Introduction

The transportation system in Alpine countries plays an important role in the European transit of passengers and freights from north to south and east to west. Moreover, the Austrian railway network is also essential for the accessibility of lateral Alpine valleys and is thus of crucial importance for their economic and societal welfare. If traffic networks are (temporarily) disrupted, alternative options for transportation are rarely available.

The harsh mountainous nature of the Eastern Alps, within which 65% of the national territory of Austria is situated (Permanent Secretariat of the Alpine Convention, 2010), poses a particular challenge to railway transport planning and management issues. Due to limited usable space or for reasons of economic or technical feasibility, railway lines often follow rivers in valley plains and along steep unsteady slopes, which considerably exposes them to flooding and, in particular, to alpine hazards such as debris flows, rockfalls, avalanches or landslides. **Such events can cause substantial damage to railway infrastructure and pose a risk to the safety of passengers, wherefore they are a great issue of concern for the Austrian Federal Railways (ÖBB)**. In recent years, the ÖBB had to cope with financial losses on the scale of several hundreds of million euros as a result of alpine hazard impacts. Herein, a significant part is constituted by the severe flooding in May and June 2013, which cost more than €75 million (ÖBB Infrastruktur AG, 2014). Some historical catastrophic events even led to fatal railway accidents, e.g. the disastrous avalanche event near Böckstein in the year 1909 caused 26 fatalities. More details on the risk profile of railway transportation in Austria are presented in Thieken et al. (2013).

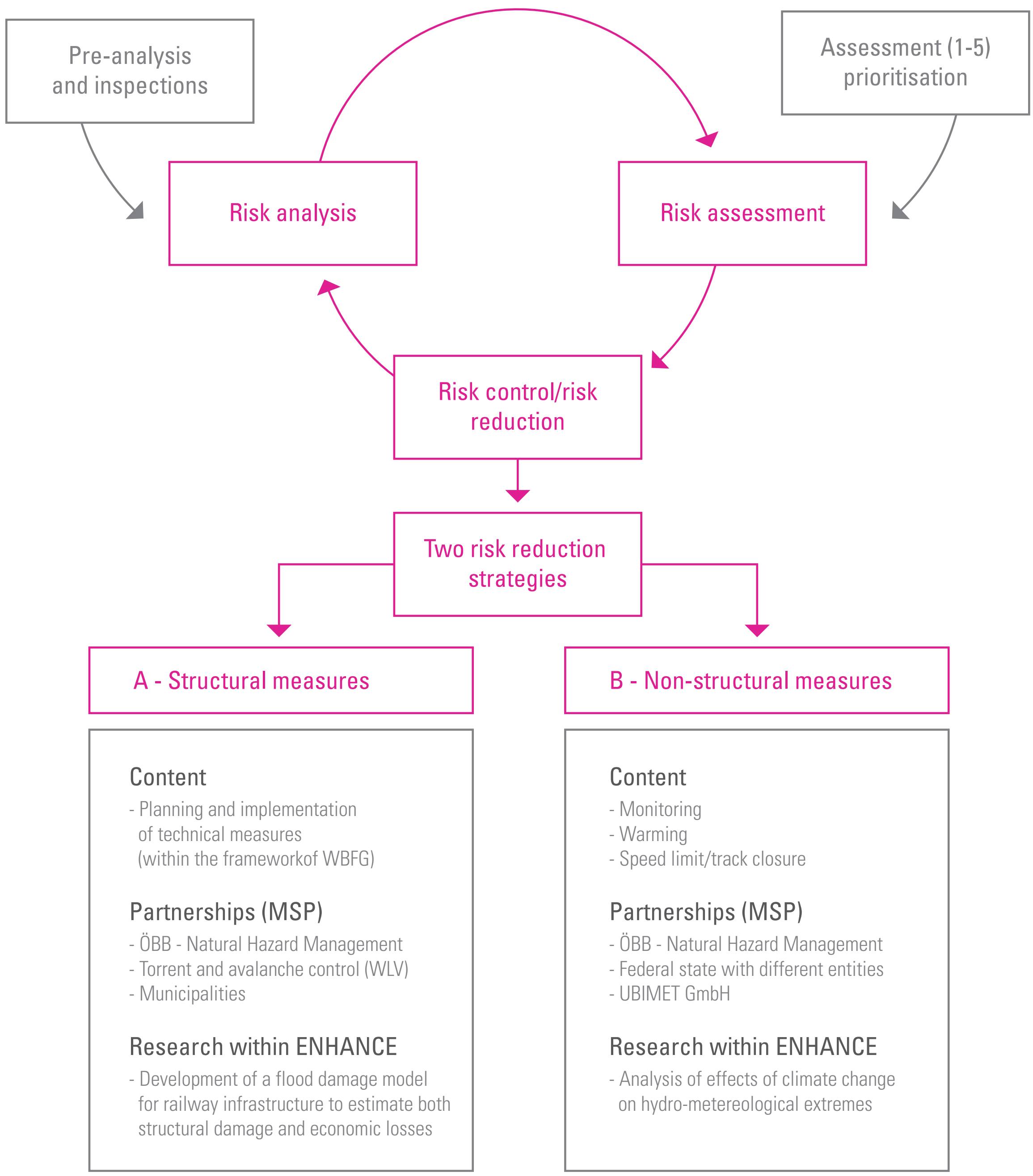
Hence, risk analysis and management are important issues of railway operation in Austria, which is indicated by the fact that the ÖBB maintains an own department for natural hazard management and partnerships with various stakeholders at different administrative levels. In this context, the ÖBB follows two main risk management strategies, namely:

