AllTraIn

All-Hazard Guide for Transport Infrastructure

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WP3 Report

Infrastructure

The following report summarizes the results of Work Package 3 – Infrastructure of the EU CIPS Project *AllTraIn*.

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Project Information

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1. Introduction

The devastating capabilities of man-made hazards and natural events in disrupting transportation systems are demonstrated by recent cases. The July 7, 2005 London bombings, the March 11, 2004 Madrid train bombings and the 2011 Domodedovo Airport (Moscow, Russia) bombing, amongst others, show how man-made hazards have intentionally targeted transportation systems. In addition, unintentional man-made hazards also had severe impacts, such as the recent 2013 Santiago de Compostela (Spain) high-speed train derailment and the July 6, 2013 Lac-Mégantic (Québec, Canada) derailment of a freight train carrying crude oil, caused by human error and/or technical malfunction during operation, or the 2001 Hintze Ribeiro Bridge (Douro river, Portugal) and the 2007 I-35W Mississippi River Bridge (USA) failures, due to design flaws. Natural hazards including earthquakes, extreme rainfall, floods, wildfires amongst others also happen across the globe with destructive potential, namely for transportation systems. Notable events include the collapse of the Cypress Street Viaduct as a result of the 1989 Loma Prieta earthquake in California (USA), the effects of 2005 Hurricane Katrina (USA) on CSX railway, which required more than five months and $300 million to complete repairs and reopen the line, or the widespread destruction of the transportation infrastructures in north-eastern Japan caused by 2011 Tōhoku earthquake and tsunami. The World Bank and United Nations (2010) emphasizes, based on data compiled by the Center for Research on the Epidemiology of Disasters (CRED), that the absolute value of damages from natural hazards is strikingly rising in wealthy countries. In fact, the consequences of such natural hazards depend on the severity of the hazard and also on the exposure and vulnerability of the elements at risk (IPCC 2012). The construction of valuable infrastructures in hazard-prone leads to supports an increased exposure and vulnerability of that infrastructure, if vulnerable to the effects of the severe impacts of a hazard. In addition, modern societies and economies are increasingly dependent on transportation systems, the disruption time required to reopen a damaged infrastructure can have severe economic repercussions than often exceed the economic losses directly related to the reconstruction or recovery costs. Therefore, modern approaches considering the exposure and vulnerability of transportation infrastructures need to include the two types of hazards: man-made and natural hazards.

The World Bank and United Nations (2010) recognize that, while natural hazards cannot be avoided, governments and owners can substantially increase prevention measures that can be cost-effective. The European Commission also acknowledges the need for protection of European critical infrastructure and for the reduction of its vulnerabilities to man-made, technological and natural threats. The council directive 2008/114/EC (EC 2008) concentrates on the energy and transport sectors and defines the general methodology for the identification of European Critical Infrastructures (ECIs) based on: (1) cross-cutting criteria - casualties, economic effects and public effects for which thresholds are identified based on the severity of the impact of the disruption or the destruction of a particular infrastructure, (2) sectorial criteria and (3) a trans-boundary criterion.

EC (2008) states that each Member state shall identify potential ECIs, and continue to do so on an ongoing basis, defined in the council directive as "critical infrastructure located in Member States the disruption or destruction of which would have a significant impact on at least two Member States. The significance of the impact shall be assessed in terms of cross-cutting criteria. This includes effects resulting from cross-sector dependencies on other types of infrastructure".

Under the European Union's specific program "Prevention, Preparedness and Consequence Management of Terrorism and other Security Related Risks" - CIPS- (EC 2007), multiple projects have been funded. The present "All-Hazard Guide for Transport Infrastructure - ALLTRAIN" is one such project, structured in six work packages.

The present report proposes a categorization of transportation infrastructure, based on the infrastructure characteristics which may influence the physical vulnerability to a particular hazard materializing. Existing research and methodologies by different institutions are discussed. Ultimately, the identification of the factors affecting the infrastructure vulnerability is based on experience and records of hazard events, on expert engineering judgment and built upon existing knowledge from literature. The proposed categorization forms the basis for establishing criteria for the physical vulnerability assessment, considering the costs of the reconstruction of the asset affected as well as the out of service time due to an impact on the infrastructure.

