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Natural hazard events affecting transportation networks in Switzerland from 2012 to 2016

Jérémie, Voumard[1], Marc-Henri, Derron[1], Michel, Jaboyedoff[1]

[1] Risk analysis group, Institute of Earth Sciences, FGSE, University of Lausanne, Switzerland

Abstract

Switzerland is a country threatened by a lot of natural hazards. Many events occur in built environment, affecting infrastructures, buildings or transportation networks and producing occasionally expensive damages. This is the reason why large landslides are generally well studied and monitored in Switzerland to reduce the financial and human risks. However, we have noticed a lack of data on small events which have impacted roads and railways these last years. Therefore, we have collected all the reported natural hazard events which have affected the Swiss transportation networks since 2012 in a database. More than 800 events affecting roads and railways have been recorded in five years from 2012 to 2016. These events are classified into six classes: earth flow, debris flow, rockfall, flood, snow avalanche and others.

Data come from Swiss online press articles sorted by Google Alerts. The search is based on more than thirty keywords, in three languages (Italian, French, German). After verifying that the article relates indeed an event which has affected a road or a railways track, it is studied in detail. We get finally information on about sixty attributes by event about event date, event type, event localisation, meteorological conditions as well as impacts and damages on the track and human damages. From this database, many trends over the five years of data collection can be outlined: in particular, the spatial and temporal distributions of the events, as well as their consequences in term of traffic (closure duration, deviation, etc.).

Even if the database is imperfect because of it was built and because of the short time period considered, it highlights the not negligible impact of small natural hazard events on roads and railways in Switzerland at a national level. This database helps to better understand and quantify this type of events and to better integrate them in risk assessment.

Keywords

Natural hazard events, floods, landslides, earth flows, rockfalls, debris flows, snow avalanches, transportation networks, Switzerland, database.

1 Introduction

Natural hazard cause many damages on transportation networks around the world (Nicholson & Du, 1997; Hungr et al., 1999; Tatano et al., 2008; Dalziell & Nicholson, 2001; Karlaftis et al., 2007; Muzira et al., 2010; Erath et al. 2009; Jelenius et al., 2012;). Particularly on mountainous areas, floods, landslides (considered as earth flows in this study), debris flows, rockfalls and snow avalanches (called avalanches in this paper) can seriously affect the traffic on roads and railways tracks, isolating areas and generating infrastructure and economic damages (Bunce et al., 1997; Budetta et al., 2004; Evans et al., 2005; Collins, 2008; Salcedo et al., 2009; Guemache, 2011; Jaiswal, 2011; Michoud et al., 2012; Laimer, 2017).

While large natural hazard events affecting roads and railways are generally well studied and documented, e.g. the Séchilienne landslide (Kasperski et al, 2010), La Saxe landslide (Crosta et al. 2014) or La Frasse landslide (Noverraz and Parriaux, 1990), this is mainly not the same for minor and medium-sized events ranging from a few cubic decimeters to a few thousand of cubic meters. Some reasons why minor and medium-sized natural hazard events are not well documented are because their direct consequences are often quite rapidly fixed i.e. the road can be re-opened few hours after the event or is only partially closes. They are also too small and too localized to be easily monitored (Jaboyedoff et al. 2013) and there is less interest to study them than for of large events that concern scientists and politic people for years.

This tendency to collect mainly large events or events generating high damages is observable in existing natural hazard spatial databases and global disaster databases. Thus, global disaster databases EMD-DAT from University of Louvain (Guha-Sapir et al., 2015), Sigma from Swiss Re reinsurance (Swiss Re, various dates) and Dartmouth from University of Colorado (Dartmouth Flood Observatory, 2007) have a disaster entry criteria of respectively at least 10 people killed and/or 100 people affected, 20 people killed and/or 50 injured, and large floods (Guha-Sapir et al. 2002; Tchögl, 2006; Guha-Sapir et al., 2015,) . If NatCat database from Munich Re reinsurance, (Bellow et al., 2009) seems to collect any property damage and/or any person affected (Munich R. E., 2011), its data are only partially available to the public and cannot be analysed as an unrestricted access database (Tschögl et al, 2006). In the same way, numerous worldwide, national and regional spatial natural hazard databases do not generally deal with very small events that can be considered as insignificant for the experts (Guzzetti et al. 1994, Malamud et al. 2004; Petley et al. 2005; Devoli et al. 2007; Kirschbaum 2010, Foster et al. 2012; Damm et al. 2014). Furthermore, with exceptions as the RUPOK database (Bíl et al. 2017), natural hazard databases usually do not have much information about consequences of geohazard events on transportation networks. For example, the Swiss flood and landslide damage database (Hilker, 2009) contains also small events but no information about track and traffic.

Problematic paused by the lack of data of small events is nowadays well acknowledged. Gall et al. (2009) highlight that small events underreporting generates a bias inducing natural hazards loss data fallacy. The director of Global Resource Information Database at the United Nations Environment Programme recognises a difficulty to evaluate losses from natural hazards since only events with estimated losses above 100 000 US$ are collected in the EMD-DAT database (Peduzzi, 2009). Head of the United Nations International Strategy for Disaster Reduction, R. Glasser, alerts that governments underestimate particularly the cost of small disasters, which result from the incapacity to know small events that are below the radar screen, that still affect many people (Rowling, 2016).

From the observation of the recognized lack of data of natural hazard small events in the existing databases added to the need of data about event impacts on road and railways tracks, we collected all natural hazard events affecting the Swiss transportation network since 2012. It is not an exhaustive database referred to geomorphic features of the events but it is a database focused on traffic.

The aim of this study is to remedy the deficiency of information about natural hazard events affecting transportation network in Switzerland through a significant effort on small events that are generally bellow radar screen. The database created for this purpose is used to determine trends of the natural hazard events in order to help decision makers to minimise their impacts on roads and railways.

2 Study area

The study area is Switzerland. Its area is 41 285 km^2 and its elevation ranges from 193 m (Lake Maggiore) to 4634 m a.s.l. (Dufourspitze). The Swiss geography can be divided into three major geomorphologic-climatic regions: the Alps, the Swiss Plateau and the Jura. The Alps cover about 57 % of the Swiss territory and are composed of a high-altitude mountain range with 48 summits over 4000 m a.s.l., and many inhabited valleys. The Swiss Plateau covers about 32 % of the territory at an average altitude of about 500 m a.s.l. and is partially flat with numerous hills. Two-thirds of the Swiss population lives on this plateau which has a population density of about 450 inhabitants per square kilometre. The Jura Mountains (11% of the territory) is a hilly and parallel mountain range with a top summit of 1679 m a.s.l.

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(Mont-Tendre). Due to its situation in Europe, the Swiss climate is a mix of oceanic, continental and Mediterranean climates and varies largely at a regional scale. The average annual rainfall is around 900-1200 mm years^{-1} on the Swiss Plateau, 1200-2000 mm years^{-1} on the Jura Mountains and between 500 and 3000 mm years^{-1} in the Alps (Bär, 1971). The Swiss average temperature is about 5.7 °C (MeteoSwiss, 2018).

The Swiss road network length is about 72’000 km with 1850 km managed by the Swiss Confederation whose 1450 km of high and motorways, 18000 km of cantonal roads and about 55000 km of communal roads (Federal Statistical Office, 2018). The Swiss railway network is 5200 km long whose 130 km of cogwheel train lanes and 330 km of tram lanes (Federal Statistical Office, 2018).

3 Data and methods

A database to collect all natural hazard event that affect the Swiss roads and railways since 2012 was designed. The present study focuses on the five years time period 2012-2016 were 846 events were collected.

3.1 Information sources

As there is no such database at national level and as not all cantons have such a database, it was necessary to find the information from a non-administrative channel. The online press channel was chosen because it has the best ratio simplicity/efficiently. Google^{tm} alerts were used to collect the events from the online press, since May 2014, with more than fifty keywords in German, French and Italian as tool to scan the Swiss online press (see Table 25 in Additional material (AM)). Each day, about ten Google^{tm} alerts were received. Each alert contained on average two online press articles containing one of the fifty keywords. Each of these online press articles was manually analysed in order to identify if the related information concerns or not an natural hazard event which has affected an transportation track. If not, it is removed. About 10 % of all online press articles highlighted by Google alerts refer to a real natural hazard event. About 1200 online press articles were kept in three years (2014-2017). The Swiss traffic information website is also periodically manually checked, as well as few social media pages susceptible to have some pictures of events. Otherwise, some events were collected directly in the field.

3.2 Natural hazard processes considered

In the present manuscript, we assigned natural hazards processes affecting the Swiss transportation network according six natural hazard processes categories:

- Flood: static or dynamic flooding processes with only little sedimentation material on the tracks including few hail events fell.
- Debris flow: often not well described in the media and confounded with landslides or floods, debris flows were often recharacterized with pictures from the press articles.
- Landslide: superficial or deep sliding of a mass of soil including shallow landslides.
- Rockfall: stones and rock falls, rockslide.
- Avalanche: snow avalanches.
- Other: snowdrifts (mainly during February 2015 in West of Switzerland) and falling trees (mainly during windstorms).

