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Impact assessment of extreme weather events on transport networks: A data-driven approach

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ABSTRACT

The present paper presents a data-driven method for assessing the resilience of the European passenger transport network during extreme weather events. The method aims to fill in the gap of current research efforts regarding the quantification of impacts attributed to climate change and the identification of substitutability opportunities between transport modes in case of extreme weather events (EWE). The proposed method consists of three steps concerning the probability estimation of an EWE occurring within a transportation network, the assessment of its impacts and the passengers' flow shift between various transport modes. A mathematical formulation for the proposed data-driven method is provided and applied in an indicative European small-scale network, in order to assess the impacts of EWE on modal choice. Results are expressed in passenger differentiated flows and the paper concludes with future research steps and directions.

Introduction

In recent years, the European transport system has been increasingly exposed to several extreme weather events (EWE). Such events often render networks of all transport modes vulnerable, hinder their operation and functionality and lead to partial or full disruptions of the transport systems. One of the most representative examples of the latter is the eruption of the Eyjafjallajökull volcano in Island in 2010 and the posterior ash cloud, which severely disrupted transport operations of all modes, considered as the largest air-traffic shut-down in Europe since the Second World War. The losses to the airline industry were considered around 1.7 billion euros according to IATA (International Air Transport Association), mostly due to the cancellation of more than 100.000 flights (the 48% of the total air traffic) affecting roughly 10 million passengers (Bye, 2011). The impacts to the European economy were evaluated in 4 billion dollars according to OECD (Organization for Economic Co-operation and Development).

It is therefore important to develop a clear overview of their impacts, map all necessary actions towards improved network resilience and robustness and identify substitutability opportunities between modes. In an effort to do so, a data-driven method for quantifying the impacts of EWE both at nodal points (cities) and at their connections is presented herein, focusing on passenger transport. Inputs of previous climate change related research efforts in regard to the classification of such EWE into categories and the detailed examination of their occurrence probability are used. The impact assessment of EWE on passenger transport networks presented in this method is measured using the duration of an EWE impact and the extent to which transport supply related performance indicators are influenced.

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The method for assessing the resilience of transport networks during EWE is based on a mode choice approach. The outcome is expressed in modal differentiated passenger trips, should an EWE (e.g. heavy snowfall in an airport or flood along train tracks) occur, thus the substitutability of modes at pan-European level is identified.

The remainder of the paper is organized as follows: Section ''EWE impact assessment'' reviews the policy setting and pertinent literature on EWE impact assessment. Section ''Materials and methods'' presents the method aiming to integrate available data on climate change EWE and to assess their impacts on passenger transport networks. Section ''Findings'' presents an indicative application of the proposed method at European level in a network consisting of 3 cities covering various climate regions. Finally, Section ''Conclusions'' concludes on the conducted research and proposes directions on future research in the field of climate change and EWE impact assessment for the transport sector.

EWE impact assessment

The exposure and vulnerability of the European Transport System to EWE have been made apparent during several EWE of the last years, with increasing frequency and severity (Enei et al., 2010; Mitsakis et al., 2013). The European Commission has long identified the consequences of climate change as difficult for several economic sectors, including transport (European Commission, 2009) and has stressed the importance of monitoring and evaluating the impacts of such EWE (European Commission, 2011) towards an increasingly resilient transport system. The Intergovernmental Panel on Climate Change has documented the assessment of observed changes and the responses in natural and managed systems, both on key future impacts, vulnerabilities as well as on optimal adaptation plans (IPCC, 2007). The latter has been also the focus of attention of research efforts in recent years, describing integrated approaches, which can effectively address the multi-dimensional nature of the problem on how to identify optimal adaptation measures and can manage the risks induced by climate change (Mitsakis et al., 2011, 2013; Government Accountability Office, 2013).

Previous work on the field has established how different EWE harm the safety and security of passengers, disrupt logistics chains, immobilize public infrastructure, reduce accessibility, delay freight deliveries, inflate supply costs for operators and analyzed multi-modal connectivity's role in reducing risks during EWE (Maurer et al., 2012; Molarius, 2012; Nurmi et al., 2012; University Transportation Research Center, 2013). Moreover, current research efforts are focused on the impact quantification of climate change induced extreme weather events and natural hazards using various modeling techniques; from traffic flow methodologies (Mitsakis et al., 2014a), mathematical tools and analyses (Mitsakis et al., 2014b) to traditional observation practices (Chang et al., 2010; Easterling et al., 2000; Eisenberg and Warner, 2004; Hassan and Barker, 1999; Koetse and Rietveld, 2009; Suarez et al., 2005). In addition, studies in several EU member states at a national level as well as projects at pan-European level have provided until today general assessments of the impacts of climate change on various modes, systems and networks at regional, national and international level, mostly by examining case-specific EWE and projecting their impacts based on long-term weather predictions. All have concluded to results and conclusions, which highlight the importance of a coordinated, integrated and dynamic (in the sense of regularly updated) adaptation process across all EU countries from a multi-modal, multi-level and multi-actor perspective (Doll et al., 2012; Leviakangas and Saarikivi, 2012; Molarius et al., 2013; Papanikolaou et al., 2011). Yet, to the authors' knowledge, no research effort has been made towards quantifying the impacts of climate change, taking into consideration the frequency occurrence of EWE, and identifying the substitutability opportunities between transport modes during such EWE and by utilizing existing data sources and synthesizing available research results.

Materials and methods

The method aims to integrate available datasets and facts on climate change (associated with the existence and occurrence probability of EWE) and their quantifiable impacts on modal networks for passenger transport. The method is designed for the assessment of the modal shift of passengers/travelers due to the effects of EWE, through the definition of short, medium and long term scenarios, where the performance of existing transport systems will be significantly affected by EWE. The method identifies the occurrence probability of EWE at cities or at their in-between connections (Step 1), assesses the EWE impacts (Step 2) and finally provides quantitative results regarding the substitutability between modes (Step 3), as shown in Fig. 1 below.

Step 1 – occurrence probability at cities and connections

This step aims to quantify the occurrence probability of EWE at cities and at their connections. EWE can include wind gusts, snowfalls, blizzards, heavy precipitation and heat and cold waves, each one classified by severity levels (except for blizzards). Previous research activities using a variety of different climate models have resulted in high-resolution projections of the future climate, such as ENSEMBLES (der Linden and Mitchell, 2009). Using these data sets the occurrence frequencies for EWEs in days per year could be extracted and analyzed (EWENT Vajda et al., 2011). Table 1 below presents occurrence probabilities of EWE (in days per year) referring to the 2011–2040 period for Amsterdam, Barcelona, Copenhagen, Frankfurt, London, Madrid, Moscow, Munich, Mallorca, Paris, Rome, Stockholm and Zurich. For each event (besides