An analysis of barriers in train traffic using risk influencing factors

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ABSTRACT: A method to evaluate/rank the effectiveness of various risk reducing measures, based on barriers and factors influencing these barriers are presented. As an example a specific railway scenario is investigated, considering the barriers to prevent a train from leaving a station when there already is another train on the anterior block section. The various barriers are first investigated by a fault tree analysis. The basic events are ranked according to their importance. By linking risk influencing factors, RIFs, (rather stable conditions related to the equipment and personnel of the operating railway company) to the basic events risk influencing models are established. By linking these RIFs to the basic events, it is possible to give a more in depth overall analysis of the relevant safety measurers and their effect. The analysis provides a ranking of the most critical RIFs, and thus offers decision support regarding the prioritising of risk reducing measures.

1 INTRODUCTION

A large number of technical and human/organisational barriers may be implemented to secure a safe operation of train traffic. This paper presents an overall approach for overall evaluation of barriers, in order to arrive at recommendations regarding the cost effectiveness of various risk reducing measures. The present paper is built on work by Albrechtsen (2002) presented in a SINTEF memo.

The barriers are analysed by a combination of a fault tree analysis (FTA) and a risk influence analysis (RIA). Throughout the paper the definitions of barriers in the ISO standard 17776 is used. A barrier is defined as a measure which reduces the probability of realizing a hazard’s potential for harm and which reduces its consequence. Barriers may be physical (materials, protective devices, shields, segregation, etc.) or non-physical (procedures, inspection, training, drills, etc.) or non-physical (procedures, inspection, training, drills, etc.). The general approach for the barrier analysis is shown in figure 1. A FTA, where the top event is barrier failures, is carried out. The final step in the FTA is a ranking of the basic events according to their importance for the top event. The basic events in the FTA are connected to the related risk influencing factors (RIFs). RIFs are relatively stable conditions affecting risk of an activity (Rosness, 1998; Hokstad et al., 2001). Some examples of RIFs related to helicopter transport taken from Hokstad et al. (2001) are: operators’ maintenance, operations working conditions, human behaviour and environment. The RIFs contributing most to the top event are identified by combining the ranked basic events and their importance measure with the linked RIFs. Thus, it is possible to identify the RIFs for which it will be most effective to implement countermeasures.

The risk influencing model (the lower part of figure 1) used in this paper is based on an approach applied in previous studies at SINTEF related to transport (helicopter, high-speed craft and ferries) (Hokstad et al., 1999; 2000; 2001; Klingenberg Hansen et al., 1999). Other examples of modelling...
influence diagrams are described in e.g. Wu et al. (1991), Embrey (1992), Moosung and Apostolakis (1992) and Paté-Cornell and Murphy (1996).

This paper first describes the case scenario used throughout the paper. In section 3a FTA is carried out, where the basic events are ranked by the help of Birnbaum's reliability measure. Section 4 shows how the fault tree is combined with a risk influencing model. Furthermore, the section gives a ranking of the RIFs by using the ranked basic events from the FTA. Finally some conclusions are given.

2 CASE DESCRIPTION

A scenario where a train A leaves a station when the approaching train B already is on the anterior block section is used to illustrate the approach of the barrier analysis. It is assumed that train B is driving legally, i.e. in accordance with rules and orders. There are two barriers that should prevent train A from leaving the station; the signalling system and the automatic train control (ATC). A third barrier become operative when the other two barriers fail; verbal communication by the use of mobile cell phone or train radio from the rail traffic control centre (RTCC) to the locomotive drivers. Figure 2 shows the situation where train A has left the station and enters the block section, where the approaching train B is located. Train A has passed the exit signal as well as the ATC. The two trains are supposed to cross at the station. In this situation, the only barrier that can stop the trains from meeting is that the traffic controllers at the RTCC warn the locomotive drivers by verbal communication. This verbal communication can either be telephonic contact with the locomotive driver's cell phones or by communication by train radio. The phone/radio call depends on (1) that the traffic controllers at the RTCC discovers the situation and (2) that it is possible to get in contact with the drivers by calling their mobile cell phones or using train radio.

The sequence of the three barriers should be noted. The first barrier, the signalling system should prevent the train from passing an illegal signal. If train A passes the exit signal, the ATC should stop the train from leaving the station. The ATC is an automatic system that should prevent the train from passing an illegal exit signal. The ATC consist of equipment on the track as well as on the train. Should train A in some way pass the ATC as well, the only barrier left to stop the train is verbal communication to the trains from the RTCC. The railway is not electrified, so it is not possible to break the power in order to stop the trains. All three barriers must fail in this order if the two trains actually shall be heading towards each other. Figure 3 shows the three barriers and their order.