3.3 Event attributes

172 attributes are used to describe the events (Figure 25 in the Supplementary material). There are distributed into eight categories: date, location, event characterization, track characterization, damage, weather, geology and source (Table 1). Date attributes describe when the event occurred, at which season or at which day part it occurred . Location attributes describe the region, the topography, the landscape and the coordinates of the event. Event characterization attributes explain the natural hazard process and its features. If available, a picture is given to illustrate the event. Track characterization attributes describe especially the track type (road, railway), its class (highway, main track, secondary track, etc.), its sinuosity, its closure duration and its deviation possibility. Damage attributes highlight the different damages due to the event on the track infrastructure but also on the vehicles and on people. Weather attributes describe the weather conditions (sun, rain, temperature, storm, wind and snow) from the event day to ten days before the event occurrence. The weather data come from the closest weather station of the 24 MeteoSuisse weather stations considered. Temperatures were corrected from the altitude difference between the event location and the weather station according the common lapse rate. The geology attributes characterize the soil (types of geology, hydrogeology, watershed, soil productivity) where the event occurred. Finally, the sources attributes provide the addresses of the consulted online press articles.

3.4 Types of analysis and statistics

Events were analysed according their 172 attributes making possible to carry out numerous analyses either in Geographic Information System (GIS) environment for spatial data or numerically for all other data. We have thus extracted simple statistics for each analysis (average, sum, mode, median, standard deviation minimum, maximum, etc.) as well as charts and histograms with trend lines and principal component analysis (PCA) especially for the weather data. The aim of the analyses is to extract trends base on the 846 collected natural events affecting the Swiss transportation network during the five years period 2011-2016.

4 Results

The 846 collected natural hazard events affecting roads and railways in Switzerland from 2011 to 2016 were analysed according:

- The types of natural hazard processes,
- The temporal distribution,
- The spatial distribution,
- The type of location with the topographic features at large and small scale,
- The types of affected tracks,
- The meteorological distribution,
- The impacts, deviations and closures.

4.1 Types of natural hazards processes

Half of the 846 collected events concerns floods with 50% of all collected events with 421 events, including hail flooding events (1% and 8 events) (Figure 1). The second most frequent process is landslides (23% and 192 events), followed by rockfalls (11% and 96 events) and debris flows (8% and 68 events). The rest concerns snow avalanches (2% and 15 events) and “other” events processes (6% and 54 events), including snowdrifts (5% and 40 events) and falling trees (2% and 14 events). Snowdrifts result from a unique and sporadic event in February 2015. In a simplified way, it can be said that half of the natural hazard events that have affected the Swiss transportation network for the period 2011-2016 is due to floods, a quarter concern landslides and the rest concern rockfalls, debris flows and other natural hazard events processes.

4.2 Factors of influence

4.2.1 Spatial distribution

Natural hazard events affecting the Swiss transportation network for the period 2012-2016 are equitably distributed on the geomorphologic-climatic region Plateau et Alps (44% each). The remaining 12% occurred in the Jura area (Figures 2 and 3, Table 4 in Supplementary material (SM)). Flood events are responsible of the high percentage of events on the Plateau with more than half of the flood events (57%) that occurred on the Swiss Plateau; debris flow events occurred mostly in the Alps (96% of them); more than half of landslides events occurred in the Alps (55%); rockfalls events occurred mostly in the Alps (88%); avalanches occurred exclusively in the Alps (100%) and the “other” events occurred mostly on the Plateau (78%).

Considering all events processes besides flood events, the spatial distribution of events, on the three geomorphologic-climatic Swiss regions is quite proportional to the surface of those areas: Alps with 60% of the Swiss territory and 64% of events, Plateau with 30% of surface and 31% of events and finally Jura with about 10% of the territory surface and 5% of all events. Rockall events occurred mainly in the Alps consecutively to the high proportion of cliffs above tracks in this region. Likewise, debris flow events are based almost exclusively in the Alps where are located large steep slopes with mobilizable soil required to trigger them.

Looking more in detail the location of events, we observe that half of events (49%) occurred in built environment (towns, agglomerations, villages and hamlets) and half (51%) of events occurred in a natural environment (countryside, 25%; forest, 22%; mountain above forest limit, 4%) (Figure 4 and Table 5 in SM).

The slope angle distribution (Figure 5 and Table 6 in SM), based on a 25 m DEM, indicates that 40% of all events occurred on a slope range from 0° to 5° and 30% of events on a slope ranging from 5° to 15°. Those slope angle values are lower than common values for natural hazard slopes because there are not slope angles at the event origin but at the end of the propagation, as tracks are located generally much below than sources of propagation. 62% of flood events occurred on a slope almost flat (0°-5°). 43% of debris flow events occurred on a 5°-15° slope. A third of landslides and rockfalls events occurred on a 15°-25°. 40% of snow avalanche events occurred on a 5°-15° slope. Two-thirds of “other” events occurred on a almost flat slope (0-5°).

Slope orientations of events occurring on mountainsides were estimated based on the Swisstopo map for 72% of events (Figure 6). Divided into eight slope orientations, half of events whose slope orientation was estimated occurred on south oriented, south-east oriented and west oriented slopes (each 17%). North and north-east oriented slopes contain the less events (8% each). Slope orientation of all Swiss mountainsides shows that south-west and north-east slopes are underrepresented unlike north-west and south-east facing slopes that are overrepresented. Comparison between distributions of slope orientation of events and of all of Swiss slopes shows that events on north-west-facing slopes are underrepresented and that they are overrepresented on west slopes. A raison for this west overrepresentation are the debris flows that occurred in the the S-Charl valley.

Several factors must be considered in the slope distribution. An explanation for the lower number of events on north-facing slopes is that there are less tracks on those slopes because there are less buildings on those shadowed slopes. Furthermore, North oriented slopes have less solar heat as south oriented slopes and thereby less freeze-thaw cycles. This can partially explain the high number of rockfall events on west, south and east oriented slopes.

4.2.2 Event volume and location of release zone

Events were classified into three classes of importance (Figure 7 and 8). The “small” class concern little events of volume bellow ten cubic meters. “Middle” event class concern events with a volume from ten cubic meters to two thousand of cubic meters. “Large” event class are events with a volume with a volume larger that two thousand of cubic meters. 95% of all events were classified as “small” events, 4% as “middle” events and 1% and “large” events. With a third of rockfall events classified as “ large” events, rockfall processes have the largest proportion of large events (Table 7 in SM).

Without considering flood events, 39% of origins of events are located far to the track (more than 50 m from the track). 35% of origins of events are near to the track (between 0 and 50 m from the track) (Table 8 in SM). One quarter of the location of origins of events is unknown. Generally, all event origin near the track are Human-Induced natural hazard events. This not the case for event origin far from the track where a part of them are natural hazard, particular with debris flows and avalanches in the Alps. All debris flow event origins arise far from the track as well as the majority of avalanche events. Without considering flood events, 80% of the origin of the events are located above the track, 7% are located bellow and 14% of event have an unknown origin (Table 9 in SM).

4.2.3 Rainfall

Different meteorological features have been attributed for each event. Data come from 24 weather stations from MeteoSwiss. For each event is a assigned a weather station which is not always the closest but which is in a similar topographic situation. Average distance between weathers stations and events is 20 km and absolute average elevation difference is 200 m. All weather data were given for three following time periods: the event day, the five last days and the ten last days. Those three periods allow to consider the weather condition from the event day until the last ten days.

17 mm of rainfall during the event day were recorded on average per event (Figure 9 and Table 10 in SM). Flood events are the natural hazard process with the highest rainfall amount with 22 mm fallen the event day. After flood events, landslide (17 mm) and debris flow (14 mm) events are the events with the most rainfall amount. Rockfall (5 mm), avalanches (4 mm) and “other” events brought up the rear. The absolute maximal precipitation recorded during the event day is 154 mm in canton of Ticino in November 2014 where a landslide occurred.

It can be highlighted that debris flows mostly occurred following strong summer storms after a quite sunny day. Floods generally occurred during days of the highest recorded rainfall compared to the daily precipitation of all processes. Landslides occurred after the greatest amount of rainfall recorded in the last ten days preceding the event. This shows general that, on a temporal scale, debris flows occurred few ten of minutes to few hours after heavy precipitations, floods after about one day of heavy rainfalls and landslides occurred up to several days after intense precipitations.

4.3 Temporal parameters

4.3.1 Clustering in time

Natural hazard events occurred often during bad weather meteorological events when precipitations last for several days. Fifteen long-lasting rainfalls were selected during the five considered years (Table 2) whose duration last from two days to fifteen days. 515 events (61 % of all events) have affected roads and railways during the 115 days of the fifteen considered meteorological events. Thus, 61% of events occurred during 6% of the five years time period 2012-2016 which shows the huge influence of intensive long-lasting rainfalls. This gives an average of 4.5 events per days. A third of the meteorological events are part of the Munich Re Topic Geo reports that annually reports the 50 major loss events around the world.