Work package 3 (WP3) - "Infrastructures"- aims at identifying criteria for the assessment of the vulnerability of the infrastructures in the most relevant transport modes, based on a comprehensive methodology for the compilation of potential vulnerabilities. The Word Package WP3 is part of the sequence chain of ALLTraIn Project' structure (Figure 1):

- WP1 – State of the Art
- WP2 – Threats
- WP3 – Infrastructure
- WP4 – Approach for Assessment
- WP5 – All-Hazard Guide for Transport Infrastructure
- WP6 – Demonstration & Validation
- WP7 – Monitoring & Dissemination

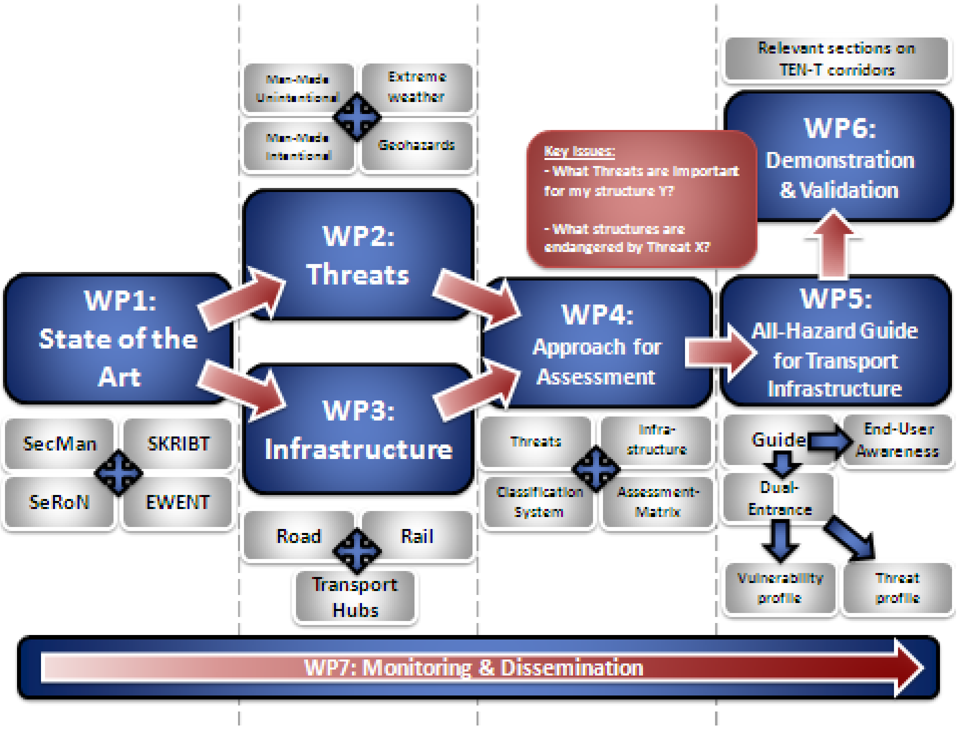

Figure 1. – AllTrain Structure

Thus, in WP2 were characterized the possible Threats or Hazards that are potential events whose occurrence can compromise the safety or reliability of the infrastructure. For this purpose, in WP2 two sets of basic factors were considered:

1. The nature of the initial event;
2. The type of local phenomenon that, as a result of the initial event, occurs in the surroundings of the infrastructure selected for analysis.

The combination of these two factors, as shown in the Report of WP2, enables the construction of the Hazard Matrix, which guides the characterization of impacts (Impact Matrix) and Consequences (Consequence Matrix) resulting from the effects on the selected infrastructure (asset).

The Work Package WP3, which is the subject of this report, aims at developing the criteria for the identification of vulnerabilities associated with the potential hazards and the selected infrastructures in order that a categorization of the potential consequences is possible.

2. Objectives and scope

According to the basic conceptual scheme or sequence chain adopted in the AllTraIn Project (Figure 2), after the characterization of potential events (Hazards) that may compromise the safety and reliability of the infrastructure follows the categorization of Local Consequences induced by the Impacts for each type of Infrastructure (Asset).

