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Risk analysis on level crossings using a causal Bayesian network based approach

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Abstract

Safety is a core issue in railway operation. In particular, Level Crossing (LX) safety is one of the most critical issues that railway stakeholders need to deal with. Accidents at European LXs account for about one-third of the entire railway accidents. They result in more than 300 deaths every year in Europe. However, due to non-deterministic causes, complex operation background and the lack of thorough statistical analysis based on detailed accident/incident data, the risk assessment of LXs remains a challenging task. In this paper, a general approach of Causal Statistic Risk Assessment based on hierarchical Causal Bayesian Networks (CSRA-CBN) is developed to analyze the various impacting factors which may cause accidents, and identify the factors which contribute most to the accidents at LXs, thus allowing for risk quantification. The detailed statistical analysis is carried out firstly according to the accident/incident database, then the CBN risk model is established based on the statistical results. In order to validate the effectiveness of this approach, we apply the CSRA-CBN approach on the basis of the accident data from SNCF, the French national railway operator. The CBN model allows for quantifying the causal relationships between the risk of accident occurring and the impacting factors considered. Moreover, the hierarchical structured modeling offers interesting benefits in terms of clarity, which makes it possible to highlight the complex factors influenced by a mass of parameters and identify the factors that contribute most to LX accidents. In addition, the main output of such a modeling system is conducive to improving safety at LXs, meanwhile, allowing for efficiently focusing on the effort/budget to make LXs safer.

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Keywords: Level crossings, causal statistic risk assessment, Bayesian networks, statistical analysis, railway safety;

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1. Introduction

1.1. Literature review on level crossing safety study

Accidents at railway level crossings (LXs) often give rise to serious material and human damage and seriously hamper railway safety reputation, although the majority of accidents are caused by road user violations. LX safety is one of the most critical issues in the railway field which needs to be improved urgently (Ghazel, 2009; Mekki et al., 2012; Liu et al., 2016). In 2012, there were more than 118,000 LXs in the 28 countries of the European Union (E.U.) which corresponds to an average of 5 LXs per 10 line-km (ERA, 2014). Accidents at European LXs account for about one-third of the entire railway accidents. They result in more than 300 deaths every year in Europe (Liu et al., 2016). In some European countries, accidents at LXs account for up to 50% of railway accidents (Ghazel and El-Koursi, 2014; Evans, 2011b). In the entire E.U. area, the overall number of fatalities per fatal accident in railways from 1990 to 2009 is 4.10, with no apparent long-term change over time (Evans, 2011a). In France, the railway network shows more than 15,000 LXs for 30,000 km of railway lines, which are crossed daily by 16 million vehicles on average, and around 13,000 LXs show heavy road and railway traffic (SNCF Réseau, 2011). In 2013, €32 million was spent by the State, SNCF (the French national railway operator) and local authorities, to improve LX safety, and about €36 million was invested in 2014. In recent years, a list of 300 prioritized LXs has been established and updated every year by SNCF Réseau, the French national railway infrastructure manager. Despite numerous measures taken to improve LX safety, SNCF Réseau counted 100 collisions at LXs leading to 25 deaths in 2014. This was half the total number of collisions at LXs a decade ago, but still too many (SNCF Réseau, 2015). If we want to significantly reduce the accidents and cost at LXs, it is necessary to develop further safety solutions to reach the most effective result.

In the literature pertaining to LX safety, a number of works can be found. In recent years, a systems analysis framework (Leveson, 2011; Read, 2016; Wilson, 2014) and a psychological schema theory (Salmon et al., 2013; Stanton, 2011) have been used to analyze the contributory factors underlying the accidents occurring at LXs. The study presented by Salmon et al. (2013) described a collision between a loaded semi-trailer truck and a train, occurring in North Victoria, caused by the truck driver crossing the LX while the barriers are closed. According to the investigation of OCI, the Office of the Chief Investigator, the truck driver in this study was not aware of the train and the activated state of the level crossing until it was too late to stop. A study conducted by Davey et al. (2008) discussed the intentional violation of vehicle drivers crossing LXs, particularly focusing on vehicle driver complacency due to the high level of familiarity. Tey et al. (2011) conducted an experiment to measure vehicle driver response to LXs equipped with stop signs (passive), flashing lights and half barriers with flashing lights (active) respectively. In this study, the vehicle driver responses result from both the field survey and a driving simulator.

Based on the above investigations, the main available studies dealing with LX safety have tended to take a qualitative approach to understand the potential reasons causing accidents at LXs. They employed surveys, interviews, focus group methods or driving simulators, rather than collecting real data. However, the aforementioned approaches show some limits. For instance, the reaction of vehicle drivers in simulation scenarios could differ from that in reality, due to the different levels of feeling of danger. Although those qualitative approaches are beneficial to explore the potential factors causing accidents, they cannot quantify the contribution degree of these factors. Thereby, quantitative approaches are indispensable if we want to understand the impacting factors thoroughly and enable the identification of practical design and improvement recommendations to prevent accidents at LXs.

1.2. Literature review on risk modeling

Current risk analysis methodologies are required to deal with increasingly complex systems with a large number of configuration parameters. Therefore, such methodologies should be equipped with the following characteristics:

- Strong modeling ability
- Easy to specify a risk scenario or a system
- High computational efficiency

In the domain of risk assessment, various methodologies are adopted for modeling and analyzing the systems or scenarios. Due to the combination of qualitative and quantitative analysis, the Fault Tree Analysis (FTA) developed by