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ANALYSIS OF THE CAUSES OF HAZARDS ASSOCIATED WITH THE TRAIN MOVEMENT IN TRACK SECTION

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Abstract: Nowadays, the train movement in the spatial system with fixed track sections is the most often used way of organizing of the train movements in track section. Hazard identification is a part of the risk analysis [4]. Risk analysis is one of the early phases of the life cycle of an interlocking system (IS). It is recommended to create a process model, which allows identifying the hazards, associated with the controlled process, to estimate the intensity of occurrence of each single hazard and the resulting consequences (human damages, material damages, etc.). In order to define safety requirements for an interlocking system, the hazards associated with the controlled traffic process, their causes, the intensity of their occurrence, their consequences and also the tolerable risk must be known. The analysis of the causes of hazards related to the train movement in a track section and the principle of the division of tolerable hazard rate for each part of the interlocking system (that ensures the safety of the control of train movements in track section) are the main topics of this paper. Analysis of the causes of occurrence of these hazards and the principle of the division of tolerable hazard rate (THR) for different parts of the interlocking system (that ensures the safety of the train movements control in track section) are the further topics of this paper.
Keywords: railway safety; risk analysis; hazard

1. INTRODUCTION

There are different kinds of organizing of the train movements in track sections. On principle, they can be divided into following train movements ([1], [2], [3], etc.):

- ✓ in time intervals;
- ✓ in space separation with fixed block sections;
- ✓ in space separation with moving block sections.

Nowadays, the train movement in the spatial system with fixed track sections is the most often used way of organizing of the train movements in track section. A characteristic feature of this way of traffic organizing is that:

- ✓ the track section (TS) is divided into several block sections (BS), which are generally bordered by signals (in extreme cases the track section needs not to be divided into block sections and then the block section can be identified with a track section);
- ✓ in the block section, there can move only one train. If this condition is not satisfied (e. g. for some technical reasons), it is necessary to take additional organizational measures to ensure the railway safety.

Safety related control systems (SRCS), which are used to control the train movements in track sections, are termed as block systems.
The main task of the block systems is to ensure the compliance with these basic safety functions (SF):

- ✓ to control the movement of trains following in the track sections, so that they could not reach each other and crash themselves (protection of following movements);
- ✓ to prevent dispatching the trains against each other along one track in the track sections with bidirectional traffic (protection of opposing movements).

The definition of these basic safety functions is based on the identification of main hazards associated with the train movement in track section. These are the following hazards:

- ✓ frontal collision of two trains moving in the opposite direction along the same track;
- ✓ when a train crashes into the previous train in the same direction along the same track.

Hazard identification is a part of the risk analysis [4]. Risk analysis is one of the early phases of the life cycle of an interlocking system (IS). It is recommended to create a process model, which allows identifying the hazards, associated with the controlled process, to estimate the intensity of occurrence of each single hazard and the resulting consequences (human damages, material damages, etc.). The combination of the intensities of the hazards occurrence and the consequences of hazard exposure presents a risk related to the controlled process. Based on the above mentioned risk knowledge and the knowledge of the tolerable risk value, the SFs can be defined and associated with their tolerable hazard rates (THR). If the failure of the control function of the interlocking system may endanger the safety of the train movement, this function should be considered as a SF and its safety requirements should be defined [5].

If the safety requirements for various control functions are defined, the safety requirements for the whole interlocking system are also defined [6]. Interlocking system can perform (and usually also performs) more SFs and on principle, each SF can have different THR required. It is necessary to respect this fact within the design of the interlocking system and to associate the THR with its individual parts according to the proportion, in which these parts of the system involve in the performance of the various SFs [7]. An interlocking system can include the parts that are involved in the performance of more SFs, but it can contain the parts that perform no SF as well. If a part of the interlocking system does not perform any SF, then there will be no safety requirements imposed, and therefore, there is no need to involve this part of the system in the safety assessment process [6].

Analysis of the causes of occurrence of these hazards and the principle of the division of tolerable hazard rate (THR) for different parts of the interlocking system (that ensures the safety of the train movements control in track section) are the further topics of this paper.