The departure procedure at the station regarding the signalling system includes the locomotive driver as well as the conductor. The conductor is in this setting a crew member who is responsible for, among other things, the safety regarding departure from a station. The locomotive driver must get a go-ahead signal from the conductor before he can drive on a legal signal. Thus, the conductor must interpret the exit signal correctly, the locomotive driver must interpret the go-ahead signal from the conductor correctly, the locomotive driver must interpret the exit signal correctly and the signalling system must function correctly if the train shall pass the exit signal legally.

3 FAULT TREE ANALYSIS

The barriers are first investigated in a traditional way using a standard fault tree analysis (FTA). The top
Train A leaves the station and is heading towards the approaching train B on the anterior block section.

The occurrence of this top event imply that all three barriers have failed; the exit signal does not prevent train A from leaving the station, the ATC does not prevent train A from passing the exit signal and the RTCC does not manage to warn the train crews at the two trains. Thus, the two first levels of a fault tree regarding the case description in section 2 will be as illustrated in figure 4.

The basic events of the FTA is presented. The probabilities of failures per year of the basic events were categorised into four groups:

- **LL**: \(10^{-7}\)
- **L**: \(10^{-5} - 10^{-6}\)
- **M**: \(10^{-4} - 10^{-3}\)
- **H**: \(10^{-2}\)

Some basic events are either present (probability 1) or absent (probability 0). These basic events are indicated by 1/0.

The basic events were assigned to these groups of probabilities. In the presentation below the related groups are given in parenthesis after the basic events.

The executed FTA gave the following basic events:

- Technical failure in the signalling system gives a legal exit signal even if conditions is not safe (LL)
- The locomotive driver deliberately drives against an illegal exit signal (LL)
- The locomotive driver believes the exit signal is legal, when it is illegal (L)
- The conductor believes the exit signal is legal, when it is illegal (L)
- The locomotive driver interprets that the conductor gives go-ahead signal when the conductor does not give this signal (L)
- The locomotive driver deliberately drives against an exit signal that is out of order (LL)
- The locomotive driver believes the exit signal is legal, when it is out of order (L)
- Technical failure gives signalling system out of order (LL)
- The traffic controller is distracted by other conditions in the RTCC (L)
- The traffic controller focuses on another section (M)
- The traffic controller does not observe the acoustic alarm (L)
- The acoustic alarm in the RTCC is out of function (LL)
- Acoustic alarm in the RTCC is not installed (1/0)
- Instructions for use of mobile cell phone as a communication media between RTCC and locomotive driver/conductor not implemented (1/0)
- The traffic controller calls the wrong phone number (M)
- The correct phone numbers are not available at the RTCC (M)
- The locomotive driver does not answer the call from the RTCC (L)
- The traffic controller’s phone is out of function (LL)
- Train radio not installed (1/0)
- Train radio out of function (L)
- The locomotive driver does not answer the train radio (L)
- Train without ATC (1/0)
- Failure in ATC (L)
- ATC deliberately disabled (M)
- It is forgotten to enable ATC (M)
- ATC not installed on track (1/0)
- Failure in ATC on train (LL)

The basic event can be a technical failure, a human/organisational error and lack of implementation of certain equipment or procedures. Figure 5 illustrates the fault tree for the barrier failure of the ATC.

A qualitative analysis of the fault trees is carried out to provide cut sets related to the various barriers. For our case, this qualitative analysis showed the importance of implementing the basic events with probability 1/0, since several of the cut sets of the lowest order included these basic events.

The basic events are ranked by the use of Birmbaum’s reliability measure. The main objective of this part of the barrier analysis is to rank the basic events with regard to their importance for the system. Thus, it should be noted that other measures for component importance could be used for this ranking as well. In our analysis the basic events related to the ATC and the basic events “Technical failure in signalling...
system gives a legal exit signal even if conditions are not safe” and “The locomotive driver deliberately drives against an illegal exit signal” are the most critical.

By the help of this ranking, the basic events were classified into five groups on the basis of their importance for the top event. The groups were weighted according to their importance, the most important/most critical group was given the weight 5 and the least important group was given the weight 1. In next section this weighting will be used to decide which RIFs are most important for the barriers.

4 RISK INFLUENCE ANALYSIS (RIA)

The main objective of the approach is to identify which conditions that have the highest effect on the safety level of the various barriers. Out of these conditions it is possible to identify which measures that will be most effective to implement in order to reduce the overall risk level. The conditions are evaluated by a risk influence analysis (RIA). The Risk influence analysis (RIA) provides decision support within a conceptual framework that integrates technical, individual and organizational factors (Rosness, 1998). The objectives of the RIA is according to Rosness (1998): 1) identifying important RIFs, 2) identifying and describing risk reduction strategies defined in terms of actions to change the RIFs and 3) assessing the effects on the total risk level of implementing each risk reduction strategy.

