ESTIMATION OF SAFETY REQUIREMENTS FOR WAYSIDE DERAILMENT DETECTORS

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Abstract

BP-Risk is a semi-quantitative approach for railway risk assessments, which has been published and validated. Semi-quantitative methods are a combination of qualitative and quantitative approaches. They can be defined as "*qualitative, model-based*" risk assessment methods. This means, that for semi-quantitative risk assessment methods, numerical (quantitative) values are assigned to qualitative scales. This article shows how a semi-quantitative risk assessment method can be applied for the estimation of safety requirements for wayside derailment detectors. Wayside derailment detectors were recently developed as a part of modern wayside train monitoring systems to guarantee operational safety in centralised and remote controlled railway operation.

1 Introduction

Wayside train monitoring systems are an important issue for modern railway operation due to the fact that more and more stations will become remote controlled by an operation centre. Therefore the task of monitoring fault states on moving vehicles, which were done by train station inspectors, has to be overtaken by autonomous sensor systems. Due to the ongoing liberalisation of the railway market, it cannot be guaranteed that every vehicle (especially freight trains) is equipped with necessary sensors for fault state monitoring when passing the network of an infrastructure manager. Therefore infrastructure managers will be forced to install wayside equipment for checking all passing vehicles as well.

The worst case scenario of not recognizing fault states in time is probably a derailment. If monitoring systems are not able to detect derailment indications at an early stage the derailment itself must be identified by dedicated devices e.g. wayside derailment detectors (see Fig. 2). For safety related usage in a whole railway network the number of necessary wayside installations has to be identified in context to financial feasibility [10].

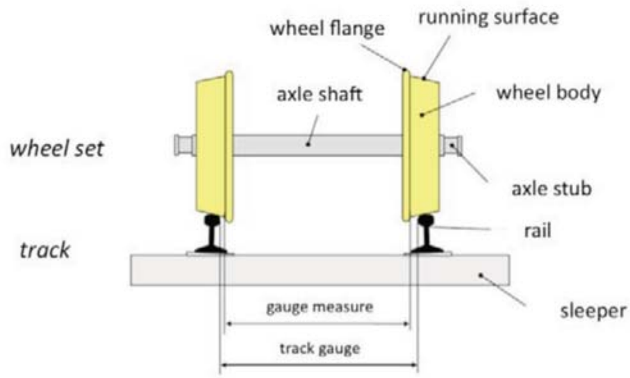

Fig. 1. Elements of wheel-rail system (based on [9])

Independent from the effective cause of a derailment, an already derailed axle can be reliably recognised by the exceeding of the clearance gauge located between the rails (see also Fig. 1). An over-riding of buffers is an exception for this definition, although this is classified as a derailment, too. Assuming a derailed axle, it is very improbable that there is no derailed wheel between the rails. If one wheel of a derailed axle gets lost, the remaining wheel will always run between the rails which can be explained in a technical way by the forces that act on the axle. Accordingly, monitoring the area between the rails is appropriate for reliable wayside derailment detection. After a detected derailment, the mechanical cage has to be replaced because of plastic deformation by the derailed axle. In case of a positive detection by closing or opening an electric circuit at a mechanical cage, a notification is sent to an operations control centre to be able to stop that train immediately [11].

Fig. 2. Wayside Derailment Detector

Multi-use wayside derailment detections are suitable for use on railways. After a detected derailment, the mechanical cage of this detection is not destroyed. Derailment detection can also be combined with dragging detection. Equipment which may brake system components, chains, cables, or steel bands used to secure lading is checked if it is exceeding the clearance profile. In contrast, for vehicle side detection the standard deviation of acceleration onboard is a common criterion which must be integrated into the braking system of one car. In case of a derailment, one brake valve has to be opened to stop the train immediately. Usually this dependency is realised in a simple mechanical way.

Because of the practical development of wayside derailment detectors national standards were mainly used for their design. In accordance to the current European standards of CENELEC the question arises if such systems have to fulfil certain safety requirements (by means of a tolerable hazard rate and safety integrity level). For a rough estimation of the recommended safety requirement the so called BP-Risk method offers a suitable methodology to answer this question.