4.3.2 Monthly distribution

The monthly distribution of natural hazard events on Swiss roads and railway from 2012 to 2016 ranged from 9 events in December to 253 events in July which give a multiplication factor of 28 between those extremes (Figure 10 and Table 11 in SM). The average monthly number of all events is 71 events with a median value of 32 events, which highlights the influence of extreme weather conditions generating many events in few hours or days. Two-thirds of all events (67%) occurred during the three months May (12%), June (30%) and July (25%).

86% of flood events occurred in the three months May, June and July. 89% of debris flow events occurred in the four months May, June, July and August. Almost two-thirds (64%) of landslide events occurred in the three months May, June and July. Although almost two-thirds of rockfall events are distributed into five months (January, March, May, October and November), they are relatively well distributed. More as half of the collected snow avalanches events occurred in March. 81% of "other" events occurred in February.

This monthly distribution indicates that flood events mostly depend mostly on two meteorological conditions: thunderstorms and long-lasting rainfalls, which occur mainly in spring, particularly with the conjunction of snowmelt, and in summer. The near absence of floods in winter is the result of the Swiss winter climate with the absence of long or brief but intense precipitations and the by the fact that the precipitation in mountains are snow. However, exceptions are possible with floods caused by winter storms as in January 2018. Debris flow events mostly occurred in summer, as the results of powerful and stationary thunderstorms. Landslide events occurred mainly in spring as result of long-lasting rainfalls added with the snow melt which generate many water saturated soils and low evaporation. Snow melt is the second trigger, after intense rainfalls, for landslides on Austrian railway tracks for time period 2005-2015 (Laimer, 2017).

Rockfalls events do not follow the trend to occurred mainly in spring and summer. There occur in every season but mainly in autumn, winter and spring as the results of numerous freeze-thaw cycles at those seasons which weak the cohesion of rocks. Without surprise, avalanches occurred mostly in winter. They occurred also in autumn as the result of fresh avalanches on soils not yet covered with snow and because of still non-effective winter track closures of roads in the Alps. The almost total absence of avalanches in the spring can probably be explain due to the still current road winter closures that avoid spring snow avalanches, as well as rockfall and landslide events, on summer opened tracks.

4.3.3 Time of day and hourly distribution

We analysed the hourly distribution based on the 33% of events having an event local standard time value (Figure 11). Half of floods occurred in the afternoon during 4 hours from 2 pm to 6 pm. 61% of debris flow events during 4 hours between 3 pm and 7 pm. Except between 5 pm and 18 pm and 11 pm to midnight are landslides fairly well distributed. Comparable situation for rockfall events that are fairly equitably distributed over all hours of the day except between 9 am and 10 am containing 14% of rockfalls. The two avalanches with a precise event time occurred in the morning at 8 am and 11 am.

Flood events mostly occurred in the afternoon, probably after strong thunderstorms. Debris flow events mostly occurred in the evening, again probably after strong evening thunderstorms. Landslide events triggers are not time concentrate as the previous event processes. Rockfall events seem to be triggered during thawing which occur mostly in the morning. Snowdrifts from the “other” category began in the afternoon, after few hours of strong wind. That is why the “other” category events are so concentrated in the afternoon.

4.4 Infrastructure parameters

4.4.1 Types of tracks

88%, i.e. 747 events, of all collected events have affected road tracks while 12%, i.e. 99 events, have affected railway tracks (Figure 12 and Table 12 in SM). Flood events represent 53% of events that have affected roads and 27% of events that have affected railway tracks. Debris flow events represent 9% of events that have affected roads and 2% of events that have affected railway tracks. Landslides events represent 20% of events that have affected roads and 42% of events that have affected railway tracks. Rockfall events represent 10% of events that have affected roads and 20% of events that have affected railway tracks. Snow avalanches events represent 1% of events that have affected roads and 4% of events that have affected railway tracks. ”Other” events represent 7% of events which have affected roads and 5% of events that have affected railway tracks.

While floods events represent more than half of events affecting roads, they are two time less (27%) for events affecting railways. On the contrary, landslide events represent 42% of all event affecting railways and two times less (20%) for events affecting roads. 79% of all events occurred on minor roads or minor railways tracks while 21% occurred on major roads or major railways. The high proportion of landslides on train tracks can be explained in particular by the presence of very earthly embankments along railway tracks.

4.4.2 Roads

Roads are classified into seven classes, according the Swiss Federal Office of Topography, swisstopo, classification (Figure 13 and Table 13 in SM). In order of importance, there are firstly highways with a usually speed limit of 120 km/h and separated traffic, followed by motorways with a 100 km/h speed limit. Both represent 3% of the Swiss road network length. There are then major transit roads with a high traffic load (12% of Swiss roads) and roads of regional importance (22% of Swiss roads) with a lower traffic load (both 80 km/h maximum speed). The three remaining roads classes (63% pf Swiss roads) concern small roads with a (very) low traffic load and with track width ranging from 2 to 6 m: minor roads including most streets (4-6 m width), little roads (3-4 m width) and the forest or land trails (2-3 m width).

57% of events on roads occurred on minor roads, 13% occurred on major transit roads, 12% on regional roads, 10% occurred on little roads. 5% of events affecting roads occurred on highways, 3% on forest and land tracks and 0.3% on motorways. According to event processes, 65% of flood events affected minor roads. 42% of debris flow events affected little roads occurred on minor roads. 48% of landslide events occurred minor roads. 38% of rockfall events affected minor roads. 36% of snow avalanches events affected minor roads. 82% of “other” events affected minor roads. Reported to the network length of track classes, highways and motorways are affected by one event every 200 km each year, major and transit road every 650 km each year and all types of minor road (minor roads, little roads and forest trails) every 450 km each year. This shows that, despite more protections than the average, highways are proportionally more vulnerable than other roads maybe because of the alignment with many imposing cuts and fills.

4.4.3 Railways

Railway tracks are classified into three classes: major, minor and trams lines (Figure 14 and Table 14 in SM). Major tracks which represent 29% of events affecting railways are national tracks linking the big towns and few tracks crossing the Alps with often double lanes. Minor tracks, often with one lane, are affected by two-thirds (67%) of events affecting railways. Tram tracks, in or around towns, are affected by 4% of events affecting railways. 56% of flood events affecting railways occurred on minor tracks and 37% on major tracks. All debris flow events affecting railways occurred on minor railways. 68% of landslide events affecting railways occurred on minor tracks and 32% on major tracks. 70% of rockfall events affecting railways occurred on minor tracks and 30% on major tracks. All snow avalanches events affecting railways occurred on minor railways. 60% of “other” events affecting railways occurred on minor tracks and 40% on tram tracks. An issue related to regional tracks may be their lack of maintenance on track embankments during the last decades, causing landslides and rockfalls. Reported to the network length of track types, railways tracks are affected by one event every 250 km each year, all tram tracks by one event every 400 km each year.

4.4.4 Track sinuosity

The sinuosity of the track where events occurred and whose location was enough precisely known, was established on the basis of the swisstopo map. To define the curvature of the event location, six categories were defined: straight line (no curve), near a wide curve (on one side there is a straight line, on the other there is a wide curve which is close), wide curve (the event is located into a wide curve), near a tight curve (on one side there is a straight line or a small curve, on the other there is a tight curve which is close) and tight curve (the event is located into a tight curve). Distinction between wide and tight curve is the curve radius. Both for roads and railways, wide curves require to release the accelerator pedal to pass the curve with a speed which is equal or slightly lower as the straight line speed. In tight curve, drivers have to brake to reduce significantly the speed.

All track sinuosity of events which localisation was “accurate” or “middle” have been estimated (65% of events). About a third of events occurred in a wide curve or near a wide curve while 9% of event occurred in or near a tight curve. 21% of events occurred in a straight line (Figure 15 and Table 15 in SM). Considering event types, flood events occurred mostly on straight tracks while debris flows, landslides, rockfall and avalanche events occurred firstly on wide curve. “Other” events (snowdrifts and fallen trees) occurred both mostly on straight line and wide curves. Events that are located in wide curves can both be avoided by drivers if they are attentive but they can also generate an impact between the vehicle and the fallen material if the driver is not attentive because the visibility is lower than on straight lines.

4.4.5 Intersections

It was analysed if the 65% of events with an enough precise location were located in, near or far track intersections (Figure 16 and Table 16 in SM). In the majority of cases (38%), events occurred on tracks with any intersections, followed by 19% events located near intersection (from few meters to about 100 m). 8% of events are located in intersections. Except flood events, all events occurred mostly on tracks with any intersections around. Because of its

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urban qualification, flood events occurred mostly near intersections. Intersection means generally greater deviation possibility than track sections without intersection.

4.4.6 Possibility of deviation

For each event has been defined, how easy it was to find a deviation track (Figure 17 and Table 17 in SM). Four categories of possibilities of deviation were selected: large (many possibilities (>3), mostly in urban areas), middle (few possibilities (1-3), mostly in country areas), small (only one possibility) and any possibility of deviation (mostly in alpine areas). For 40% of events, it was a large possibility of deviation, for 23% of events the possibilities of deviations were qualified as “middle” and for 12% of events there were given as “small”. For one quarter of events, it was no possible to take an alternative tracks to bypass the closure.