(1) the prevention of alpine hazards through the implementation of *structural protection measures;*
(2) the use of *non-structural/organisational risk reduction strategies* such as a weather monitoring and warning system.

Both strategies, the multi-sector partnerships (MSPs) collaborating in the respective risk reduction strategies, and the research conducted within the ENHANCE project are depicted in Figure 17.1 and described in greater detail below.

Figure 17.1.
Two main strategies of risk reduction in railway transport and according work strands in ENHANCE (Source: own illustration. Information derived from interview/consultation with the ÖBB Natural Hazards Management Department). [WBFG = Hydraulic Engineering Assistance Act; MSP = Multi-sector partnerships; ÖBB = Austrian Federal Railways].

"Alpine railways are key for freight and travellers transport and subject to multi-hazard risks. In August 2005, floods blocked a section of an Alpine railway, it took €30 billion and 100 days to get it back in operation."



ÖBB risk management strategies

Structural protection measures

To protect their railway infrastructure from Alpine hazards, the ÖBB plans and implements structural (protection) measures on its own. If other stakeholders are affected by these protection measures, the ÖBB engages in partnerships to jointly plan and implement them. The core of these partnerships on structural measures lies in cost-sharing and, in preparation for it, also in information exchange. It includes formal, standardised processes fixed in regulations, as well as informal elements and ad-hoc negotiations. Further details on the strategies and specifications of the multi-sectoral-partnerships identified in this case study can be found in Otto et al. (2014).

Taking the core of partnerships on structural risk reduction measures into account, this ENHANCE case study focussed on supporting strategic decision-making regarding structural protection measures via provision of quantitative information on risks by means of **a statistical modelling approach derived from empirical damage data**, i.e. photo-documented structural damage on the Northern Railway in Lower Austria caused by the March river flood in 2006, and simulated flood characteristics, i.e. water levels, flow velocities and combinations thereof. A model was developed which enables the estimation of 1) expected structural damage for the standard cross-section of railway track sections and 2) resulting repair costs. The first step in particular is usually skipped in existing flood damage models, since only (relative or absolute) monetary losses are computed. However, the localisation of significant structural damage potentials at specific track section and, coupled therewith, the identification of risk hot spots creates great added value for railway operators in terms of network and risk management. Such information allows, for example, the targeted planning and implementation of (technical) risk reduction measures. In this regard, the results of the risk assessment indicate that the model performance already proves expedient as the mapped results plausibly illustrate the high damage potential of the track section located closely adjacent to the course of the river March as well as a general accordance with inundation depths. The estimates of financial losses (i.e. repair costs) amount to a plausible order and scale as the total costs increase for lower probability events and the results for the flooding in 2006 only overestimate the real expenses by approximately 2 %. The findings, furthermore, show that the development of reliable flood damage models for infrastructure is heavily constrained by the continuing lack of detailed event and damage data. This affects also the estimation of indirect damage, which can be indicated by the availability of a railway line. To feed a process-oriented methodology, sufficient input data is still missing. Therefore, only a rough estimation can be carried out to give an indicator for the worst case scenario when interpreting all processes as being independent. More details on the structural risk assessment results are presented in the ENHANCE case study deliverable 7.3 and in Kellermann et al. (2015c, 2016a).

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Non-structural/organisational risk reduction strategies

Since the possibility to address the risks from natural hazards in the Alpine topography by means of technical protection measures such as dikes or avalanche protection is limited, due to the sheer number of torrents and avalanche paths, the ÖBB additionally engages in non-structural/organisational risk reduction measures (see Figure 17.1). This strategy focusses on risks occurring from meteorological hazards (i.e. extreme weather) and alpine hazards (e.g. avalanches, torrential processes, debris flows).