2. ANALYSIS OF THE CAUSES OF HAZARDS

2.1. Assumptions of the analysis

Let us assume that for the analysis of the causes of hazards, as defined in the introduction of the paper, the following assumptions are valid (Figure 1):

- ✓ a track section with one track is divided into two block sections (BS1, BS2), on whose borders are block signals (Lo, So) with the separate distant signals (PrLo, PrSo);
- ✓ the borders of the track section are demarked by the entrance signals of neighboring stations (entrance signal S in the station A and L in the station B);
- ✓ the train movement is controlled by an automatic block system (ABS), which requires the information about train location; an information about train location is related to the subsections (S1.1, S1.2, S1.3, S2.1, S2.2, S2.3);
- ✓ ABS must cooperate with the interlocking system in the station A, and the station B respectively; the mutual cooperation of these systems (IS ↔ ABS) is the object of the analysis of the causes of hazards, in contrast to the function of the interlocking system in the station A, and in the station B respectively, which is not an objective in this case.

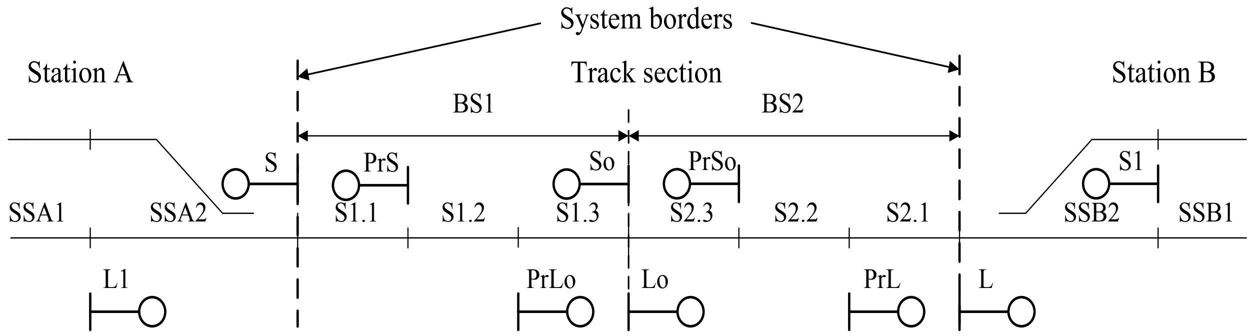

Figure 1. The considered track section – division into block sections and subsections

The considered hazards can occur only by the assumption that at least two trains are in the track section and at least one of these trains is in the movement. The number of trains will not affect the results of the cause analysis of the considered hazards, if their number is greater than two. Therefore, in the cause analysis of hazards it will be considered with:

- ✓ the movement of two trains against each other;
- ✓ the movement of two trains in a row.

According to the location of a place, where a train collision is possible to occur, it is possible to divide the track section into zones of hazard occurrence (Figure 2):

- ✓ zone 1 – the part of the station A;
- ✓ zone 2 – block section BS1 of the track section;
- ✓ zone 3 – block section BS2 of the track section;
- ✓ zone 4 – the part of the station B

