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Identifying locations along railway networks with the highest tree fall hazard

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ABSTRACT

Disruptions of railway traffic have many reasons. Tree falls onto railway tracks or overhead lines rank among the most common causes of disruptions of a natural origin. 2039 tree-fall events, containing up to 70 individual trees per event, were registered on the Czech railway network between 2012 and 2015. 32% of them were directly caused by 14 weather extremes during which more than 20 concurrent tree-fall events were registered. Moreover, 12 train derailments due to fallen trees were registered on Czech railways within the same period.

We combined land use data along railway tracks and data on tree falls. Land use and railway tracks data were obtained from a freely available Open Street Map database. The tree fall hazard was then computed using empirical data, data on land use and a generalized rule of succession. The clustering approach was also applied to focus on localities where tree falls were concentrated regardless of the resulting segment hazard. There were 59 rail track segments (out of 2960) with the highest tree fall hazard and 267 clusters were finally identified. The clusters and the most hazardous railway segments will be among the first in the process of line side vegetation monitoring in order to minimize potential losses from tree fall. The presented method can be widely applicable elsewhere.

1. Introduction

Railway transport has many advantages over road traffic. Trains carry larger cargo than trucks, train transportation is safer (European Union Agency for Railways, 2016) and more environmentally friendly than cars (e.g., Rodrigue, Comtois, & Slack, 2009). Large CO_2 savings could be achieved through a shift of freight from road to railways (IEA, 2009). Certain countries therefore support this mode of transportation along with the European Union (e.g., Railway Gazette, 2016).

High speed trains are, particularly for short and medium distances, alternatives to cars and even to air transport. However, railway routing is often affected by topography because of limited capacities of locomotives to cope with high gradients. To overcome these natural barriers expensive engineering solutions are applied such as tunnels or bridges (Rodrigue et al., 2009). Railway transport is, therefore, more vulnerable to traffic interruptions than transport on roads due to generally lower railway network densities and thus the limited number of alternative routes (Mattsson and Jenelius, 2015). Securing the serviceability (for definitions see e.g. Berdica, 2002) of railway transportation is thus among the main aims of railway operators.

Railway transport functioning is heavily influenced by adverse weather (Ludvigsen & Klæboe, 2014). Physical railway track blockages of a natural origin are thus common causes of traffic disruptions (e.g., by landsliding (Jaiswal, Van Westen, & Jetten, 2011)), flooding (Kellermann, Schönberger, & Thieken, 2016) or snowfall (Ludvigsen & Klæboe, 2014). Other causes of traffic disruptions include man-made ones such as car-train crashes at railway crossings (Clark, Perrone, & Isler, 2013), crashes with pedestrians outside railway crossings (e.g., Skládaná, Skládaný, Tučka, Bidovský, & Sulíková, 2016; Wang, Liu, Khattak, & Clarke, 2016) and technical failures of both locomotives and infrastructures (Briggs, Loveridge, & Glendinning, 2017).

1.1. Trees along railways

Trees along railways are currently situated on both earthworks (elevated embankments or depressed cuttings) and on the neighboring land close to tracks. Vegetated earthworks are, however, a

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fairly new phenomena. Earthworks were regularly cleaned from vegetation because of the fire hazard from sparks which accompanied steam locomotives (Briggs, Smethurst, Powrie, O'Brien, & Butcher, 2013). Tree fall hazard along railways became a safety issue when steam engines vanished from the European railways during the 1960–70s and the earthworks have not been maintained for vegetation (e.g., Gellatley, McGinnity, Barker, & Rankin, 1995).

Planting trees along embankments is sometimes encouraged, however, as they help stabilize the slopes (e.g., Greenwood, Norris, & Wint, 2004; Sargent, 1984). The leaf problem also ranks among issues connected with the existence of trees too close to railway tracks. This is particularly important at cuttings where opposite slopes face railway tracks. Leaves on rails are transformed into a material which decreases adhesion between the rail and the wheels of the engines (Higgins, 2002).

1.2. Causes of tree falls

The most common causes of tree falls are extreme winds (Ennos, 1997; Kolejka, Klimánek, Mikita, & Svoboda, 2010; Schindler, Bauhus, & Mayer, 2012; Goldman, Eggen, Golding, & Murray, 2014), heavy snow (Ludvigsen & Klæboe, 2014), or glaze (Zahradníček et al., 2017). These phenomena usually cover extensive areas as they are related to regional weather extremes (windstorms, heavy rain or snowing). Extreme winds were, for example, behind 46% of non-planned cutting down in state forests in the Czech Republic between 1963 and 1999 (Brázdil and Kirchner, 2007). Strong wind gusts, when occurring in the winter, are primarily connected to low-pressure systems, whereas in the summer they are related to mesoscale convective systems (Vajda et al., 2014).