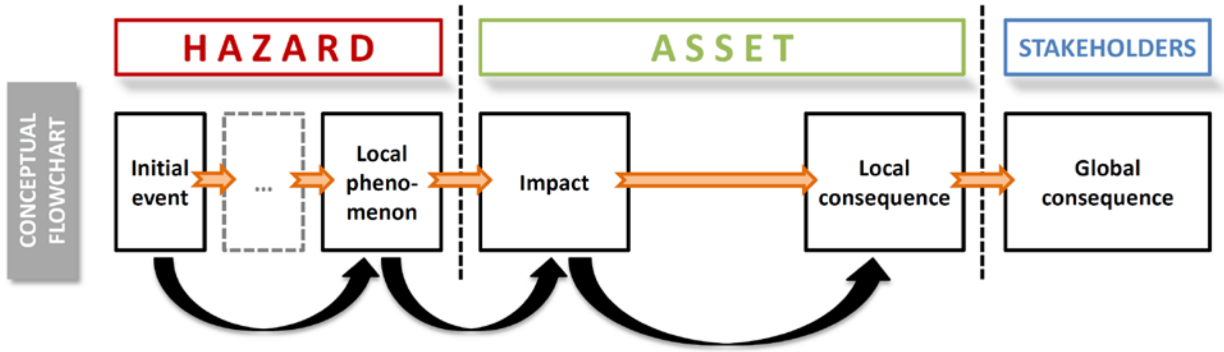

Figure 2. – Sequence chain

The overall goal of WP3 is to identify the type of potential Consequences resulting from the occurrence of a Hazard and directly associated to the physical vulnerabilities of each type of Infrastructure (Local Consequences), taking into account the type of impact caused or induced to the infrastructure. The Impacts may also induce other types of consequences for the stakeholders and the community in general (Global Consequence), which are not considered in this Project.

For the application of the adopted methodology, a set of types of infrastructures was considered relevant in the transport system:

1. Bridges
2. Tunnels
3. Embankments
4. Cuts
5. Ferries

With the exception of the last type (Ferries), all the considered infrastructures may be embedded in road, rail or mixed transport systems.

The WP3 prepares the information for the next step that is the assessment of the set of threats and Infrastructures (WP4).

3. Methodology

3.1 Transportation physical vulnerability

The influence of vulnerability on the impacts of hazards can be observed in past events. The U.S. DOT (2002) reports the transportation damage by the 1994 Northridge earthquake. At the time, a seismic retrofitting program for bridges and overpasses was underway in California to reduce the vulnerability of bridges, following the devastating effects of the 1989 Loma Prieta earthquake. The retrofitting program, while uncompleted at the time, was effective for the earthquake ground motion as none of the already retrofitted overpasses collapsed, amongst the eleven overpasses which did (EQE 1994).

Different concepts of vulnerability exist in literature. The assessment of the physical vulnerability of transportation infrastructure for an all-hazard approach thus requires that a single common terminology be considered in this project. Therefore, the definitions of the most relevant basic terms used in this report are here presented.

The EC (2010) recognizes the lack of a single common terminology for disasters, of natural and man-made origins, and related concepts. It also recognizes that both the linguistic diversity and the different frameworks of research communities studying distinct hazards contribute to such consistency challenge. Addressing this issue, the EC (2010) defines guidelines for risk assessment and mapping for disaster management considering a multi-hazard approach, based on a common definition of terms. Furthermore, the guidelines account for EU legislation including: the directives on flood risks (European Parliament and Council of the European Union 2007), on the protection of European Critical Infrastructures (EC 2008) and on the control of major accident hazards (EC 1997). Moreover, the guidelines consider a number of Eurocodes, such as "Eurocode 8: Seismic Design of Buildings".

The following definition of terms is assumed by the ALLTraIn project, in accordance with the EC (2010):

Risk is a combination of the likelihood of an event and its negative consequences.

In risk and hazard analysis, the effects of the impacts are often expressed in terms of vulnerability and exposure. Vulnerability (V) is defined as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. Exposure (E) is the totality of people, property, systems or other elements present in hazard zones that are thereby subject to potential impacts and losses:

Risk =F(probability*E*V)

The following definitions are assumed by the ALLTraIn project:

Exposure: Defines the value of the infrastructure which is subject to the impacts of the local phenomenon induced by a hazard. It only depends on the characteristics of the infrastructure (asset).

Vulnerability: Defines the part or percentage of the Exposure that is likely to be lost due to the impacts of the hazard.

Vulnerability is understood as the degree of damage that the infrastructure would sustain in the event of a particular impact, in consistency with the definition of terms assumed. It can be considered that the attractiveness to a terrorist attack is an exposure or category and not a vulnerability category.