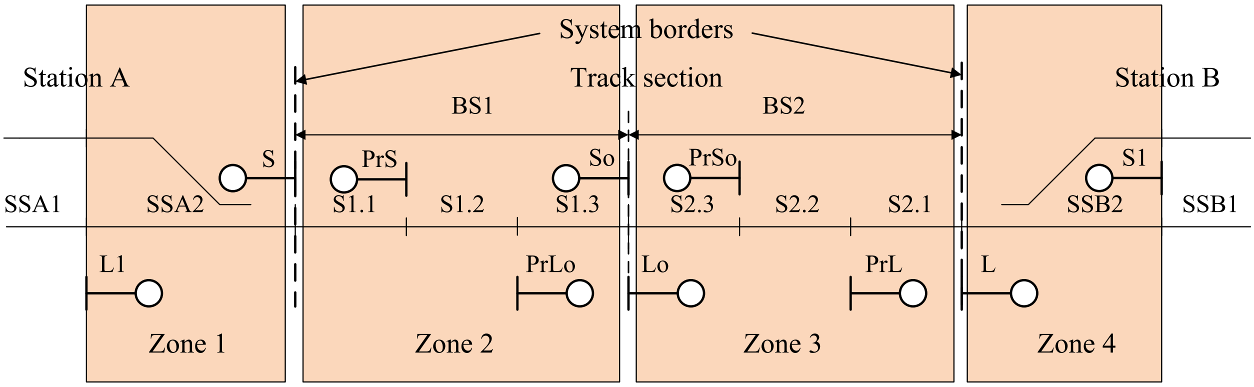

Figure 2. Zones of hazard occurrence

2.2. Definition of the operational situations

Let the traffic direction from station A to station B to be specified and trains (T1, T2) are moving against each other. There may such hazardous operational situations occur:

- ✓ train collision in zone 1; train T2 is in the zone 1 and train T1 enters the zone 1 (from station A); collision cannot occur due to failure of the ABS (situation A.1.1);
- ✓ train collision in zone 1; train T1 is in the zone 1 and train T2 enters the zone 1 from zone 2 (situation A.1.2);
- ✓ train collision in zone 2; train T2 is in the zone 2 and train T1 enters the zone 2 from zone 1 (situation A.2.1);
- ✓ train collision in zone 2; train T1 is in the zone 2 and train T2 enters the zone 2 from zone 3 (situation A.2.2);
- ✓ train collision in zone 3; train T2 is in the zone 3 and train T1 enters the zone 3 from zone 2 (situation A.3.1);
- ✓ train collision in zone 3; train T1 is in the zone 3 and train T2 enters the zone 3 from zone 4 (situation A.3.2);
- ✓ train collision in zone 4; train T2 is in the zone 4 and train T1 enters the zone 4 from zone 3 (situation A.4.1);
- ✓ train collision in zone 4; train T1 is in the zone 4 and train T2 enters the zone 4 (from station B); collision cannot occur due to failure of the ABS (situation A.4.2).

Let the traffic direction from station A to station B to be specified and trains (T1, T2) are moving in the row. There may such hazardous operational situations occur:

- ✓ train collision in zone 1 cannot occur due to failure of the ABS (situation B.1.1);
- ✓ train collision in zone 2; train T1 is in the zone 2 and train T2 enters the zone 2 from zone 1 (situation B.2.1);
- ✓ train collision in zone 3; train T1 is in the zone 3 and train T2 enters the zone 3 from zone 2 (situation B.3.1);
- ✓ train collision in zone 4; train T1 is in the zone 4 and train T2 enters the zone 4 from zone 3 (situation B.4.1).

For the specified opposite traffic direction (from station B to station A) the analogous hazardous operational situations can be identified. There is no need to perform an analysis, because it is based on the same considerations as in the situations described herein and it also leads to analogous conclusions.

For each hazardous operational situation A.X.Y (B.X.Y) an event *AXY* (*BXY*) is assigned. For example, the situation A.1.1 corresponds to the event *A*11.

In Figure 3 the hazardous operational situation A.2.2 is shown. Such an operational situation can be caused by:

- ✓ faulty function of the interlocking system in station B (not analyzed) and failure of signal So control (basic event *CSo*); or
- ✓ faulty authorization to dispatch the train T2 from station B to station A (basic event *DBA*) and failure of signal So control (basic event *CSo*).

The analysis of the causes, that can lead to other hazardous operational situations, can be performed in a similar way.

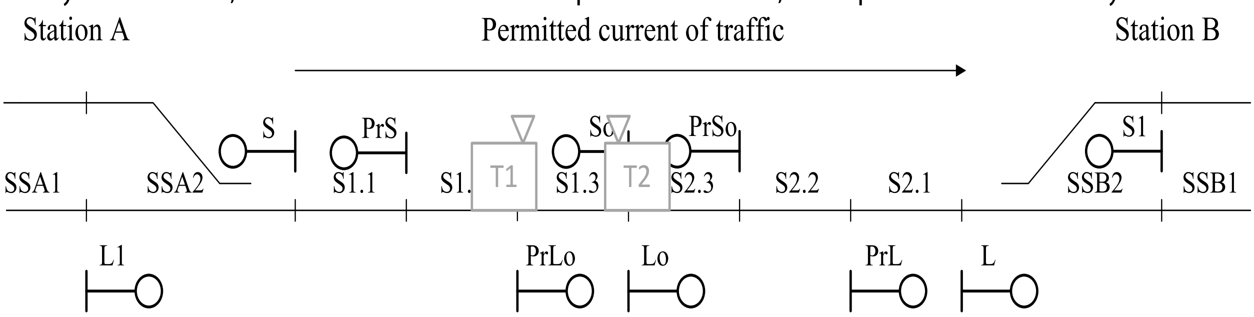

Figure 3. Example - hazardous operational situation in zone 2

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2.3. Creation of the hazard trees