By event types, almost two-thirds of flood events and half of “other” events could be bypassed. In contrary, it existed any deviation possibilities for 70% of debris flow events, 43% of rockfall events and 40% for landslide events. Thus, it is sometime difficult or even impossible to find a deviation path for numerous debris flow, landslide, rockfall and avalanche events.

4.5 Impacts and damages

4.5.1 On track

A damage level on tracks and track infrastructure was estimated for all event Damages have been characterized by four levels partially based on Bill et al. (2015). First level is “no closure or track damage” where the event generates any traffic perturbation neither track damage. 149 events -i.e. less 18% of all events- are categorized in this first damage level. Second damage level is “closure” when the track is closed due to material carried landslide by the natural hazard event and contain 463 events i.e. 55% of all events. After evacuation work, tracks can be used again, without any repairing work. The third damage level is “partial damage” when tracks, in addition of its closure, require superficial repairs and minor stabilization of the track embankment (143 events, 17% of all events). Fourth level is “total destruction” when the track embankment has to be reconstructed (53 events, 6% of all events). 4% of all events (i.e. 38 events) have damages that could not be estimated. Three-quarters of all events that generate no track damages, while one-quarter generates track damages (Figure 18 and Table 18 in SM).

With about a third of flood events that cause no track closure and two-thirds remaining events that generated only track closure, floods are the natural hazard which generate the least damages. The high percentage of floods which does not require track closure come from the fact that vehicles on roads or railways can pass through a certain water level. It is not uncommon to have flooded tracks and keep nevertheless a restricted traffic level. 40% of debris flows generated partial damages of the track and a quarter of debris flows generated damages of total destruction level. Half of landslides generated no track damages but only a track closures and one-third landslides generated partial damages on tracks. Almost similar for rockfalls with half of event generating only track closures and 39% generated partial damages. Avalanches generated mainly only track closures (81%) as well as "other" events (96%) due to snowdrifts. Due to their configuration of massive and heavy material, landslides generate often massive damage. Furthermore, when they are located just below the track, they almost always generated total damage to the track infrastructure. Similar for debris flows that could generate high damages due do their high energy stone blocks.

4.5.2 On vehicle

About vehicle damage, 5% of all collected events (i.e. 43 events) have generated damages on different vehicles (Figure 19 and Table 19 in SM). Those vehicle damages can be categorized into two classes: "direct impact" when a vehicle is directly reach by a hazard and "indirect impact" when a vehicle collides an event mass already fallen on the track. 25 events with a direct impact on vehicles were collected while 18 events caused indirect impacts on vehicles. Except a falling tree impacting directly a tram, all direct impact concern roads. Concerning indirect impacts, two trains impacted indirectly avalanches, four trains impacted indirectly landslides and one train impacted indirectly rockfalls. 1% of all events affecting railways caused direct impact whereas 7% of events on train tracks caused indirect impacts. Conversely, 3% of all events affecting roads generated direct impacts while 1% caused indirect impacts. The fact that there are more direct impacts than indirect impacts on roads show that drivers can generally stop their vehicle before to impact a fallen event unlike trains that cannot stop on a short distance and that reach the fallen mass. In addition, there is a much higher probability that a vehicle on a road will be directly impacted by an event than a train on a track because road traffic is excessively more dense than on a railway line.

4.5.3 On people

People are rarely affected by events. 98.2% of all events, i.e. 831 events, did not cause injuries while 1.8% of events (15 events: 13 on roads and 2 on rail tracks) have caused injuries (Figure 20 and Table 20 in SM). With 5.2% and 4.3% of events generating injuries, rockfall and debris flow events are natural hazard which generated the highest percentage of injuries. 20 injured persons have been identified whose 10 in a train derailment in the Canton of Grisons due to a landslide in August 2014. Three events (0.4% of all events) generated each one death. Once of the three events was the same as previously mentioned in canton of Grisons while the second, again on a train track, occurred in Gurtnellen (Canton of Uri) in June 2012. A rockfall killed a specialist working on a cliff where consolidation works were carry out following several rockfall on the track. The third event occurred also on the Canton of Grisons where a coach without passengers has been directly impacted by a rockfall killing instantly the driver in March 2012. According to track types, 0.1% of events on roads caused the death while 2% of events on railways generated deaths. Thus, there is one killed people for three injuries during the considered time period which is to short to extract mortality and injuries trends.

4.5.4 Closure duration

Closure duration of 296 events (35% of all events) were collected from the online press articles. Half of those closures 50% lasted less than one day while 41% lasted from one day to one week. 9% of closures lasted over than one week with a maximum of 15 months (Figure 21). Closure duration depends largely on the damage level generated by the event. Thus, 87% of flood events closures lasted less or equal to one day. While this percentage decreases to 71% for avalanches, 62% for rockfalls, 59% for landslides and 37% for debris flows.

4.5.5 Deviation length for roads

When they were known, deviation lengths for roads were collected from the online press articles. For all other events who needed a track closure, they were measured on a GIS. There are no possibilities for deviation tracks for one quarter of events because it exists any alternatives tracks. Those events with any deviation tracks are located mostly in narrow alpine valley. For the remaining three quarter, the deviation length varies from 1 km to 350 km (Figure 22 and Table 21 in SM). Thirty-one percent of all deviation track lengths are equal or less than one kilometre long. 28% of deviation lengths measure from 2 to 9 km long. One quarter of deviation lengths measure from 10 to 20 km long. The remaining 16% of deviation paths measure over 20 km. Deviation length is dependent with the event location. Thus, the average deviation length in the Alps is 40 km, 9 km in the Jura and 7 km in the Swiss Plateau.

4.5.6 Direct damage costs

Direct damage costs include all costs directly related to the rehabilitation of the track to guaranty the traffic service. All repair costs of the tracks are included. The estimated direct costs did not take into indirect costs like vehicle repairs (a train repair costs a lot), implementation of deviations, replacements buses in case of railway closure, all costs generated due to the traffic restriction for road and railway users, as well as all mitigation works and protective measures.

Direct costs were estimated on the basis of the damage on the track. For each damage class was attributed six estimations of costs per square meter according to the event importance (small, middle and large event) and the track type (road or railway). Costs, initially estimated on Swiss francs, were estimated on surface area defined at 100 m^2 for small events, at 200 m^2 for middle events and 300 m^2 for large events. Costs are given in Euros with value as mid January 2018 of 1 EUR = 1.17 CHF = 1.23 USD. A “no closure” cost was estimated on average at EUR 6 per square meter, at EUR 230 for a “closure” cost, at EUR 400 for a “partial damage” cost, at EUR 1000 for a “total destruction” cost and at EUR 230 for a “unknown” cost (Table 22 in SM). Costs were evaluated in the basis of road and railways reports (Canton de Vaud et du Valais, 2012; SBB CFF FFS, 2017) and on the basis of repair works experience in the civil engineering.

The annual direct damage on infrastructure of natural hazard events on Swiss transportation track was estimated at EUR 3.4 million. On average, cost of one event is EUR 19900. Direct costs of a flood is, on average, EUR 8000; EUR 47800 for a debris flow; EUR 31700 for a landslide, EUR 33100 for a rockfall, EUR 21900 for an avalanche and EUR 10200 for an “other” event (Figure 23 and Table 23 in SM). “Total destruction” costs are the highest costs (EUR 1.3 million), followed by “closure” and costs (EUR 1.2 million), followed by “partial damage” costs (EUR 0.8 million) (Figure 24). A “small” event costs in average EUR 15800, EUR 76200 for a “middle” event and EUR 175700 for a “large” event. Small events (95% of all events) represent 76% of the total direct costs; middle events (4% of all events) represent 15% of the costs; large events (1% of events) represent 9% of costs. Roads (86% of total transportation network length) represent 73% of the total cost, while railways tracks (14% of all Swiss tracks) represent 27% of all costs.

Floods generate the least damage by event with about a third of flood events that cause no track closure and two-thirds remaining events that generated only track closure. The high percentage of flood events which does not require track closure come from the fact that vehicles on roads or railways can pass through a certain water level. It is not uncommon to have flooded tracks and to keep nevertheless an unrestricted traffic level. Debris flows are the more costly process by event because they generate high track damages. The 17 destructing debris flow in the S-Charl valley in July 2015 influence those results.

Although floods are the less costly process by event, their annual cost comes in second place (EUR 0.58 million per year) because of their high number of events. Annual cost of debris flows is estimated to EUR 0.54 million, almost almost as much as floods because of their high individually damage cost. Annual cost of landslides reach almost the million Euro (EUR 0.95 million) which the highest annual cost of all processes. The reason is because their individually cost is high and because they are numerous. Similar to debris flow annual cost, the annual cost of rockfall is evaluated to half million Euro. With EUR 50000 and EUR 90000 per year, avalanches and “other” events costs are much lower than other processes.