2 BP-Risk (Best-practice Risk)

2.1 BP-Risk

BP-Risk is a semi-quantitative approach for railway risk assessments, which has been published [3] and validated [1]. Semi-quantitative methods are a combination of qualitative and quantitative approaches. In [8], they are defined as "*qualitative, model-based*" risk assessment methods. This means, that for semi-quantitative risk assessment methods, numerical (quantitative) values are assigned to qualitative scales. Examples for semi-quantitative risk methods can be found in the automobile industry and in the IEC 62061 [7] standard "safety of machinery".
For BP-Risk semi-quantitative implies, that on the outside, the risk analyst uses the front-end tables, provided by BP-Risk to assess the risk parameters. On the inside, there exists a risk model, which is implemented in the tables and actually uses numerical input values. Therefore BP-Risk uses the following risk model:

$R = f * g * s,$

where f is the hazard frequency - expressed as a Tolerable Hazard Rate (THR), g is the probability, that the considered hazard leads to an accident, and s represents the potential damage. The two risk parameters g and s are divided into sub parameters to ease their assessment. The general approach for risk assessments with the help of BP-Risk includes the common aspects (as required by standards and regulations):

– System definition
– Hazard identification
– Consequence analysis with BP-Risk tables
– THR derivation with BP-Risk table

These steps are described in the following for the application of BP-Risk for the safety requirements of derailment detection systems. It has to be noted, that this is not a complete risk assessment, but that this paper tries to highlight the most important aspects and tries to bring out some first reasonable results.

System definition

Derailment detectors can be interpreted as monitoring devices that detect a derailment. Their primary function is to minimize the damage to the track superstructure arising from derailed train wheels. It is important to note that the detectors are not designed to prevent a derailment, but should help to reduce the potential material damage of a derailment.
The considered function could be called: "derailment detection".

For this paper, the following assumptions were made:
- We assume, that there is **no** on-site staff (e.g. station inspector) watching the trains, which could detect a derailment and prevent further damage.
- We don't consider derailments for shunting trains.
- We consider a track with mixed traffic.
- The focus of the risk assessment will be on freight train. The critical case would be freight trains where even the train driver usually is not able to detect a derailment himself.

For more information on system definition for BP-Risk, please refer to [2].

Hazard identification

For the hazard identification, we assume, that a derailment already exists, independently from its cause.
A derailment can be caused by several fault states e.g.:
- blocked brake or wheel,
- broken axle shaft,
- broken axel stub,
- broken wheel,
- faulty flange of wheel,
- faulty suspension and component,
- faulty frame,
- unbalance (during vehicle run),
- violation of clearance gauge,
- faulty buffer,
- overriding of buffers,
- objects within the clearance gauge,
- variation of width of the track gauge,
- track distortion,
- broken rail,
- insufficient track bed.

If the derailment detection fails unnoticed one possible consequence could be the damage of track superstructure. Thus, the considered hazard is the "failure of the derailment detection". The hazard scenario considers a derailed train and the resulting damage of the infrastructure until the train reaches a junction. At the junction, the derailed train will be stopped in any case.

Consequence analysis

To assess the potential mitigation of an accident or undesired event and the possible consequences, the BP-Risk parameters are used for the risk analysis. To assess parameter *G*, which assesses possible mitigation factors, two sub parameters are used: parameter *B* and *M*.

Table 1. Probability of confrontation (Parameter *B*)

B	operating density	explanation
1	Low	below network average, e.g. freight corridors
2	Regular	network average, e.g. local lines
3	High	above network average, e.g. high speed lines

Sub parameter *B* is called “operating density”, because it considers the possibility of a train entering an occupied track. For derailment detection and in particular for our considered hazard scenario, this aspect is not that crucial. But it is important for parameter *G* to assess the possibility of an approaching opposite train, whose train driver might detect the derailment of the considered train. Thus, the aspect of how often an opposite train can approach is covered by the operating density of parameter B. As we assume a mixed traffic line, for parameter B, value 2 is chosen (Table 1).

Table 2. Human prevention (Parameter *M*)

M	human prevention	explanation
1	often possible	“skill-based” action under disadvantageous circumstances
3	seldom possible	“rule-based action under disadvantageous circumstances
5	almost never possible	random human intervention

Sub parameter *M* assesses if human mitigation is possible. Thus, it assesses a situation where the hazard already exists and where only human intervention can prevent an accident. For derailment detection this could be the train driver of a opposite train who might detect the damage that the derailed train already caused. The train driver of the derailed train has no possibility to detect a derailment by himself – sometimes he doesn’t even recognize a derailment when only one wheel derails and the air pipe is still working well. Therefore the only potential intervention can be carried out by the other train driver. We assume that this can be considered as seldom, possible because this is not a routine action, but still feasible. Hence, the *M* value is determined to be 3, if you refer to Table 2. Accordingly, parameter *G* has the following value: G = B + M = 2 + 3 = 5

