If cars of different types with unlike detachment rates are present in the train one should first calculate the probability of detachment of n cars for each group of similar cars. Then one computes the probability of uncoupling of n cars from the train using the total probability formula [7].

Let us discuss a specific example. Suppose the train consists of 30 cars of kind I with detachment probability $P_{\mathrm{I}} = 0{,}066$ and 20 cars of kind II with detachment probability $P_{\mathrm{II}} = 0{,}052$. The probability to choose at random a car of the first kind equals P(I) = 30/50 = 0,6. For the second type cars it is P(II) = 20/50 = 0,4. The conditional probabilities of uncoupling of the cars of both kinds are

$$P_{\mathrm{I}}(1;\,30) = C_{30}^1 \cdot P_{\mathrm{I}}^1 \cdot (1 - P_{\mathrm{I}})^{30-1} \approx 0{,}273;$$

$$P_{\mathrm{II}}(1;\,20) = C_{20}^1 \cdot P_{\mathrm{II}}^1 \cdot (1 - P_{\mathrm{II}})^{20-1} \approx 0{,}323.$$

One can compute the probability of uncoupling of one car of each kind using the total probability formula

$$P(1;\,50) = P(\mathrm{I}) \cdot P_{\mathrm{I}}(1;\,30) + P(\mathrm{II}) \cdot P_{\mathrm{II}}(1;\,20) = 0{,}293.$$

The probabilities of uncoupling of any number of cars are determined similarly.

As our calculations have shown, the probability of an in-transit car detachment is significant considering the actual rather low reliability of the car fleet. The probability of uncoupling of a car is close to 0,37 for transportation distance from 2500 km to 3000 km. Whereas the probability of uncoupling of two wagons becomes 0,27 for a route length from 5500 km to 6000 km. Taking into consideration an increasing cargo turn-over between the countries

WEB ISSN 2535-0307
PRINT ISSN 1313-5031

of the European Union and Asia-Pacific region [8] it is necessary to estimate risks relating to delay of freight delivery.

5. Uncouplings for a variable number of cars in the train

The results obtained above can be generalized to the case when the number of cars in the train is unknown in advance being a random variable with a definite probability distribution law. In this work we assume that the number of cars in the train is equal to Z+1, Z being a random Poisson distributed variable with the parameter λ . We have introduced a shift by unity in order to exclude the case of trains with zero number of cars. Thus the probability that there are N cars in a train is equal to

$$q(N) = e^{-\lambda}\frac{\lambda^{N-1}}{(N-1)!} \tag{5}$$

Here $\lambda + 1$ has the meaning of the average number of cars in the train. The probability that the number of cars in a train is within the range from 46 to 55 equals 0,53 at λ = 49. This probability amounts to 0,85 for the range from 41 to 60 cars. Fig.6 plots this probability versus the number of cars in the train.

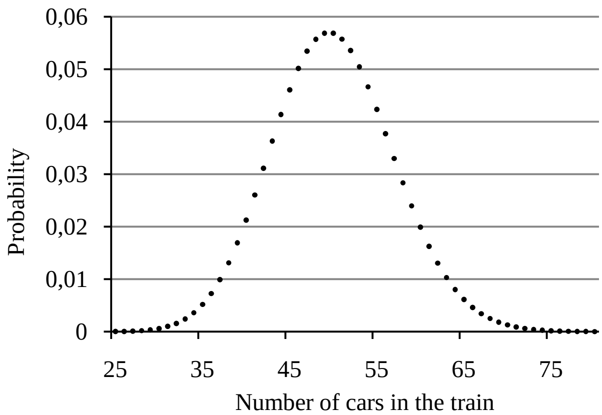

Fig.6. *The probability of various numbers of cars in a train.*

The detachment probability for n cars is calculated by the formula of total probability [7]:

$$P(n) = \sum_N P(n;N)\cdot q(N). \tag{6}$$

The probability of detachment of n cars from a train containing N cars is determined using formula (3). Note that $P(n;N) = 0$, if $N < n$. The curve in Fig.7 plots the probability of detachment of various numbers of cars evaluated by formula (6). As is seen from the figure the most probable number of uncoupled cars is equal to 3.