In principle, the analysis of the causes of hazards can be made either generally (without considering the specific ABS), or considering the specific ABS. Based on results of the cause occurrence analysis of all the identified hazardous operational situations a hazard tree can be constructed. Part of this tree is shown in Figure 4. The top event is defined as a hazard of the accident in track section. It is appropriate, if the basic events can be defined, so that their occurrence is identical with the failure occurrence of the specific part of the ABS (failure rate of the considered part of the ABS is equal to the intensity of the occurrence of considered basic event).

Hazard tree (Figure 4) can be described with a logic function, expressing a relation between top event *H* and the identified basic events as:

$$\begin{gathered} H = HAB + HBA, \\ HAB = A11 + A12 + A21 + A22 + \cdots + B41, \\ HBA = C42 + C41 + C32 + C31 + \cdots + D12, \\ \cdots \\ A22 = CSo + CSo.DBA = CSo, \\ \cdots \\ C31 = CLo + CLo.DAB = CLo, \\ \ldots \end{gathered} \tag{1}$$

where *HAB* is the hazard of collision of trains in the specified traffic direction from station A to station B, *HBA* is the hazard of collision of trains in the specified traffic direction from station B to station A, *A*22 (respectively *C*31) is the basic event corresponding to the operational situation A.2.2 (respectively C.3.1).