The losses can be quantified by monetary values (replacement costs) or by the operational time cost (traffic obstruction) induced by the hazard impact. All loss values can be quantified by dimensionless values.

The above definitions consider that the risks associated to a particular hazard are inexistent if either the exposure or the vulnerability of the elements at risk is null. This is consistent with the World Bank and United Nations (2010) supporting that disasters are not natural but rather result from human acts of omission and commission. One of the four major findings of the report (World Bank and United Nations 2010) is that the exposure to hazards will rise in cities, but a greater exposure does not necessarily mean an increase in vulnerability. The influence of exposure and vulnerability in risk are considered separately.

It is also noted that while vulnerability is considered a fraction of the exposure that is likely to be lost, and thus dimensionless, exposure can represent a number of people, the cost of replacing assets, the maximum disruption time, etc.

Finally, it is highlighted that the vulnerability degree is related to a particular threat of a particular intensity or magnitude (Cardona 2003). The SecMan and SeRoN projects (Annex I), although considering a different definition of terms, do require that descriptive and relatively detailed hazard scenarios are defined for assessing the expected damage. This can be analogously bridged to the AllTraIn WP3 concept of vulnerability.

A delineation of the assumptions of the categorization proposed in this report is presented in 3.2 before outlining the approach defined in WP3 for infrastructure categorization.

3.2 Key assumptions and factors

After the selection of the five types of infrastructures already mentioned in the chapter 2, the key factors were defined that bind the fundamental features of the two types of the impacts due to local phenomenon to the local consequences considered: s

A- The type of physical or operational **Impact** acting directly on the Infrastructure (contact between the Local Phenomenon and the Infrastructure). Three major types were selected:

Obstruction: the physical presence of volumes on the traffic section. Examples: snow falls or rock blocs and landslides. These volumes may also collide with vehicles.

Operational Impact: a reduction of the functionality of the traffic infrastructure equipment. Example: damage in signaling or traffic control system caused by lightning.

Structural Impact: a reduction in the resistance characteristics of the structure caused by a significant change in the elements constituting the structure. Example: an explosion of a steel bridge can damage essential elements of the structure thus changing the strength characteristics of the bridge.

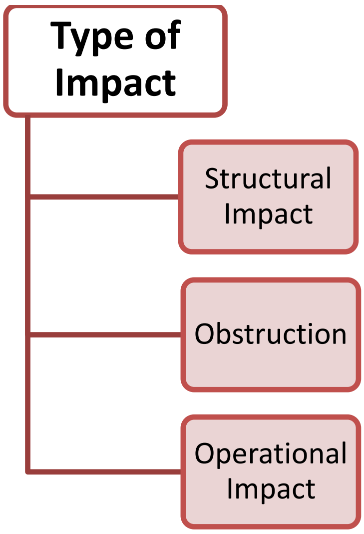

Figure 3. – Types of impacts considered

B - As **Local Consequences** resulting from an Impact and the characteristics of the infrastructure specific vulnerabilities, including physical or structural vulnerability, the surrounding natural environment and the nature of the respective traffic. The two following types were selected:

Damage - Repair and replacement costs: set of physical damage to the infrastructure that requires a repair and (or) a replacement of components or even the partial or total replacement of the infrastructure. These costs are considered likely to be quantified in monetary unit (e.g. euro) or by dimensionless factors as a function of a reference exposed value of the asset.

Disruption - Out of service time: total or partial interruption of traffic or normal service of the infrastructure, as part of a system of transport infrastructures network. This effect will induce different damage to users and to the community, as well as to the entity that manages the infrastructure constituting a component of Global Consequence whose evaluation is not covered by the AllTraIn Project. The quantification of this type of effect is reflected, thus, by the duration of the interruption (e.g. days) or by dimensionless factors as a function of a reference operation time.

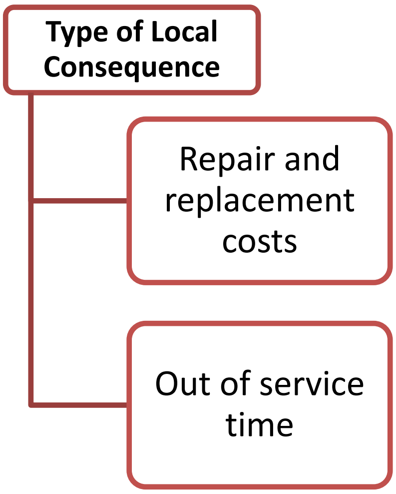

Figure 4. – Relevant types of local consequences

C- The relationship between these two sets of factors depends on several types of **vulnerabilities** associated to each type of infrastructure. Once again, these vulnerabilities were grouped in a set of factors that characterize the physical vulnerability (three) and one group that characterize the operational vulnerability:

Structural factors, associated with the built infrastructure and its design specifications, including the characteristics of the vulnerability considered relevant associated with the physical structure, the mechanical system that materializes the infrastructure. These characteristics will affect the susceptibility of the infrastructure to the considered Impacts. Example: the type of the structure material.