Table 3. Train category (Parameter T)

T	train category	example
1	short-distance passenger traffic	local train, rapid-transit, commuter rail
2	long-distance passenger traffic + high speed traffic	trainset, passenger train, night train, motorail train
3	freight traffic	freight trains

To assess the potential damage *S*, three sub parameters are used: parameter *T, V* and *A*.
Sub parameter *T* considers the mass of the trains, because parameter *S* takes the kinetic energy into account. As **Table 3** illustrated, the more mass the trains have, the higher is the T-value and thus the higher will be the risk value afterwards. As we consider a derailment, the mass of the trains doesn’t really play a role for this accident type. It can even be advantageous to prevent a derailment, if the train is heavier because of the higher Q-force in relation to the Y-force (in accordance with the derailment criteria defined by NADAL (relation of lateral Y forces and vertical Q forces) [12]. Therefore, we won’t consider sub parameter *T* and thus assign it the value 0.

Table 4. Decisive speed (Parameter *V*)

V	decisive speed	Example
1	minor	shunting, running at sight, freight corridor
2	medium	line with limited traffic
3	high	local line, regional service
4	very high	long distance or high speed line

The decisive speed *V* of our considered freight train is estimated to be around 100 km/h on a mixed traffic line. This would correspond to a high speed when referring to **Table 4**. Thus, the value for *V* is chosen to be 3.

Sub parameter *A* assesses how many people might be affected by the potential accident. In our example, we consider only material damage to the track superstructure caused by a derailment. It has to be noted, that the severity of the damage depends on the type of track superstructure, which is not considered here.

We focus on material damage and not on physical injuries or fatalities. As Parameter *A* only considers affected persons, the value of *A* is set to 0.
Note, that the parameter *A* could be enhanced with monitory values. One option would be to take the marginal costs for a prevented fatality and assign it to the Parameter *A* classes.

Table 5. Affected persons (Parameter *A*)

A	number of affected persons	example
1	single person	collision with obstacle (not other train)
2	few persons	collision at level crossing
3	several persons	derailment
4	many persons	
5	very many persons	head-on or end-on collision (of trains)

Parameter S can be calculated by adding the three sub parameters: S = T + V + A = 0 + 3 + 0 = 3.
Altogether the sum of G and S is 5 + 4 = 8.

It has to be noted, that due to the derailment of a freight train a train on the adjacent track may collide with the freight train This scenario is not discussed here, because it would be a worst-case scenario, which are not considered while using BP-Risk. If worst-case scenarios would be considered, the derived safety requirements would be unreasonably high and thus inefficient.

THR Derivation

Table 6. Table for deriving a tolerable hazard rate (THR)

THR = $(\sqrt{10})^F$ **(per function)**	**G + S**	**description**
10^{-4} / h	8	once in 1 year
3 * 10^{-5} / h	9	once in 3 years
10^{-5} / h	10	once in 10 years
3 * 10^{-6} / h	11	once in 30 years
10^{-6} / h	12	once in 100 years
3 * 10^{-7} / h	13	once in 300 years
10^{-7} / h	14	once in 1,000 years
3 * 10^{-8} / h	15	once in 3,000 years
10^{-8} / h	16	once in 10,000 years

To derive the THR for the considered function, Table 6 is used. The sum of *G* and *S* corresponds to a certain tolerable hazard rate (THR). For our example, this would be THR = 10^{-4}/h. Note, that BP-Risk uses RAC-TS as a risk acceptance criterion which was implement in Table 6. Please refer to [6] for more information on RAC-TS and to [1] for the calibration of BP-Risk.

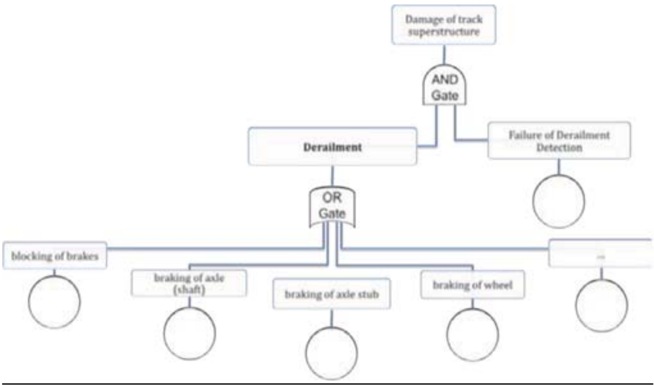

Fig. 3. Simplified fault tree

A simplified fault tree in Fig. 3 illustrates a possible way from the considered hazard “failure of derailment detection” to the top event “damage of track superstructure”. It is important to note, that the derailment detection is not determined to a technical component at this stage. The THR is determined for a function.
The following section describes the conversion for wayside equipment, if only technical components are considered to fulfil this function. For this example, we assume that the devices are independent from each other.

