Impact evaluation of human-made hazards on terrestrial transport infrastructure assets: modelling variables and failure modes

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Abstract

This work provides an overview of human-made hazards impact on the malfunctioning of terrestrial transportation systems. The impacts evaluation is gathered in four major groups, specifically: human, economic, environmental and political/social impacts. For further characterization or forecast of human-made hazards impact in real case scenarios, a traditional risk assessment framework is proposed by assuming four main steps: i) hazard identification; ii) probability of occurrence; iii) asset vulnerability; iv) impacts. The present work was carried within the SAFEWAY project, which aims at improving the resilience of transport infrastructures, developing a holistic toolset with transversal application to anticipate and mitigate the effects of extreme events at all modes of disaster cycle.

Keywords: human-made hazards; transportation networks; risk assessment; impact quantification.

1 Introduction

Management systems and decision-making processes for transportation network assets often rely on risk assessments as means to define preparedness, response and recovery to extreme events. The impact evaluation of a hazard in a given system is under the scope of a risk analysis. In that case the first necessary step focr a risk assessment is the definition of the system itself and the scope of the assessment. Having this in mind, the current work highlights the assessment made to transportation infrastructure network systems damaged by human-made hazards. In this sense, a human-made hazards are disastrous or disorder events caused by men or women activity, as users of terrestrial transportation network leading in many cases to negative outcomes. For an adequate risk assessment, it is imperative the definition of exposure, vulnerability and the robustness of the system, being the last two, a feature of the system responsible for higher or lower direct and indirect consequences, given the same hazard magnitude. On one hand, with higher vulnerability of the system it is more likely to have a larger number of fatalities and injuries occurrence and increased costs of restoration of the system. On the other hand, for the lack of robustness of the system it is often attributed the increase of indirect consequences such as the cost of disruption of the economy and immediate and long-term emergency measures.

This research is developed within the European project SAFEWAY [1], which main goal is to design and implement holistic methods, strategies, tools and technical interventions to significantly increase the resilience of inland transport infrastructure by reducing its vulnerability and strengthening network systems to extreme events (natural and human-made). For achieving the SAFEWAY project goals, one of its working package aims at identifying risk factors (natural and human-made) and vulnerabilities in order to provide an updated inventory of hazards and their impacts. Within this context, this work provides a synopsis on human-made hazards outcomes on the safety and malfunctioning of the infrastructure terrestrial network systems. The following goals can be targeted:

- Proposal of a framework for vulnerability assessment.

- Identification of human provoked disasters or accidents that could lead to disruption of the terrestrial transportation networks (railway and roadway).

2 Framework

Aiming at a holistic risk-based information, related to human-made hazards, for infrastructure network management it is crucial to consider the overall view of the hazardous event that leads to malfunctioning of the network. After the contextualization and definition of the system, the risk assessment is usually followed by four main steps (*Figure 1*) that govern the risk quantification: i) hazard identification; ii) probability of occurrence of the hazard; iii) vulnerability of the exposed assets; iv) consequence quantification (impacts).

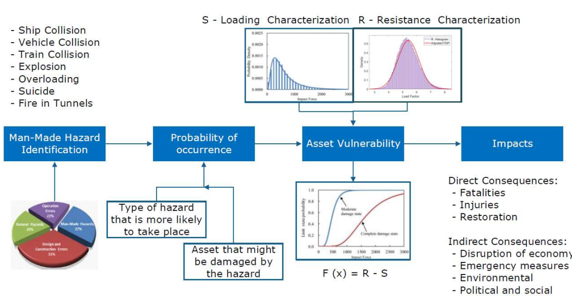

Figure 1. Framework for human-made hazard risk assessment [2]

The infrastructure network is composed by different types of assets, therefore not only the source of the event is important but also where it will affect the system itself, as to determine possible failure scenarios. It is also known that failure of transportation system assets is not the only consequence of a hazardous event, but when it comes to impact on society they have for sure enormous direct and indirect consequences, namely, high fatality and injury rate, and downtime (immediate and full unavailability), which is directly correlated to the cost of disruption of economic activities.