Natural factors, associated with the natural environment of the site where the infrastructure is built, including the characteristics of the natural environment where the infrastructure is located and which are considered relevant for the infrastructures behavior in relation to the Impacts. Example: the geological characteristics of the site.

Traffic factors, including the main characteristics of traffic at/on the infrastructure that may significantly influence the non-structural effects (disruption). Example: the mode of traffic, road or rail, mixed transport.

Factors affecting operational vulnerability, including the existence and type of centralized systems connected to the infrastructure and also the possible connection to a hub. These characteristics can affect the operational susceptibility of the infrastructure and also of other infrastructures.

The application of the integrated methodology, involving the specific methodologies of WP2, WP3 and WP4, will be sustained through decision trees. These trees will facilitate the linking of successive factors and the use of the All-Hazard Guide (WP5).

Finally, it is recalled that the general methodology developed in the AllTraIn Project is a qualitative/semi-quantitative one. The consequent level of strictness of the analysis and of both the assessment of vulnerabilities and the final assessment is compatible with the type of parameterization and categorization adopted.

3.3 Assumptions of the categorization proposed

3.3.1 Perspective of the analysis

A World Bank working paper on the economics of natural disasters (Hallegatte and Przyluski 2010) discusses how different cost assessment purposes is one of the factors contributing to discrepancies often observed in different impact assessments from the same hazard. Different cost assessment purposes, by different agents which are interested in different types of cost, are discussed to correspond to different issues included and definitions of what a cost includes. This fact is also emphasized by the World Bank and United Nations (2010).

It is acknowledged in the research project that the different potential users of the AllTraIn Guide (infrastructure owner, operator, end-user, stakeholders) can have different viewpoints related to the local consequences. All potential users' perspectives cannot be accommodated within the guide. Instead, the categorization assumes the guide is developed based on an infrastructure owner/operator perspective. This assumption does not minimize the importance of stakeholders' or infrastructure users' perspectives, in another context.

3.3.2 Hazard effects considered in the analysis

The effects of hazards can be extremely diverse, being often difficult to establish the full range and magnitude of effects that can result from the occurrence of a specific hazard. In fact, hazard effects depend on the characteristics (type and magnitude) of the hazard itself but also on factors such as the characteristics of the infrastructure exposed to the hazard occurrence. And while some hazard impacts derive directly from the hazards, other impacts occur due to a chain of causes. While one can attribute a market value to some losses for others value cannot be properly captured by a market value. The different types of losses are extensively discussed in literature (Hallegatte and Przyluski 2010; Mileti 1999; Rose 2004; World Bank and United Nations 2010).

For the specific case of transportation infrastructure, multiple effects of hazards may occur including physical damage to the infrastructure, loss of life or injuries, service disruptions (ranging from short delays to service interruption). The infrastructure's performance-related customer satisfaction is also an important issue (Fellesson and Friman 2008).

For different hazard effects, different factors affecting the infrastructure vulnerability need to be identified, as discussed by Melis and Maltini (2009). However, there is a great complexity in an all-hazard approach in the assessment of the multiple levels of vulnerability in different transportation modes.

Accordingly, the infrastructure categorization for the AllTraIn project considers only the repair costs of the physical damages to the infrastructure and/or its service disruption ("out-of-service") time. Therefore, the categorization focuses exclusively on local characteristics or factors affecting the vulnerability leading to those effects. In order to unequivocally exclude from the analysis other possible consequences that are only relevant at another scale (global consequences that require analysis of the infrastructure network and of the social losses), which is beyond the scope of the AllTrain project, only the local consequences are considered in WP3.