Conversion

BP-Risk was designed to have a system boundary of a train (illustrated by Fig. 4). We would like to consider a derailment detection, that would be implemented as a technical wayside device. We assume that only the wayside function is involved and that the transmission and the interlocking don’t play a part in fulfilling this function. Thus, the resulting THR must be converted for a wayside reference and referring to wayside devices.

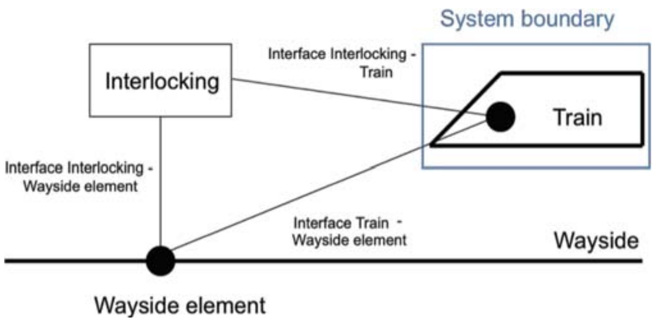

Fig. 4. System boundaries for BP-Risk

Table 7 is used for that conversion. It has to be noted that for this table, the German track standards from DB [5] were used. Thus, if another classification is available, this table can be adapted for other specific constraints.

Table 7. Table for conversion factor u

track standard	degree of speed (km per hour)	degree of capacity (trains per hour)	conversion [u] (train per km)
high speed line	135	5.0	0.037
long distance passenger traffic	108	4.0	0.036
long distance passenger traffic	93	3.0	0.033
short distance passenger traffic	90	2.0	0.023
short distance passenger traffic	60	1.3	0.022
freight traffic	18	0.4	0.023

For our example, the short distance passenger traffic standard with an average speed of 90 km/h and with a capacity of two trains per hour was chosen to represent a mixed traffic route. Therefore, the THR must be multiplied with the resulting conversion factor u, which leads to the following equation: THR = 10^{-4} / h · 0,023 = 2,3 · 10^{-6} / h per km.

To receive the THR per wayside device, another conversion needs to be carried out, that takes the wayside devices per kilometer into account. We assume that a derailment detector (DD) is placed at every signal, which have an average distance of about 2,5 km. We could also assume that a detector is placed in the distance of every junctions, which would be around 7,5 km. The resulting THRs are as follows:

2,3 · 10^{-6} / h per km · 2,5 km/DD = 5,75 · 10^{-6} / h per DD.

2,3 · 10^{-6} / h per km · 7,5 km/DD = 1,7 · 10^{-5} / h per DD.

It has to be noted, that the distance between the detectors are a crucial aspect for this calculation. On the one hand, the more detectors there are on the track, the more probable it is that a train meets a failed detector. On the other hand, if the detectors are placed quite close to each other, a second nearby detector could also reveal the derailment and still reduce the track damage in comparison to having no detectors at all. Also if the detectors are very close to each other, the possible track damaged is reduced as well. This aspect would have to be taken into account when carrying out an in depth analysis.

3 Conclusions

The application of BP-Risk for the derivation of safety requirements for technical derailment detection systems shows that such devices can be designed with a THR of around 1,0 · 10^{-5} / h per wayside derailment device.

During the analysis, it was noticed that some of the well-designed parameters within BP-Risk don't fit 100% for this particular hazard scenario. Adapting the parameters (*T* and *A* especially) within the method can be carried out without changing the basic concepts and boundary conditions of the BP-Risk method. Although a new calibration of the whole method would be needed for those changes.

However, it can be concluded that BP-Risk offers the possibility to receive a rough estimation for the safety requirements of derailment detection systems within a short time. For each parameter the arguments considered in the decision making process are comprehensible and allow therefore a simple modification in case of updates.

Nevertheless, it will be necessary to carry out an in depth analysis for certification of derailment detection systems. The results of this paper shall be considered as a first approach for a possible way forward.

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