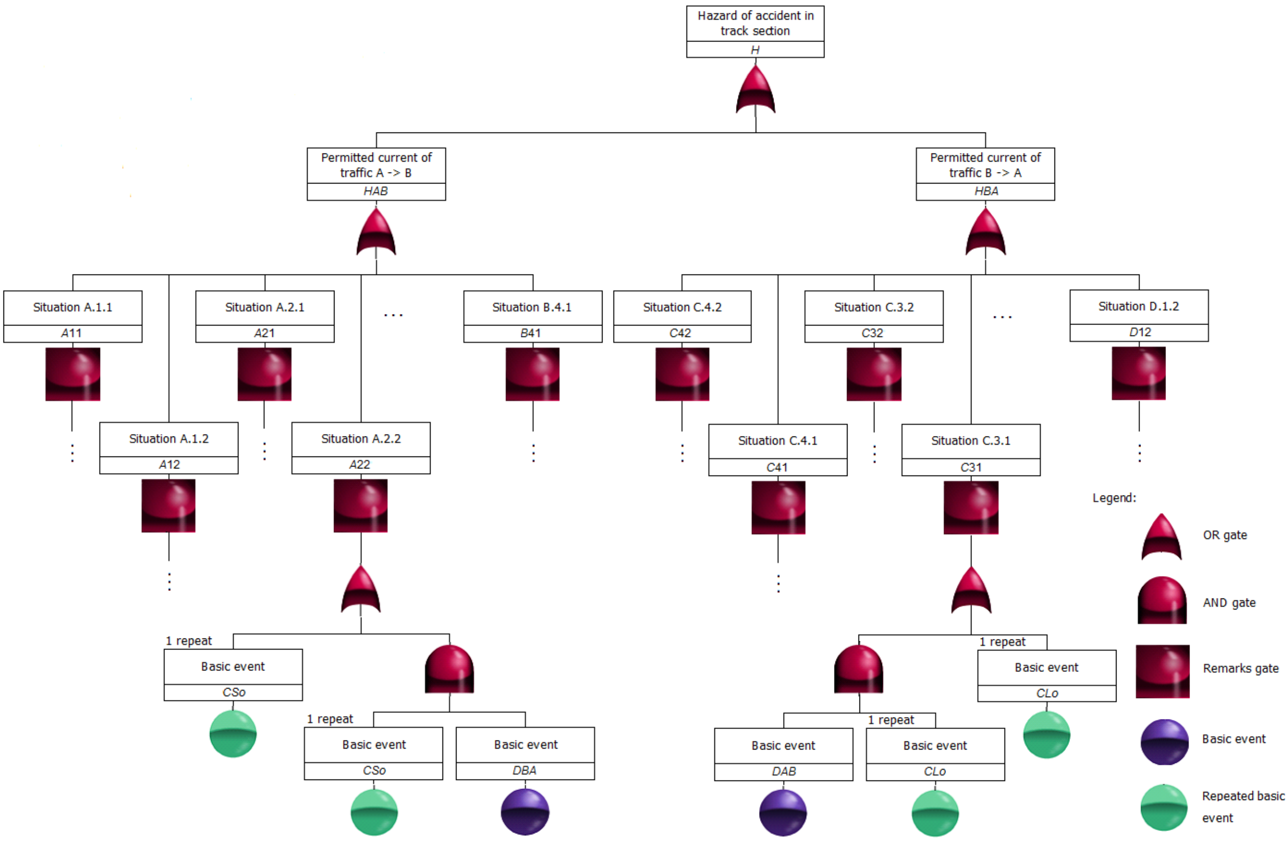

Figure 4. Hazards tree

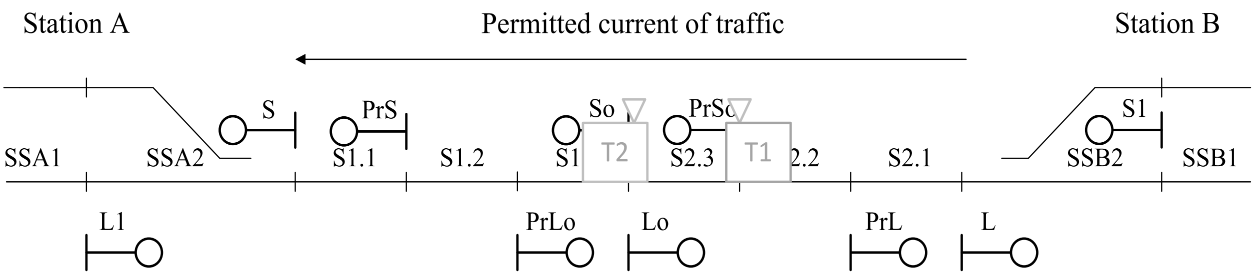

Figure 5. Example - hazardous operational situation in zone 3

In Figure 5 the hazardous operational situation C.3.1 is shown, which may occur when the traffic direction from station B to station A is specified. Train T1 is in zone 3 and train T2 enters the zone 3 from zone 2. Such an operational situation can be caused by:

- ✓ faulty function of interlocking system in station A (not analyzed) and failure of signal Lo control (basic event *CLo*); or
- ✓ faulty authorization to dispatch the train T2 from station A to station B (basic event *DAB*) and failure of signal Lo control (basic event *CLo*)

3. ASSIGMENT OF THR TO THE INDIVIDUAL PARTS OF ABS

Generally, the ABS may be designed as a decentralized system, or as a centralized system. In the case of centralized ABS, the logic of the system is concentrated in a single location (for example, in station A) and in the individual block stations, there are interfaces provided, which carry commands from the central logic to change the state of the field elements (signals, axle counter, ...) and they provide information about the status of these elements to the central logic.. In the case of decentralized ABS, the equipment on block station also contains its respective control logic. In Figure 6, there is a block diagram of the decentralized ABS, which is formed by:

- ✓ equipment located in the stations (S-ABS);
- ✓ equipment located on the block stations (B-ABS).

To ensure the railway safety in the block section, the following equipment is involved:

- ✓ S-ABS and B-ABS, in the case of block section adjacent with the station;
- ✓ B-ABS and B-ABS, in the case of block section adjacent from both sides with other block sections (Figure 6 does not contain such a situation);
- ✓ S-ABS and S-ABS, in the case of track section, which is divided into block sections.

Figure 6 shows the information links among the field elements and the equipment of ABS and also shows the information links among the equipment of ABS.