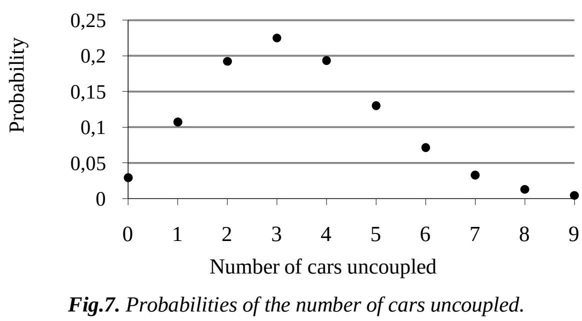

Fig.7. *Probabilities of the number of cars uncoupled.*

Let us notice that fig. 2 and 7 differ only slightly. Therefore variability of the number of cars does not influence the results of calculations of the uncoupling risk probability essentially if the average number of cars is fixed.

The expectation value, *i.e.*, the mean number of wagons uncoupled in the train with a variable number of cars, is computed in the following way

$$n_{av} = \sum_n nP(n) = \sum_n n\cdot\sum_N P(n;N)\cdot q(N).$$

n_{av} = 3,4 for the parameter set chosen (L = 9882 km; N = 50 wagons; Ψ_p = 0,00003741; d = 0,78; K = 0,162).

6. Conclusion

The methodology of a numerical analysis of operational reliability of the car fleet is given in this paper. When calculating the single-car in-transit uncoupling probability due to a technical malfunction an exponential distribution was used with the distance covered as its argument. Prediction of the uncoupling rate was done on the basis of statistical data of freight cars. A formula was developed to obtain the probability of at least one car uncoupling depending on the number of cars in the wagon batch and the length of transportation route. The probability of detachment of n cars from N ones in the batch was calculated by the Bernoulli formula for independent trial sequence. A method was demonstrated for determining the maximum number of car detachments given the confidence level. The results obtained were generalized to the case when the actual number of cars in the train was not known beforehand.

The obtained dependences of the uncoupling probability on transportation distance allow assessing safety level in international transit corridors where each local railway administration shares liability for damage to cargo and railway equipment in the course of transportation through their area of responsibility. The technique of assessment of the car uncoupling risk outlined in this paper can be utilized by insurance companies to justify their financial assets in insuring freight delivery.

7. References

1. Ustich P.A. Rolling stock: A textbook for railway transport universities./ Ustich P.A., Haba I.I., Ivashov V.A., edited by P.A. Ustich− Moscow: Marshrut, 2003. – 559 p.

2. Vologdina L.B. Development of the system insuring safely operating freight wagons basing on modern information technologies: Abstract of a PhD thesis in Engineering.− Moscow, 2004. – 24 p.

3. Ivanov A.A. Characterization of security parameters for freight wagons. Guidelines for practical classes./ Ivanov A.A., Ustich P.A. − Moscow: MIIT, 2009.− 40 p.

4. Sirina N.F. Theoretical foundations of the railway car technical maintenance: Guidelines for practical classes ./ Sirina N .F.− UrGUPS, 2005. – 36 p.

5. Mityukhin V.B. Enhancement of rolling stock effectivity using modern information technologies: Abstract of a PhD thesis in Engineering.− Moscow, 2002. – 25 p.

6. Nalabordin D.G. Assessment of the influence of the freight wagon safety level on parameters of the car maintenance and repair system: PhD thesis in Engineering.− Chita, 2015. – 209 p.

7. Gmurman V.E. Theory of probabilities and mathematical statistics. / V.E.Gmurman. – Moscow: Vysshaya shkola, 1977. – 479 p.

8. Shapovalova I.M. Basic tendencies in increasing competiveness of railway transit carriage inside the Russian Federation , Vestnik AGTU, ser.: Economics, Astrakhan, AGTU, 2012, No. 1, pp 73−79.