For the quantification of human-made hazards' possible contribution in the malfunctioning of a network system and subsequent impacts it is important to identify the assets that are more likely to be damaged by certain types of events and conditions. For instance, bridges crossing highly traffic seaways, roadways or railways, are more likely to be damaged by a ship, vehicle or train collision. Another example is the identification of bridges supplying or close to highly traffic harbours from where heavy vehicles might depart leading to overload bridges which are not suited or were not designed to sustain such loading conditions. With this type of screening procedure, a semi-qualitative analysis of the probability of occurrence may be achieved.

The vulnerability of structures exposed to a certain hazard can be measured by means of fragility curves representing different damage states that can be reached. The damage states are usually defined by different limit state functions, and therefore, they should be carefully defined for each specific hazard and accordingly to the aim of the analysis. Although there is a wide range of human-made hazards and a significant choice of possibilities of representing them, a fragility curve in this work is considered to be a function that represents the relationship between the demand and the structural capacities to sustain such demand. Therefore, each scenario of failure must be correctly addressed according to civil engineering good practices and according to the available statistical information, that allows the probabilistic characterization of the safety boundaries.

Related works concerning human-made hazard impact, proposed for this work, are scarce. Thus, the information here presented is mostly extracted and adapted from works addressing other types of hazards. Accounting to expert knowledge and based on the analysed databases, the following sections of this work describe the variables needed for analysis within the SAFEWAY project regarding the construction of suitable fragility curves and quantification of the impacts of human-made hazards on terrestrial transport networks.

3 Assessment variables

3.1 Human-made hazards and impact variables

The hazard impacts, within the scope of this work, are clustered into four main sub-fields, namely, human, economic, environmental and political/social impacts. Each one of the impacts is clustered into several sub-groups which are linked to different parameters for monetization purposes. The monetization process is considered in order to obtain a common variable for quantification and comparison purposes.

Table *1* provides an overall summary of the different levels of information required for the quantification of the impacts, within the scope of this work.

Table 1. Impacts on humans, economy and environment with respective monetization groups and sub-variables

Impacts	Sub-groups	Relevant parameters for Monetization	Sub-parameters
Human	- Fatalities	- Cost per fatalities	
	- Injuries	- Cost per injuries	
	- Displaced people	- Cost per displaced people	
Economic	- Immediate or long-term emergency measures	- Debris Removal	- Equipment
		- Alternative paths/detour	- Labour Force - Time of detour - Distance of detour
	- Restoration of infrastructure	- Cost of Inspection	- Material
		- Cost of Reconstruction	- Equipment
		- Cost of Repair	- Labour Force
		- Cost of Demolition	
	- Disruption of economic activity	- Restoration time	- Alternative road moving speed
		- Detour Paths distance	- Alternative road capacity
		- Changes in accident rates	- Disturbed average daily traffic
		- Additional travel time	
Environmental	- CO_2 Emissions due to repair works	- Material production emissions	- CO_2 emission costs per Kg
	- CO_2 Emissions due to traffic congestion	- Detour emissions	- Disturbed average daily traffic
	- Emissions of pollutants	- Burned materials emissions	- Average cars emissions per km
		- Restoration time	- Congestion rates
		- Detour Paths distance	- Alternative road moving speed
			- Alternative road capacity
Political / social	- Public outrage - Anxiety - Social psychological impact - Impact on public order - Political implications	- Cost of strikes - Cost of psychological treatments	- Social Anxiety - Loss of credibility - Loss of popularity of politicians - Felling of safety