Tree falls predominantly affect trees of a certain height. Nyberg and Johansson (2013) suggest that trees with a height over 15 m should be used for modelling of wind-related damage. Actual tree heights are, however, not always available in spatial data. Minor causes of tree fall are the results of unprofessional cutting and the loss of stability of rotten trees due to neglected tree maintenance.

1.3. Impacts of fallen trees

Hydro-meteorological extremes were identified as a primary cause of threats to critical infrastructure including railway networks (Nogal, O'Connor, Caulfield, & Brazil, 2016). Impacts of fallen trees on railways are usually indirect, i.e. fallen trees interrupt railway traffic. The losses are then related to traffic delays, rescheduling or even cancellation of train connections. Railway network topology is thus an important factor which influences the potential amount of indirect losses due to track blockages.

At times, fallen trees physically interrupt the overhead lines causing additional losses to railway administrators. The minority of tree-fall events end with train-tree crashes which are always costly events. Significant direct and indirect losses from tree falls have been registered in many countries, e.g. in Britain (Johnson 1996; DOT, 2014), Finland (Juga & Vajda, 2012; Vajda et al., 2014), Sweden (Nyberg & Johansson, 2013) and Poland (Ludvigsen & Klæboe, 2014).

Trains, when crashing into fallen trees, can also derail. Casualties were evidenced after these events in the media. Identification of locations along railway tracks where tree fall hazard is the highest, is thus an important issue. Railway segments with the highest hazard should therefore be inspected among the first. Geographic information systems (GIS) can be used for this type of spatial analyses.

The aim of this paper is to present a universal methodology, a combination of an exposure based assessment and a clustering, for tree-fall hazard computation based on open data which can be applied along railways anywhere.

2. Data

We have used, in this study, data on fallen trees, vector line data indicating railway network and land use data.

2.1. Tree fall data

Data on 2039 events, during which trees fell on railway tracks between 2012 and 2015, were obtained from a database managed by the Czech national railway administrator (CNRA). The data on tree falls were located by CNRA workers using a linear stationing system with 100 m precision (hectometers). One event usually contained more than one fallen tree, but these numbers were not always specified in the reports. The majority of the events occurred in July (Fig. 1).

The species of fallen trees were not always included within the attributes or additional free text. Only 36% of the data had this specification. The majority of the identified species of fallen trees were spruces (221 out of 738; 30%) as they also are the most abundant tree species in Czech forests (approximately 52% of all trees in forests are spruces).

2.2. Railway tracks data

Data on rail tracks were obtained from Open Street Map (OSM, www.openstreetmap.org). The original data were cleaned and made topological. Data are represented with vector lines connecting two neighboring railway stations. The Czech railway network ranks among the densest in Europe. The overall length of the Czech railway network is ○ 9566 km (density 12 km/100 km^2), represented here, in GIS data, by 2960 individual railway segments.

2.3. Land use data

Land use data were also obtained from the OSM. Only land use within a 200 m wide belt along railways was used for the analyses. This data set is maintained by the public. We have compared this

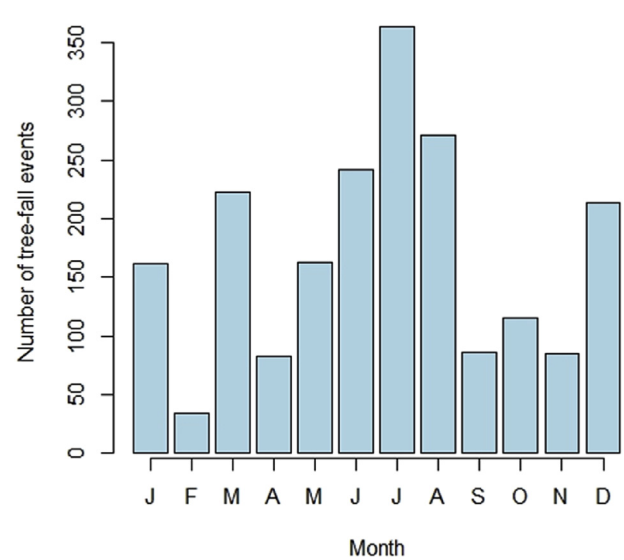

Fig. 1. Sum of tree-fall events on the Czech railway network for individual months between 2012 and 2015.