Next risk influencing models are established based on the FTA presented in section 3. These models are constructed by linking relevant RIFs to the relevant basic events found in the fault tree analysis. In that way the RIFs are connected to the fault tree. In addition influences between the various RIFs are constructed. In figure 6 such a construction is illustrated by linking RIFs to the basic events in the fault tree of the event “ATC does not prevent the train from leaving the station”. Similar diagrams related to failure of the other two barriers are presented in the memo by Albrechtsen (2002).

The first step in our RIA is to define which RIFs should be used in the analysis. The RIFs are classified into three levels; operational RIFs, organizational RIFs and regulatory related RIFs. Furthermore, the operational RIFs can be divided into technical, human and external factors. The RIFs used in this analysis is found in the lower part of figure 6. These RIFs are defined as relatively stable conditions (Rosness, 1998, Hokstad et al., 2001). For example is the RIF “Maintenance of signalling system” defined as the quality of the maintenance work on the signalling system in order to keep the signalling system on a defined/wanted safety level. The organisational RIF “Train crew” is defined to be the way the train crew plans and carries out their work that directly and indirectly influences the safety level. The RIF “Regulators” is defined to be the quality of the national and international legal framework related to train safety.

The operational RIFs used in our analysis are:

- Design of trains
- Maintenance of trains
- Design of signalling system
Figure 6. Risk influencing model for event ATC does not prevent the train from leaving the station.
The organisational RIFs used in our analysis are:

- Manufacturers and suppliers
- Train crew
- Traffic controllers
- The National Railway Administration ("Jernbaneverket")
- NSB, the Norwegian State Railway

Finally we have used the RIF “Regulators” at regulatory level (Norwegian Railway Inspectorate).

In the analysis presented in this paper we have only taken the operational RIFs into consideration. A more comprehensive analysis should take the organisational and regulatory RIFs into consideration as well.

By linking the RIFs to the basic events it is possible to give a more in depth overall analysis of the relevant safety measures and their effect. By the help of the ranking of the basic events it is possible to rank the RIFs as well. The ranked basic events are placed into five groups with regard to their values from the calculations in our FTA (section 3).

The ranking of the operational RIFs are carried out by counting the number of basic events each RIF is influencing. The objective of this counting is to arrive at a weighted sum for the operational RIFs. When weighting the sum the importance of the basic events is taken into account. The sum is weighted by the help of the groups of ranked basic events found in our FTA. This weighted sum will provide a ranking of the operational RIFs. In table 1 the weighted sums for the ranked operational RIFs are presented. The number of times an operational RIF influences a basic event is counted and combined with the associated ranked group of basic event. It is also taken into consideration that barrier 1 is the most critical one, since failure in this barrier is necessary if the other two barriers should come into action. Thus the operational RIFs influencing basic events for barrier 1 is additionally weighted by a factor 2.

From the table it can be seen that the operational RIF “Human behaviour, train crew” is the condition that contributes most to the situation where two trains are heading towards each other. Thus, this is the RIF that should be reduced if the probability for barrier failure should be reduced. Risk reducing measures will be most effective when directed at the behaviour of the train crew.

5 CONCLUSIONS

A general method is presented to qualitatively and quantitatively assess the importance of various risk influencing factors on the safety of an activity. The approach is scenario based, and starts by analysing the safety barriers of a scenario using FTA. By linking the RIFs to the basic events of the fault tree, direct measurement of the importance of the RIFs are obtained (gives a rather sound basis for evaluation).
Such a method provides a good tool for evaluation and priority of safety reducing measures related to the RIFs, which not necessarily are directly linked to the barriers.

Any measure can be related to the improvement of a RIF, thus the resulting risk reduction can be assessed. The approach has been successfully applied to a railway scenario, providing specific results regarding the importance of the RIFs relevant for this scenario.

In an actual situation, a number of scenarios should be analysed, thus giving safety management a good tool for evaluation of the effectiveness of risk reducing measures.

The method is simple (based on well-known techniques) and transparent, and can be supported by illustrative diagrams showing relative importance of the relevant factors.

ABBREVIATIONS

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ATC</td>
<td>Automatic train control</td>
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<td>FTA</td>
<td>Fault tree analysis</td>
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<td>NSB</td>
<td>the Norwegian State Railway</td>
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<td>RIA</td>
<td>Risk influence analysis</td>
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<td>RIF</td>
<td>Risk influencing factor</td>
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<td>RTCC</td>
<td>Rail traffic control center</td>
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REFERENCES