Within the scope of this work and the SAFEWAY project, human-made hazards were defined as disastrous or disorder events caused by men or women activities, as users of terrestrial transportation networks leading in many cases to catastrophic consequences. It is important to highlight, for clarification purposes, that this human-made hazard definition does not cover human activities as an engineer/designer. With this is meant that disastrous consequences caused by conceptual, design, construction and operational engineering activity, when addressed in this work, will be referred to as human errors [3]. Human errors in the design/construction phase will be considered as an uncertainty to be implemented within the resistance models of the structure/infrastructure. As to better understand the previously mentioned definition, to refer to potential causes of malfunctions of the terrestrial transportation system caused by human activity, the following examples, within the scope of this work, are listed and divided in two groups [4][5], taking into account the intention or purpose of producing physical and/or functional failure (e.g. damage, disruption of services) to an asset:

1. Unintentional:

- Highway-rail grade-crossing accidents/ incidents;
  - Train collisions;
  - Derailments;
  - Suicides (also on common rail tracks);
  - Vehicle obstruction;
- Ship collision against bridges;
- Vehicle and train collision against bridges;
- Bridges overloading by live load (Infrastructure user's error);
- Fire in tunnels or fire vehicle under and over the bridges;
- Fire with source in human's action, evolving to large wildfires;
- Explosion (i.e. gas explosion);
- Suicides.

2. Intentional (Sabotage):

- Strikes/occupancy of lines for manifestations;
- Bombing/explosion with terrorist purposes;
- Fire with source in human's action, evolving to large wildfires;
- Track hazards (removing of rail track tie bars).

3.2 Exposed assets

A terrestrial infrastructure transportation system is composed by different types of assets connected to complement each other. Every day, assets are subjected to different exposure events, namely, natural extreme events, environmental chemical agents, human-made hazards, human errors and normal cyclic loads. Some assets are physically and/or functionally more vulnerable to a given type of exposure than others and some are more critical for the proper operation of the network system then others according to the importance of the service they provide. Looking at the network system, the following crucial assets are highlighted:

- Bridges and viaducts (roadway, railway and footway);
- Tunnels;
- Embankments;
- Retaining wall;
- System operation centres of railways;
- Train stations;
- Rail tracks;
- Roadway;
- Elevated tracks;
- Power infrastructures.

Another important step in the vulnerability assessment of infrastructures is the identification of the asset's failure modes that can be triggered by the exposure or hazardous events given the uncertainties that surround the civil engineering structures.

3.3 Recorded occurrences

For gathering purposes of statistical information and for a better understanding of human-made hazards significance in the malfunctioning of the terrestrial transportation system, a database of recorded occurrences is required. The database itself should contain information on the: i) source event; ii) asset to be analysed, and iii) consequences to the asset.

Among the human-made hazard events that can take place on the terrestrial transportation system, several different types of failure modes can be triggered. Therefore, the limit state function that should be used for the proper assessment of the fragility of the asset should be carefully set using the correct formulation that represents a probabilistic distribution of the system resistance and the correct loading features related to the human-made hazard under consideration.

For a risk analysis of structures subjected to accidental actions, the probability of failure of the structure should be quantified according to its damaged state and the probability of occurrence of the hazard. Therefore, within the SAFEWAY project, fragility curves were proposed to quantify the network assets vulnerability to accidental action caused by humans.

4 Impacts

As part of the risk analysis, the quantification of impacts on the infrastructure is a fundamental step to obtain risk-based information for a better management of the terrestrial transportation network system. Following, detailed description is provided in order to exemplify the procedure for distinct groups of consequences/impacts on the infrastructure management.

Human impacts can be estimated in terms of the number of affected people (e.g. the number of displaced people, fatalities and injuries), economic/environmental impacts in terms of costs/damage in monetary values (e.g. costs of immediate or longer-term emergency measures, costs of restoration of public infrastructure, costs of disruption of economic activity). The political/social impacts will be generally referred to as a measure of public outrage and anxiety, social-psychological impact, impact on public order and safety and political implications. When it comes to monetizing the direct and indirect impacts, Table 2 reflects some recommendations given on the literature. However, nowadays, some current works are trying to monetize some of the considered non-market values.