5 Discussion

5.1 Results

5.2 Data quality

5.2.1 Completeness of the database

The integrity of the presented database is affected by several factors. Natural hazard events affecting Swiss transportation network are not all identified in the online press articles. The publications of those type of articles depend of numerous criteria such the number of casualties, the severity of the injuries, the resources available in the article redaction, the preventive or educational interest, the presence of images, etc. Article occurrence is theoretically higher in summer when the actuality is lower because the quieter the actuality, the less likely it is that a subject will be published. If an terrorist attack occurs in the middle of the summer, the likelihood of the natural hazard article appearing decreases. When a large natural hazard event occur, small events affecting roads or railways are not in a priority list. Sources for the articles are press agencies, concurrent media, social media as well as reader reporters.

A advantage of the Google Alerts is the variety of the online sources as all available online newspapers are checked and not only one unique source as for Badoux et al. 2016. To publish press articles about natural hazards affecting transportation tracks is challenging because we talk here mostly not about fatalities which are usually well reported in newspaper. For example, a Swiss-German newspaper will relate with a high probability a death resulting of a natural hazard on a track in the Swiss french part of Switzerland or in Ticino (Badoux et al. 2016), while it will probably not relate a forest path closure near of the redaction building.

Another factor influencing the data collection is the difference of perception between different areas as the Swiss Plateau and the Alps. A 0.5 m^3 rock fallen on a track in the plateau have more probability to be related in a press article as a similar event in the Alps. That because for people living in mountainous areas, those events are more or less common while they are exceptional for people living in the Swiss Plateau. Furthermore, when several events occur simultaneously like during an intensive a bad weather meteorological event, the probability that events are related in press articles decreases because media do not relate all events because they focus on the most impressive ones.

In order to estimate the proportion of missed events with our methodology, we compared our results for the Canton of Vaud with data from the natural hazard division of the administration of the same canton. The missing proportion of data our database for the canton de Vaud compared with the database of the canton de Vaud administration is about two-thirds. Many of those missing events occurred on forest paths and were collected by the forest service. If we extrapolate the missing data proportion to the entire country, we must multiply our total number of collected events by three, which gives about 2’500 events for the 5 considered years and thus gives 500 events by year and 1.4 event by day. Compared with results of events affecting roads and railways in 2014 derived from the Swiss flood and landslide damage database (Hilker, 2009), the missing proportion of data our database is a third. If we extrapolate the missing data proportion, we must multiply our number of events by 1.5, which gives about 1’250 events in five years and thus about 250 events by year and 0.7 event by day. We see here the difficulty to have a complete database and we note that a database at a large scale, i.e. Switzerland, is less complete as a little scale database, i.e. canton of Vaud even though we collected events that were not considered in the canton of Vaud database.

5.2.2 Range of considered years

During the 5-year period 2011-2016, 846 events were collected. They ranged from 60 to 269 events by year (Figure 25 and Table 24 in SM). Google Alerts were only used since May 2014. Before this date, event collection was less systematic which generated less events observations. Thus, we observe a average number of events of 80 for the years 2012 and 2013 (data collected without Google Alerts) and a average number of events of 257 for the years 2015 and 2016 (data from Google Alerts). 2014, with 173 collected events, is a transitional year with about half of the year carries out with Google Alerts and the other part without.

The observed period of five years (2012-2016) is too short to show trends of the events. Statistical predictions about a small sample of events are intrinsically imprecise (Davies 2013). The annual

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cost damage by natural hazard in Switzerland (Hilker, 2009) in the period 1972-2007 shows great damages disparities overs the years. This indicates that some extreme meteorological events as long-lasting rainfall or successive storms greatly increase the number of events collected in one year.

Our database must be considered as a focus on the time period 2012-2016 and must not be considered as representative of natural hazard events affecting roads and railways during the last 50 years. Collected data are like a photography at time *t* capturing the events and their impacts of a high number of events which could be classified at 95% as "small" with low impacts on the track and low material volume (lower than 10 m^3). Those small events are like a background noise of natural hazard events where large events are well studied. But together, this background noise represent a certain amount of roads and railway disturbance that could be highlighted.

5.3 Estimation of direct damage costs

Estimation of direct damage costs depend of many factors that are difficult to estimate. The hour has an impact of the cost: repair works during the night or the weekend are greater as during office hours. The event location impacts the costs too: costs in a alpine valley far away of any construction companies is higher than works in a agglomeration where construction machines and landfill for the excavated material are close. The date has also in impact on the costs: an event occurring during a time period where weather conditions are difficult will last longer. The emergency of the situation has also an influence of the direct cost: damage on a secondary road or on a highway will be treated with a different emergency level. We can also notice the influence of the among of traffic, the presence of damaged retaining walls and protective measures, the slope angle, the financial situation of the responsible administration for the repair works, necessity of work in the slope or the cliff above the track, etc.. Works on railways cost more than repair costs on roads because the access is often more difficult as on roads and because contact line and rails repairs can become very quickly expensive. All those factors can easily vary costs by plus or minus 50%.

An estimation of the costs of the "small" events is possible because the main work is to release the road from fallen materials. Costs estimation for the "middle" events and especially for "larges" ones is more complicated because the repairs require large construction sites which have their own characteristics that can not be compared that can not really be compared.

The estimated costs must be considered as order of magnitude of the direct costs generated by natural hazard events on the Swiss transportation network. However, obtained results are more refined as results in the previous study of Voumard et al. (2016) where costs of event bellow EUR 8500 were not considered.

5.4 Events trends

Statistic analyses and data analysis with especially PCA did not highlight particular or unexpected trends. Rain precipitations, with on average 17 mm water the event day, 45 mm the last 5 days and 71 mm the last 10 days, seems to have a undoubted influence as event trigger. As well as long precipitation periods as short strong storms are strong triggers for floods, debris flows, landslide and rockfalls. Laimer (2017) has shown that intense precipitations are triggers for 78% of landslides collected on railway tracks in Austrian during the time period 2005-2015. Freeze-thaw cycles during the winter season are also strong trigger for rockfalls.

With a summary of all the values of attributes, features of the mean natural hazard event affecting the Swiss transportation network for the time period 2011-2016 are the following: it is a flood occurring in Spring, in June, during the afternoon, located on the Swiss plateau, on a small South oriented slope, in the canton of Bern, on a minor road, on a straight path near an intersection in a village. It generates a road closure of few hours with a deviation distance less as one kilometre but causes no injuries or death. The possibility of deviation is large. Population is moderately directly affected by the road closure and little indirectly affected (minor road in a village). The soil of the event location is composed of gravel and sand and the soil productivity is a exploitable saturated zone. The day of the event, the sun shone half of the event day and it fell 10 mm of rain (20 mm the last 5 days and 35 mm the last 10 days) and the temperature average during the event was 20°C. There have been about 1000 lighting around the event location the event day and the wind speed was 7 km/h and a North North-East.

5.5 Event definition

The terminology of natural hazard event on road and railways is quite usurped because if the direct event origin is natural i.e. rain, heat, etc., the indirect origin is very often anthropic. Transportation network construction, use and maintenance induce the seven changes or actions potentially affecting slope stability proposed by Jaboyedoff et al. (2016) that is based on Terzaghi (1950) classification of mechanism of landslides. Those causes are slope re-profiling, groundwater flow perturbation, surface water overland flow modifications, land degradation, inappropriate artificial structures, traffic vibration and ageing of infrastructure. Indeed, track construction generates a modification of the slope topography that imbalance the natural slope stability and that modify landslide occurrence (Larsen and Parks, 1997). Furthermore, new infrastructures added in an already built area often generate an under sizing of existing drains that are are not suitable to the adding of new track. Water can be concentrated into slope parts and generate its destabilisation. People are thereby very often responsible to aggravate the hazard consequences with constructions build without an enough knowledges about natural hazard risk. Those natural hazard events can be hence characterised as Human-Induced natural hazard events (Jaboyedoff et al., 2016). This high proportion of Human-Induced events on transportation tracks is shown in the study of Laimer (2017) with 72% of events that are Human-Induced events.

5.6 General discussion about natural hazard and transportation networks

If the thematic of natural hazard affecting roads and railways has interest for some experts working with this topic, this is not the case for the most of political people and population. Compared with other societal thematises like health, old-age pensions or even transport sector, our interest obtains only little financial support because it is not in the prior list of the political people as a result of a lack of knowledge of the involved risk.

However, depending of current latest events, natural hazard affecting transportation network becomes a current thematic in Switzerland. For this, the event in Bondo, canton of Grisons, Switzerland, where a mountain collapse of 3 million m3 generated a debris flow which destroyed an international road in August 2017 is a good example. Thus, the magazine of the Touring Club Suisse, the largest motor club in Switzerland, dedicated twelve pages to natural hazards impacts on transportation network in its newspaper in autumn 2017.

