A Review of the State-of-the-Art in Railway Risk Management

Claudio Martani†, Natalia Papathanasiou and Bryan T. Adey

Abstract

With railway in Europe carrying a consistent number of passengers and amount of goods on an aged infrastructure network, the risk related to infrastructure is high. When it is not possible to execute all of the interventions that are desired to offset deterioration, for example, due to budget constraints, the interventions that result in the largest risk reduction for the amount of resources available should be executed, i.e. included in the intervention program to be implemented. To determine the interventions to be executed, it is first necessary to assess the infrastructure related risk and then, second to determine which interventions should be executed. Two tasks that are currently done in the management of railway infrastructure relatively heterogeneously, and mainly at the object level. In this paper, a summary of the state-of-the-art of risk assessment and the development of intervention programs for railway infrastructure is presented. The summary is grouped in overviews of work done on the assessment of risk at both the network and object level, and on the development of intervention programs at both the network and object level. In the conclusion, attention is drawn to the work required to improve both, and steps for future research are given.

Keywords: Railways, Risk assessment, Risk reducing intervention programs, Literature review

1. Introduction

With railway in Europe carrying a consistent number of passengers and amount of goods on an infrastructure network that has been built largely between 1850 and 1950 (SMARTRAIL, 2014), the risk related to infrastructure is high. To help ensure that railway infrastructure related risk stays within acceptable limits, interventions must be executed. The evaluation of what might go wrong with railway infrastructure over time and the determination of what should be done to prevent it from happening is a field in which there has been substantial work. This work can be grouped in two main categories, 1) work on risk assessment, i.e. work on the assessment and prediction of the state of infrastructure and the resulting consequences, and 2) work on the determination of which interventions to be executed when the state of the infrastructure and possible consequences are known.

The first is required to identify when interventions should be executed to reduce the probability of failures or the economic, environmental and societal costs that may be a result of them. The works in this category include those focused on the estimation of the reliability, vulnerability, fragility and resilience of infrastructure to natural hazards and gradual deterioration processes. The second is required to ensure that optimal intervention programs are developed, i.e. the plans of the interventions to be executed to optimally provide the expected level of service over time. This requires the consideration of the economic, societal and environmental costs of interventions and inadequate levels of service, as well as, the speed of deterioration and the amount of time that parts of the railway network are to be closed to execute both preventive and corrective interventions (MAINLINE, 2014). The works in this category include those focused on the determination of both optimal intervention strategies, and optimal intervention programs.

Building on the works in both of these categories, an increasing number of decision support tools have been developed to improve the development of intervention...
2. Risk assessment

Over the last two decades a substantial amount of work has been focused on developing risk assessment processes (RAPs) for railway infrastructure. This work can be divided into 1) work focused on multiple object types within a network, and 2) work focused on a single object type.

Of the main articles reviewed, 37 were seen to be representative of the state-of-the-art in railway risk assessment. An overview of the publications is given in Table 1, where these works are classified in relation to: 1) whether consequences were assessed qualitatively, semi-quantitatively, and quantitatively, 2) whether probabilities of occurrence of events were assessed qualitatively, semi-quantitatively, and quantitatively, and 3) whether the focus was on each object type, as defined by (Profillidis, 2014). As the works were selected to represent the state-of-the-art, most have used quantitative methods for both the assessment of probabilities and consequences, which mirrors the trend away from the use of qualitative methods to quantitative methods. They have, however, mainly been focused on one or more objects in one of the 10 categories of railway objects. Only a few (3 out of 37) were focused on the network. Interestingly, no work was found using quantitative methods to assess risk at the network level for railway networks. There is also a wide variability in terms of both prospective (stakeholders, or risk owners, for which the assessment is performed) and methods of the analysis. In the network level works, semi-quantitative methods for the estimation of both probabilities and consequences were used in (INFRARISK 2014), taking into consideration also the (spatial and temporal) connections of different object types in the network, a semi-quantitative method for the estimation of probabilities and a qualitative method for the estimation of consequences was used in (Bepperling 2009) and in (An et al. 2007) quantitative methods were used for the estimation of probabilities and a semi-quantitative method was used in the estimation of consequences. Many of the object level works were concentrated on engineering structures and ground areas. There has been less work focused on other object types. The review of literature shows that the main deficiency in the work done on risk assessment for railway networks is that no work has been done on the development of an overall RAP, able to take into consideration: (i) all of the objects in the network in a systematic way, in order to allow comparison of the risk related to each object; (ii) the effect of object failure on the level of service of the network; (iii) the perspective of different stakeholders.