In order to provide a general overview of some specific points to be taken into account, Table 3 is provided for the impact assessment described in this work. In such a table, an attempt for a general distinction between structural and functional failure of the services provided by the asset is presented. Accordingly, the failure modes and the main modelling variables are suggested. The modelling variable column concerns the variables for impact quantification rather than the modelling of hazards. For functional failure, the most relevant modelling variables are usually time and availability. Being the last one the indicator that describes the level of services restriction caused by the hazard. Distinct modelling variables from the previously mentioned ones, are targeting inputs for structural impact quantification, although structural failure is followed by a functional failure. For clarification purposes, it must be said that the highlighted modelling variables are not targeting all the impact sub-fields, rather some of them. For further detail on the input variables for overall impact quantification, Table 1 should be addressed.

Table 2. Classification of consequences, adapted from [6]

	Market values	Non-market values
Direct	- Physical damage caused by the hazardous event - Costs associated with clean up, rebuilding or repairing	- Human casualties - Ecologic damages - Damage to cultural icons
Indirect	- Loss of mobility - Economic consequences of loss of mobility	- Depressions, Psychological problems - Increased vulnerability; lack of access to service

The “Impact” columns must be considered as being a screening procedure of the most relevant fields to be analysed, rather than absolute information for impact quantification. Especially because, the outcomes of many of the mentioned human-made hazards are enormous, thus, even a small impact in all the subfield should be expected.

5 Conclusions

When dealing with human-made hazard impact quantification within the scope of transportation networks, related works are still scarce. Thus, this work compiled and adapted the impact quantification from works addressing other types of hazards.

Accounting to expert knowledge and based on the analysed databases, a traditional framework for risk assessment was proposed taking into consideration fragility curves. In that sense, the variables needed to evaluate the impact of human-made hazards in the terrestrial transportation network were compiled.

Table 3. Classification of human-made hazards with modelling variables and failure modes. Grading should be considered within each event, where "+" means a significant impact and "-" a lower impact compared to the remaining types of consequences

	Hazard Characterization		**Asset**		**Impacts**				
	Hazard Scenario	**Main modelling Variables**	**Type**	**Failure Mode**	**Structural**	**Human**	**Economic**	**Environmental**	**Social /Political**
Unintentional	Collision of trains	Time/Availability	Rail track	Closed or traffic reduction	-	+	+	+ / -	+
	Derailments	Time/Availability	Rail track	Closed or traffic reduction	-	+	+	-	+
	Suicides	Time/Availability	Rail track / Roadway	Closed or traffic reduction	-	+	+	-	-
	Vehicle obstruction	Time/Availability	Rail track / Roadway	Closed or traffic reduction	-	+	+	+	-
	Ship collision against asset	Impact Force	Bridge	Failure, collapse, damaged element	+	+	+	+	+
	Train collision against asset	Impact Force	Bridge	Failure, collapse, damaged element	+	+	+	+	+
	Vehicle collision against asset	Impact Force	Bridge	Failure, collapse, damaged element	+	+	+	+	-
	Asset overloading by live load	Load Value	Bridge	Failure, collapse, damaged element	+	+	+	+	+
	Fire in tunnels	Time/Availability	Tunnels	Closed or traffic reduction/Failure, collapse, damaged element	+	+	+	+	+
	Fire vehicle under/over the bridge	Time/Availability	Bridge	Closed or traffic reduction/Failure, collapse, damaged element	+	+	+	+	+
	Fire evolving to large wildfires	Burned Area/Time/Availability	All	Global Failure	+	+	+	+	+
Intentional	Strikes/occupancy of lines for manifestation	Time/Availability	Rail track / Roadway	Closed or traffic reduction	-	-	+	-	+
	Bombing /explosion (terrorism purposes)	Peak pressure force/ Pressure timing	Train station/ Bridges/ Tunnels	Failure, collapse, damaged element	+	+	+	+	+
	Fire evolving to large wildfires	Burned Area/Time/Availability	All	Global Failure	+	+	+	+	+
	Track hazards (removal of rail track tie bars)	Time/Availability	Rail track	Closed or traffic reduction	-	-	+	-	+

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