Recent events in Switzerland ask the questions of the cost of closures that are very difficult to estimate. Several methods exists (Nicholson, 1997; Erath 2009) but they are all more or less imperfect because quantification of costs, especially for indirect costs, depends of many factors that are various and whose damage costs are difficult to estimate. We think that the resilience must be carefully considered since people find often solutions to skirt the track closure (deferred travel, meeting realized with digital technologies, alternative sources of supply, etc.). This question concerns more scientists as political since closure costs due to natural hazards, as traffic jam costs, are not compensated in Switzerland.

If issues of natural hazard affecting transportation tracks are not understood, there is no interest to have database of such of event and thus there is any interest to collect data, particularly for small events. Event if any natural event can always be qualified as a large event, depending on the point of view of the affected people. Similarly to Davies (2013), which puts back the importance of the event in the context of the affected person, a minor landslide that affect a person is completely unworthy of notice to the vast majority of a population, but is also momentary considered as catastrophic for the person that must reconsider its travel.

After different discussions with several people using natural hazard databases, observations are clear-cut concerning data acquisition: information acquisition is challenging and hard because it depends of several people working on field like roadmenders, railway maintenance workers and forestry workers who have sometimes no or little interest in the natural hazard thematic. Their primary purpose is to guarantee the passage of vehicles or trains. They usually have little time and/or interest to collect event data. This generates a loss of information and special situations where it is not uncommon for a state service to obtain information about an event in the press rather than through their services. Events can also be reported in a very inhomogeneous matter according the responsible person of the event announcement. Hence, there are possible improvements of database quality by the state governments (municipal, cantonal and federal levels) and for semi or private companies as SBB (Swiss main railway company) to collect data. To this end, new tools as off-line collaborative web-GIS (Aye et al. 2016; Olyazadeh et al., 2017) can help to facility the event collect.

Acquaintance of the natural hazards impacts on roads and railways also goes through make known events for the population. This can be made by different channels as the traditional media (newspapers, TV, radio) or the social media. As example of tool to sensitize the population is the Facebook page of the Colorado Department of Transport (CDT) in United States. In addition of preventive posts, all daily traffic restrictions are related on an active Facebook page. This diffusion channel allows the CDT to highlight all natural hazard events that affect roads in the Colorado department as thus to sensitize drivers of their travel impacts.

6 Conclusion and perspectives

In this study, we collected from online press articles natural hazard events that have affected the Swiss transportation network for a 5-year period from 2011 to 2016. With 172 attributes by event in different domains like natural hazard, traffic and track infrastructures, this database is, from our point of view, unique at the Swiss level. We are able to describe in detail the 846 collected events classified into six hazard processes -flood, debris flow, landslide, rockfall, avalanche and “other” processes- with their damages and consequences on the traffic (Table 3).

We can thereby estimate that the frequency of a natural hazard event affecting a track is of one event every two days. We estimate, on the basis of a database of a cantonal administration, that our database represent a third of known events by the experts. Our results highlight the certain importance of natural hazard events on the Swiss roads and railways, especially of little event with a fallen volume of less as 10 m^3 that are commonly are rarely or not collected and that represent 95% of the database events. The direct costs of all events were estimated at EUR 3.4 million by year and the average event cost at EUR 19900. Direct cost of small events was estimated at EUR 2.5 million by year which represents three quarter of the total direct costs. Comparatively, annual damages caused by natural disasters in Switzerland for the time period 1972-2011 are evaluated at EUR 290 millions (OFEV, 2013). Switzerland allocates EUR 2.5 billions by year for protection against natural hazards, which corresponds to 0.6% of its GDP (OFEV/OFS, 2011). 21% (EUR 0.5 billion) of this allocated amount concerns intervention and repair (OFEV/OFS, 2007).

With several factors as climate change generating always more extreme weather conditions and permafrost melt, densification of the infrastructures, traffic increase and lack of funding for track maintenance, we could wait for always more natural events affecting the Swiss transportation networks with an increase of damages on tracks and people. Moreover, a lot of events like flood and landslide events could occur almost everywhere and it is impossible to protect every meters of road and railways tracks with protective measures as the financial help is only just enough or even insufficient to protect the most critical areas. As usual, the key to reduce the risk due to natural hazard on tracks is obviously financing. In canton of Valais, the third canton in number of collected events and that has a lot of mountain roads, there is a lack of money of about EUR 35 million per year to provide services of the 1800 km of cantonal roads (Le Temps, 2018). Even worse, there is a lack in the road maintenance and the rehabilitation of this cantonal road network is estimated at EUR 1.3 billion. The Valais mobility strategy will reduce on a third the length of the network by transferring 600 km to the communes. These will leave the least used tracks. There is also different projects to reduce costs like for example to replace a 10 km road whose rehabilitation and security would cost EUR 30 million by a 6.6 km cable car whose investment is estimated at EUR 21 million (Le Temps, 2018).

In view of obtained results and, we perceive in winter storms one of the greatest threat for the Swiss transportation network because they can trigger many natural hazard events that requires track closures preventively or following an event occurrence. Winter storms, that are relatively rare occurrence, produce generally heavy precipitations falling in the form rain on the Swiss plateau and that can fall of the form snow in the Jura and the Alps with a zero degree limit around 1000 m a.s.l.. In such a case, many roads and railways are preventively closed because of the danger of avalanche in the Alps and rockfall, landslide, debris flows and floods affect the Swiss plateau since runoff water can no longer infiltrate into a saturated soil. After few hours or days in this precipitation configuration, it is quite possible that zero degree limit takes altitude up to 2000 – 2500 m. This generates high snowmelt producing many floods and other natural processes in all country. Winter storms can generate also many track closures due to falling trees. First half of January 2018 has seen successively three winter storms that produced a lot of track closure. As example, 150 road and railways track closures were identified for the single day of 13 January 2018. This number represents almost 90% of the average annually number of events collected in the five years time period 2012-2016.

The presented database and its event analysis can be helpful for the decision makers at the three Swiss politic levels (the Confederation, the cantons and the municipalities) to plan and enforce protective measures. For this purpose, we create open access online maps of the events in Google Maps and ArcGis Online (Figures 26 and 27 in SM) in order to promote the problematic. Our analysis also useful to take notice of the real impacts of known little events that can be considered as almost insignificant taken separately and that are generally unknown.

Data availability

Date used in this paper are available on demand.

Competing interests.

The authors declare that they have no conflict of interest.

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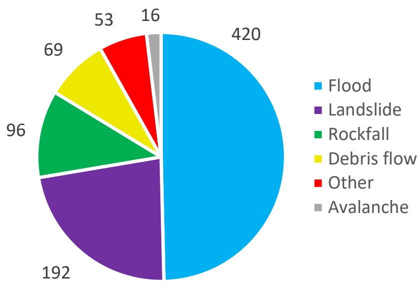

Figure 1: Number of events according natural hazard events on the Swiss transportation network from 2012 to 2016.

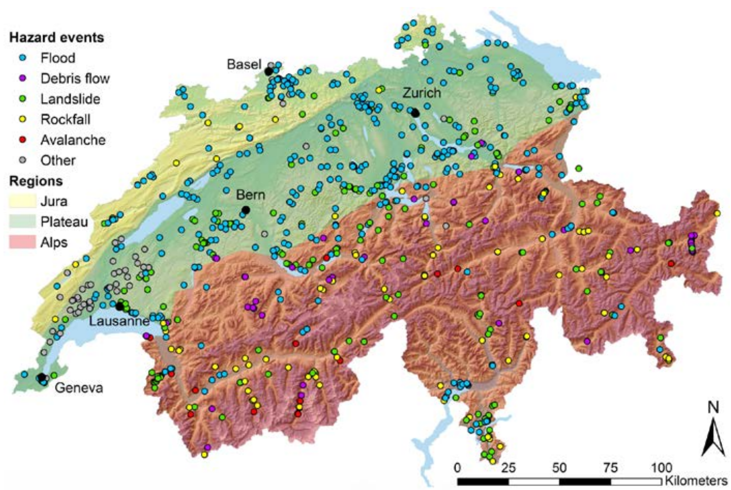

Figure 2: Spatial distribution of natural hazard events affecting roads and railways in Switzerland from 2012 to 20126. Source of the map: swisstopo.

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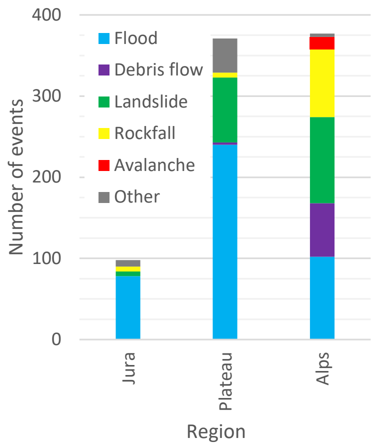

Figure 3: Distribution of natural hazard events on the Swiss transportation network from 2012 to 2016 according the three large geomorphologic-climatic regions.

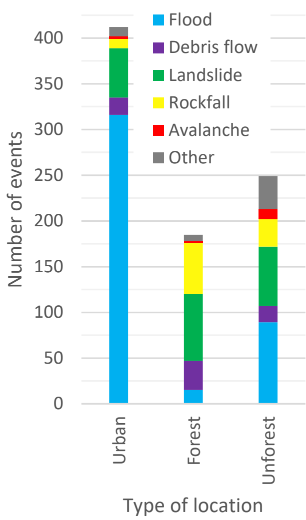

Figure 4: Distribution of the type of location of natural hazard events on the Swiss transportation network from 2012 to 2016.