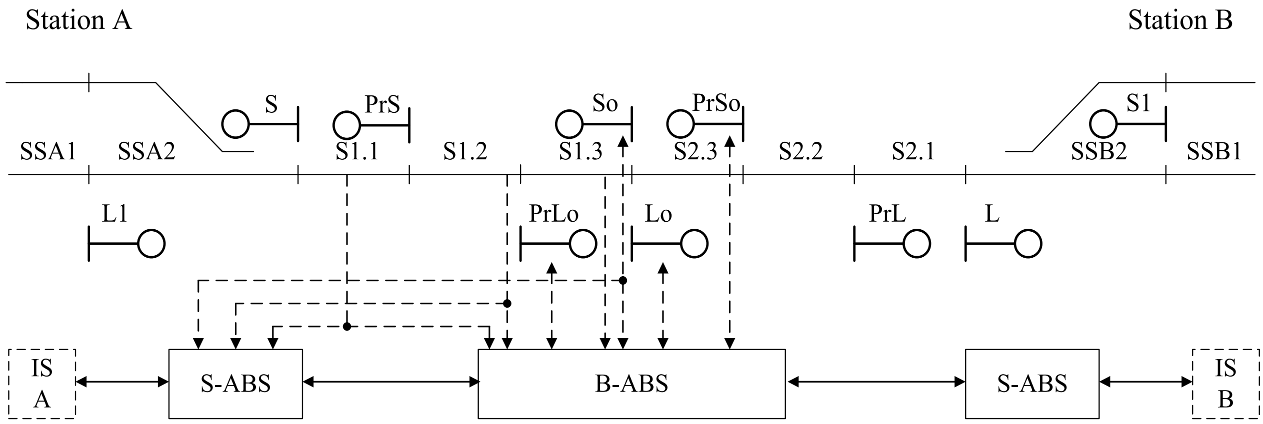

Figure 6. Block diagram of decentralized ABS

Because the individual risk of passenger's exposure, while driving in track section, should be independent of the technical solution of ABS and also of the number of block sections, the value of tolerable risk should be calculated to a comparable unit - for example, the block section.

Let us assume that for the decentralized ABS, the railway safety in block section is required and it corresponds with the tolerable hazard rate THR_O [4]. Then following relations must be valid:

$$\begin{gathered} \mathrm{THR_O} = \mathrm{THR_{SABS}} + \mathrm{THR_{BABS}}, \\ \mathrm{THR_O} = \mathrm{THR_{BABS}} + \mathrm{THR_{BABS}}, \\ \mathrm{THR_O} = \mathrm{THR_{SABS}} + \mathrm{THR_{SABS}}, \\ \mathrm{THR_O} \geq \lambda^{\mathrm{H}}_{\mathrm{SABS}} + \lambda^{\mathrm{H}}_{\mathrm{BABS}}, \\ \mathrm{THR_O} \geq \lambda^{\mathrm{H}}_{\mathrm{BABS}} + \lambda^{\mathrm{H}}_{\mathrm{BABS}}, \\ \mathrm{THR_O} \geq \lambda^{\mathrm{H}}_{\mathrm{SABS}} + \lambda^{\mathrm{H}}_{\mathrm{SBBS}}, \end{gathered} \tag{2}$$

where THR_{SABS} is tolerable hazard rate to equipment S-ABS, THR_{BABS} is tolerable hazard rate to equipment B-ABS, λ^{H}_{SABS} is hazardous failure rate to equipment S-ABS and λ^{H}_{BABS} is hazardous failure rate to equipment B-ABS.

Values λ^{H}_{SABS} and λ^{H}_{BABS} are dependent on the specific solution of ABS and the functions that equipment S-ABS and B-ABS perform.

4. CONCLUSION

In the paper, there is a situation considered, where a track section is divided into two block sections and a length of block sections is considerably larger than braking distance (block signals have a separate distant signal). In practice, there may be various other operational situations. For example - track section is constructed of more tracks, track section is not divided into block sections, track section is divided into more than two block sections, on the borders of block sections are overlaps considered, etc. The procedure described in this paper can be also applied to these cases. Basically, it is a simplification of considerations or multiple repetition considerations presented in this paper.

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