The main idea of partnerships following this precautionary strategy is to gather and exchange information in order to better evaluate risk situations. Herein, a key element is the weather monitoring and early warning system called **Infra:Wetter**, which is jointly operated by the MSP[25] between ÖBB and the private weather service Ubimet GmbH. Also information from the national meteorological office (ZAMG) is included in this system. In addition to providing individualised and route-specific warnings to approximately 1500 users, Infra:Wetter is also used to identify so-called critical meteorological conditions (CMCs) in advance: weather conditions that potentially lead to larger disruptions of train traffic and thus require coordinated action by the Natural Hazards Management Department of the ÖBB.

Since knowledge and information are the main focus of the partnership on the non-structural risk reduction measure Infra:Wetter, the case study at hand delivered new insights into possible climate change impacts on frequencies of extreme events to support decision-makers in the comprehensive and sustainable natural hazard management. The frequency analysis of CMCs in a changing climate revealed a noticeable to strong alteration of the current hazard profile in Austria. Notwithstanding the fact that climate change impacts can also have positive effects on some sectors (e.g. winter service), the occurrence of the most relevant type of CMCs analysed, i.e. very intensive rainfall events, is likely to increase considerably in the future, which overall leads to new challenges for the ÖBB natural hazards management. If no action is taken, the costs due to extreme weather events must be expected to rise in the future. Based on historical experiences, e.g. from the extreme rainfall event in 2013, the weather monitoring and warning system Infra:Wetter proved to be a rather cost-effective non-structural risk mitigation measure. However, the modification of the thresholds for the identification of CMCs revealed that frequencies of extreme weather events are quite sensitive to changes of this decisive factor. In the context of climate change, this result emphasises the importance to carefully define and constantly adapt and validate the thresholds in order to optimise the effectiveness as well as the adaptive capacity of a weather monitoring and warning system. Since the necessary data for an empirical evaluation of the threshold are currently not available in respect to data quality and temporal coverage, the importance to continuously collect detailed event and damage data following a standardised procedure is striking. Event documentation including 'near misses' can enable risk managers to better understand and learn from historical events and, thus, to adapt natural hazards management to future changes. More details on the non-structural risk assessment results are presented in Kellermann et al. (2015b, 2016b).

[25] MSPs as defined by McLean et al., 2013, p.1.

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Using the risk assessment results described above as a basis, the non-structural risk reduction solution Infra:Wetter and the MSP addressing the risk from CMCs were then further discussed and evaluated against several criteria (Kellermann et al., 2015a):

- Currently, CMCs are defined using a threshold approach, which was defined by experts of the MSP, i.e. ÖBB and Ubimet GmbH. Given the importance of these thresholds, potentially resulting in precautionary operational measures such as track closures and/or temporary speed limits, an empirical examination of these thresholds would provide important insights into the suitability of these thresholds. Therefore, a method to assess the suitability of the current thresholds is provided and exemplified. For a real application of this method, a more detailed longitudinal damage data base would be required, though, which again highlights the importance of event and damage documentation.
- An application of the risk layer approach (Mechler et al. 2014), which evaluates the suitability of risk reduction strategies based on disaster risk characteristics shows that Infra:Wetter in combination with a risk absorption mechanism provided by the federal government, is generally an appropriate solution for addressing risk from CMCs.
- After Infra:Wetter was established in 2006 in the aftermath of a major flood event in 2005, the system was stress-tested for the first time in June 2013, when extreme rainfall resulted in floods and debris flow events obstructing and interrupting train transportation in large parts of Austria. An analysis of this stress test showed that the system generally performed well also under extreme conditions. The event was predicted with a sufficient warning time and operational measures such as track closures and temporary speed limits reduced the risk to passengers and staff. An evaluation of the potential impact of climate change on CMCs furthermore revealed that such extreme situations could become more frequent in the future. This could mean additional stress for the risk absorption mechanism currently provided by the federal government.

The evaluation presented in this report builds upon the work that was conducted within the case study over the last three years. The basis for the scientific work in the project was the close cooperation with and support by the principal stakeholder ÖBB and included several internal project meetings, workshops and the provision of data as well as their feedback. Moreover, several interviews were conducted with additional stakeholders such as the Federal Ministry of the Interior, the Disaster Unit Salzburg, Water Management and Flood Control Unit of Salzburg and the Forest Engineering Service in Torrent and Avalanche Control (Otto et al., 2014). A full list of interviewed stakeholders can be found in Otto et al. (2014). Further details on the MSP evaluations can be found in Kellermann et al. (2015a).

Photo by ÖBB.