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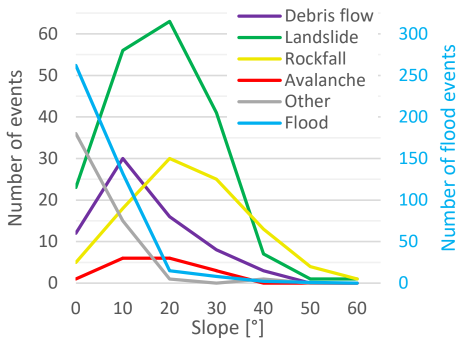

Figure 5: Slope angle distribution of natural hazard events on the Swiss transportation network from 2012 to 2016. Flood events are on the secondary vertical axis.

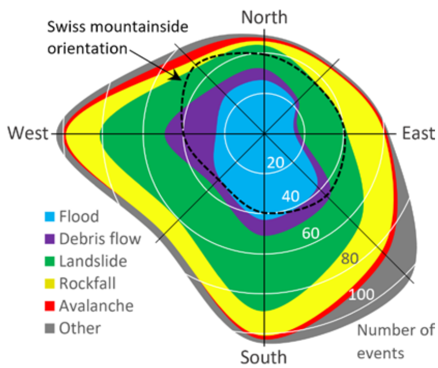

Figure 6: Slope orientation distribution of natural hazard events on the Swiss transportation network from 2012 to 2016. Relative distribution of Swiss mountainsides orientation is given with the black dashed line.

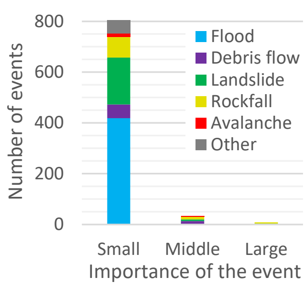

Figure 7: Importance of natural hazard events on the Swiss transportation network from 2012 to 2016. Small event: 0-10 m^3; middle event: 10-2000 m^3, large event: >2000 m^3.

Figure 8: Examples of events affecting roads. Left: small event already removed but still unstable on the unique access road to the small village of Morcles (canton of Vaud). Middle: middle event on a minor road in Ollon (canton of Vaud). Right: large event with a volume estimated at 3500 m^3 that cut on a 50 m length the international road between France and canton of Valais near the Forclaz pass (Trient). Road closure is estimated of six weeks. Images taken on 24 January 2018 after a winter storm.

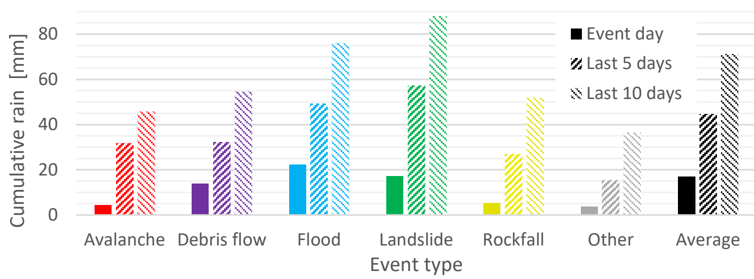

Figure 9: Cumulative rain [mm] distribution of the day of natural hazard events and last five and ten days.

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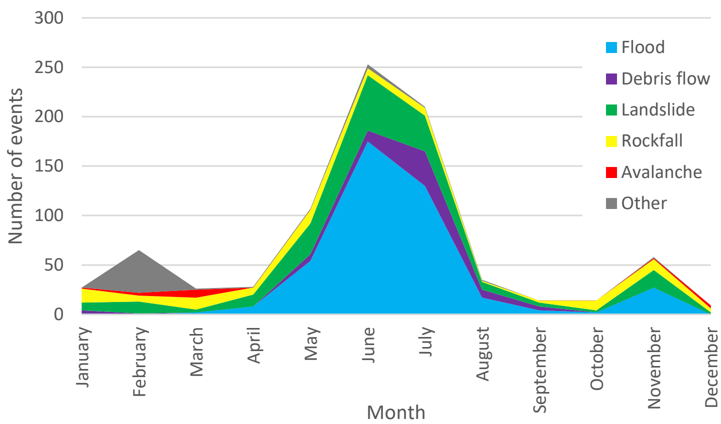

Figure 10: Monthly distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.

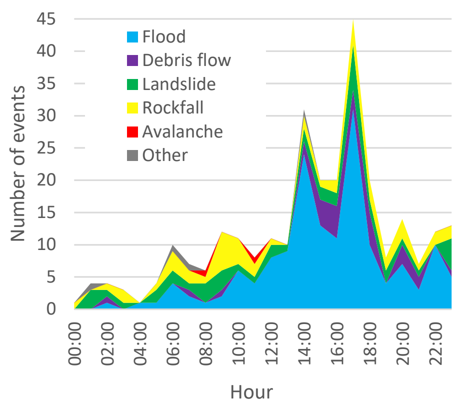

Figure 11: Hourly distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.

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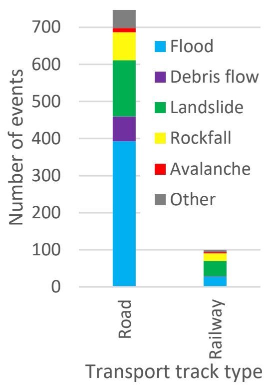

Figure 12: Distribution of transport mode of natural hazard events on the Swiss transportation network from 2012 to 2016.

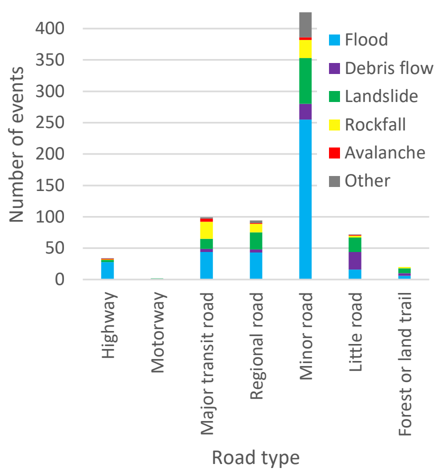

Figure 13: Road types distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.

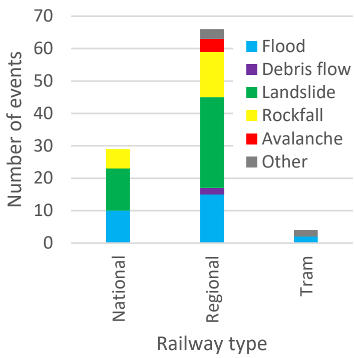

Figure 14: Railway types distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.

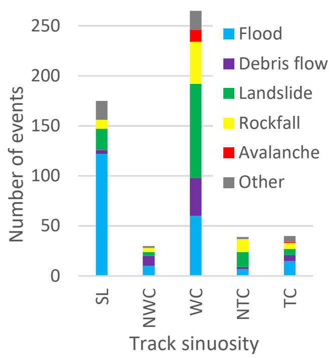

Figure 15: Distribution of track sinuosity of natural hazard events on the Swiss transportation network from 2012 to 2016. SL: straight line; NWC: near wide curve; WC: wide curve; NTC: near tight curve; TC: tight curve.

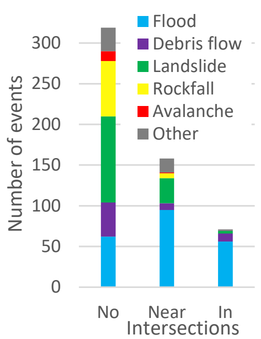

Figure 16: Distribution of presence or not of a intersection near the natural hazard events on the Swiss transportation network from 2012 to 2016. No: no intersection in the area. Near: intersection close to the event location (0 to hundred of meters); In: event location is in a track intersection.

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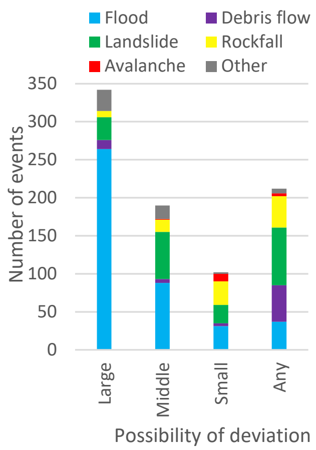

Figure 17: Distribution of possibility of deviation during natural hazard events on the Swiss transportation network from 2012 to 2016. Large possibility of deviations: >3 possibilities; middle: 2-3, small: one possibility; any: no possibility.

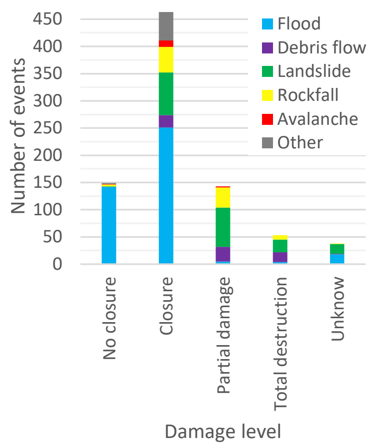

Figure 18: Damage distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.