In order to set the basis for this work, a review of literature is herein presented that includes a review of works on the risk assessment of the railway infrastructure (section 2), along with a review of works on the determination of the interventions to be executed, i.e. the development of intervention programs (section 3). Because a large amount of the works reviewed, refer to objects of one type, a consistent breakdown of the railway infrastructure in object categories was used to organize the review. The categorization used was that proposed by (Profillidis, 2014), which is based on the European Community Regulation 2598/1970, that includes 10 categories of objects: track and track bed; ground area; switches and crossing; engineering structures; level crossings; passengers and goods platforms and access ways; safety, signaling, telecommunication installations; electricity power supply; lighting installations for traffic and safety purposes; and buildings.

The article is concluded with a summary of the works done and suggestions of where future works should be focused. It is, however, noted that substantial work in these areas is done internally by national railway agencies, and the work cannot be found in publicly available sources.
### Table 1 Overview of main characteristics of articles focused on risk assessment

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3. Intervention program determination

Once it is determined that the amount of infrastructure related risk is not acceptable, interventions need to be planned to reduce it so that it is acceptable. This section includes a review of the most advanced works focused on developing intervention programs. An overview of 18 relevant works is given in Table 2 where characteristics of the process used are shown. Each process is classified as being qualitative, semi quantitative or quantitative, and the quantitative are also distinguished between these using algorithms to provide optimal solutions or near optimal solutions. The works are also classified with respect to the objects on which they were focused or the network.

A large share of the works reviewed were focused on new intervention program development processes (IPDP) for individual objects such as engineering structures - as bridges and tunnels - (7 of 18) and tracks (5 of 18). The vast majority of the works (13 of 18) used quantitative methods to find either the optimal or nearly optimal intervention programs. All the works involving the use of quantitative methods to find near-optimal intervention programs concern tracks and engineering structures. It seems that only near-optimal intervention programs were targeted due to the high combinatorial problems involved in determining the optimal intervention programs for large and complex infrastructures over multiple years. As shown in Fig. 2, innovative methods have not yet been employed to determine optimal intervention programs for object of all types. It can be seen that little research has been done on the development of intervention programs for switches and crossings, and signals. Most research in this area has been conducted rather on the development of optimal intervention strategies, using reliability centered maintenance concepts for single objects.

In addition to the research done, a number of tools have been developed in the last 30 years both by the EU, through European projects, and at the national level to help conduct risk assessments and to determine optimal intervention programs. These include: ECOTRACK (Rivier, 1998); RAMSYS (Jovanovic & Zoeteman, 2010); (RAIL, 2000); MOVE (Levi, 2001); (INNOTRACK, 2010); (SMARTRAIL, 2014). These tools are, however, only as good as the underlying processes they support.

4. Conclusion

There is substantial literature on processes to be used to assess the risk related to railway infrastructure, as well as, on processes to develop intervention programs for railway infrastructure. Despite this rich literature, there is not one particularly suitable process to be used to assess the risk related to railway networks and to develop intervention programs to be executed for railway networks. Indeed, the works reviewed showed that there are significant variations in terms of scale, stakeholders, scenarios and types...
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and number of consequences, not to mention the methods used. There is no unified view that would help railway managers to determine how, depending on their situation, risk should be assessed or intervention programs should be determined.

From the literature review it is, therefore, concluded that:

(i) a risk assessment process for railway network needs to be developed that systematically takes into consideration all of the objects in the network as well as, the effect of object failures on the level of service of the network. The development and implementation of such a process is now possible, given the maturity of methods, to evaluate the probable state of one or more objects, and the consequences of related to an object being in each state.

(ii) a new process to develop intervention programs needs to be developed that minimizes risk by systematically looking into consideration all the objects in the network and how they work together to provide an adequate level of service. Since the assessment of risk and the development of intervention programs is a process for which the time and expertise required to be implemented can vary significantly, different levels of effort and accuracy should be allowed depending on the problem description.

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