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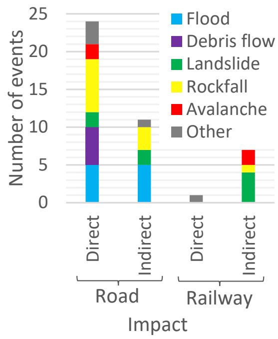

Figure 19: Distribution of impact types between vehicle on roads or railways and natural hazard events on the Swiss transportation network from 2012 to 2016.

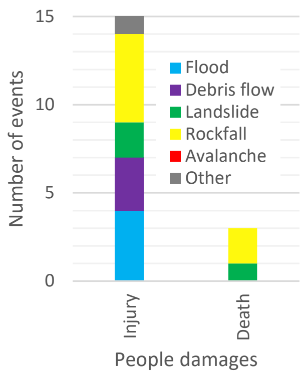

Figure 20: Distribution of injuries and deaths resulting of natural hazard events on the Swiss transportation network from 2012 to 2016.

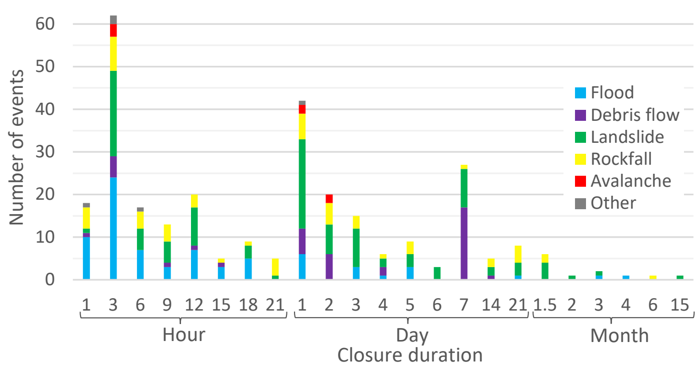

Figure 21: Closure duration distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.

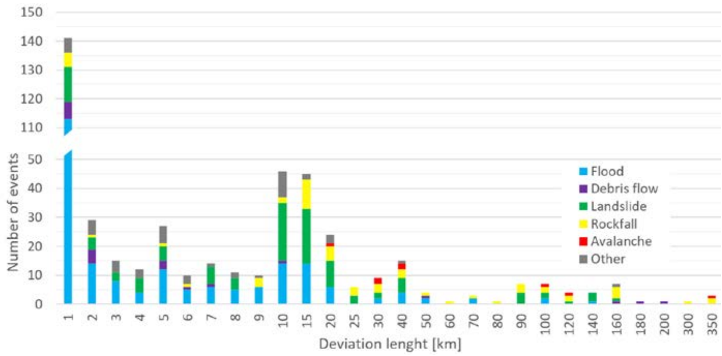

Figure 22: Deviation length distribution of road closures due to natural hazard events on the Swiss transportation network from 2012 to 2016. The vertical axis is cut between values 50 and 110.

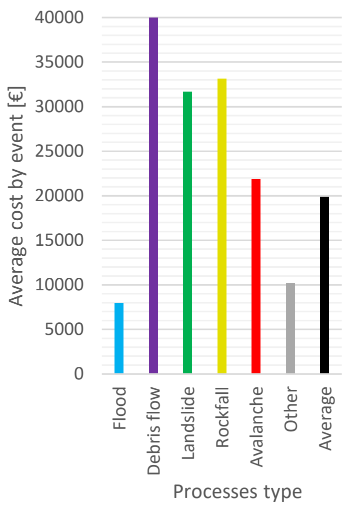

Figure 23: Average event direct cost distribution of natural hazard events on the Swiss transportation network from 2012 to 2016

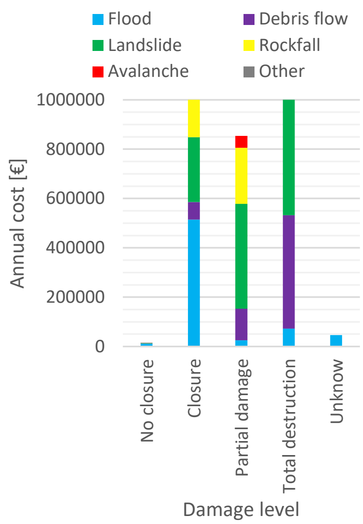

Figure 24: Annual direct cost distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.

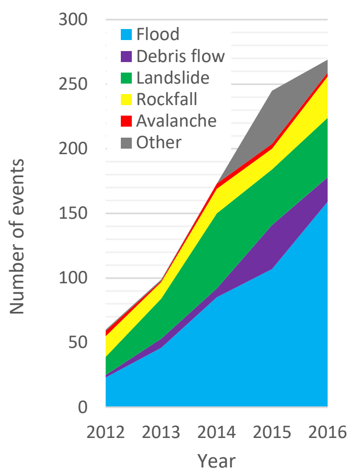

Figure 25: Annual distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.

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Table 1: Attributes categories to describe events in the database.

Attribute category	Answer the question	Number of attributes	Main source
ID	Event ID	1	-
Date	When did the event occur?	15	Online press article
Location	Where did the event occur?	21	GIS[1]
Event characterization	Which natural hazard event?	12	Online press article
Track characterization	On which track?	17	Swisstopo[2]
Damage	Which kind of damage?	11	Online press article
Weather	What was the weather?	68	MeteoSwiss[3]
Geology	On what soil did it occur?	11	Swisstopo[2]
Source	What are information sources?	16	Online press article

[1] GIS: Geographic Information System
[2] Swisstopo: Swiss Federal Office of Topography
[3] MeteoSwiss: Swiss Federal Office of Meteorology and Climatology

Table 2: Long-lasting rainfalls where occurred 61% of the collected natural hazard events on the Swiss transportation network during from 2012 to 2016.

Date	Number of days	Number of events	Avg number of event by day[2]	Munich Re event[3]
2012.01.06-07	2	2	1	2012.01
2012.11.04-14	11	12	1.1	-
2013.06.01-03	3	26	8.7	2013.06
2014.02.15-18	4	4	1.0	2014.02
2014.06.03-12	10	10	1.0	2014.06
2014.07.04-15	12	44	3.7	-
2014.07.22-31	10	51	5.1	-
2014.11.13-18	6	35	5.8	-
2015.04.27-05.07	11	55	5.0	-
2015.06.05-15	11	75	6.8	-
2015.07.22-25	4	37	9.3	-
2016.06.02-09	10	80	8.0	2016.06
2016.06.15-25	14	49	3.5	-
2016.07.22-28	7	35	5.0	-
Total	115	515[1]	4.5	-

[1] 61% of all events.
[2] Events number / number of days.
[3] Sources: Munich Re, 2012, 2013, 2014 and 2016.

Table 3: Summary of event processes key features.

Attribute (with values of the greatest occurrence)	Flood	Debris flow	Landslide	Rockfall	Avalanche	Other	Mean
Event importance	Small	Small	Small	Small	Small	Small	Small
Yearly number of events	84	14	38	19	3	11	169
Months	6, 7	7, 6	6, 7, 5	1, 5, 3, 11, 10	3	2	6, 7
Season	Spring	Summer	Spring	Spring, Winter	Winter	Winter	Spring
Day part	Afternoon	Afternoon	All day	All day	Morning	All day	Afternoon
Hour	12-19	15-19	0-24	0-24	8-13	0-24	14-19
Region	Plateau	Alps	Alps	Alps	Alps	Plateau	Alps, Plateau
Canton	Bern	Graubünden	Valais	Valais	Valais	Vaud	Bern
Slope angle	0-10	10-20	20-30	20-30	10-20	0-10	0-10
Slope orientation	S	W	S	W	N-W	S-E	S, S-W and W
Location	Village	Forest	Forest	Forest	Mountain	Country	Village
Damage on track	Closure	Partial dam.	Closure	Closure	Closure	Closure	Closure
Direct costs by event	6900	39000	25700	261000	155000	8600	16000
Track geometry	Str. line	Wide curve	Wide curve	Wide curve	Wide curve	S. line & w. curve	Wide curve
Crossing	Near	No	No	No	No	No	No
Closure duration	3 hours	1 week	1 day	3 hours	1-2 days	3 hours	3 hours
Possibility of deviation	Large	Any	Any	Any	Small	Middle	Large
Deviation length	0-1 km	No deviation	No deviation	No deviation	250-350 km	2-5 km	0-1 km
Event origin distance	-	Far	Near	Far	Far	Near	Near
Event above bellow	-	Up	Up	Up	Up	Up	Up
Altitude [m a.s.l.]	525	1139	809	897	1274	614	701
Track type	Road	Road	Road	Road	Road	Road	Road
Track importance	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Rainfall event day [mm]	22	14	171	5	4	4	17