3.3.3 Consideration of mitigation and/or prevention measures in the analysis

The categorization assumes that the AllTraIn project aims at analyzing existing transportation infrastructures. All existing infrastructure characteristics are considered for assessing the hazard vulnerability through a common methodology. This means that only the mitigation and/or prevention measures existing at the time of the analysis are considered characteristics of the infrastructure.

The vulnerability assessment criteria will consider the effects of all the current design considerations and construction implementations. Furthermore, it is considered that "measures" represent further actions that could be implemented in addition to the present infrastructure characteristics.

3.3.4 Basic principles used in categorization

The methodology adopted in WP3 is based on the following basic principles:

a) The definition of vulnerability as a degree of loss that shall be defined for the transportation infrastructure characteristics. The vulnerability assessment will consider the characteristics of the hazards established in WP2.

b) The influence of the scale of the analysis, as it is discussed by Melis and Maltini (2009), namely if it is carried on for a network or for a specific component of the network (bridges, embankments, tunnels, etc.). The approach taken for the categorization considers the main characteristics influencing the vulnerability of an infrastructure and for specific sections of the network.

c) A multitude of characteristics of these systems affect their hazard vulnerability. For systematically addressing this issue, Husdal (2004) proposes grouping the infrastructure characteristics influencing its physical vulnerability into three major factor categories: structural, natural and traffic (Figure 5). Such an approach is considered in the AllTraIn project for categorizing the infrastructure attributes that affect the vulnerability of the infrastructure and is in accordance with the four factors adopted in WP3 and presented in section 3.2 : structural, natural, traffic and operational factors.

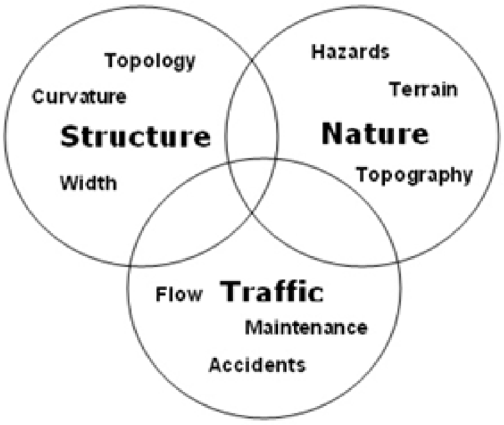

Figure 5 - Major factor categories used to describe infrastructures: structural, natural and traffic (Husdal, 2004)

The categorization criteria for these factors are identified in detail for:

i. Road and Railway Bridges;
ii. Road and Railway Tunnels;
iii. Road and Railway Embankments;
iv. Road and Railway Cuts.

d) All factors identified in the AllTraIn categorization aim at identifying the physical and operational vulnerability of the infrastructure that allows the assessment of repair costs arising from physical damage of the infrastructure and out-of-service time.

3.4 Overview of the Proposed WP3 Approach for Vulnerability Assessment

Based on the definitions and assumptions already presented, the WP3 approach aims at establishing how the degree of vulnerability of the infrastructure, for a particular impact resulting from an hazard threat or threat scenario, is influenced by its characteristics.

Given the all-hazard context of the project, multiple hazard loading conditions and circumstances are to be considered, for which the infrastructure performance will depend on multiple characteristics. In fact, the most relevant characteristics of the infrastructure affecting the vulnerability depend on the particular hazard being analyzed (and also on the "type" of loss under consideration). A representative infrastructure categorization is proposed. The categorization is based on a preliminary identification of the infrastructure features that may be relevant for any of the threats/impacts identified in WP2.

For the sake of consistency, the factors affecting the physical vulnerability of transportation systems are grouped into three main categories, according to their sources: structural, natural and traffic. Structural factors are those associated to the built infrastructure and its design specifications, natural factors are associated with the characteristics of the site where the infrastructure is built and traffic vulnerability factors are those concerning to the traffic characteristics. Additionally, operational factor were also considered.

All factors identified in the following tables aim at identifying the physical and operational vulnerability of the infrastructure that allows the damage or loss assessment.

The Figure 6 schematically represents how the asset vulnerability assessment fits into the overall project. In fact, using the impact characterization developed in WP2, the vulnerability of the asset is derived from both the characteristics of the impact and the characteristics of the asset. Combining the vulnerability of the asset with its exposure value (expressed in terms of reconstruction cost or time), which depends exclusively on its own characteristics, a local consequence level can be estimated. The global consequences are not directly related to the local consequences, a correct evaluation of the former being beyond the scope of the project.

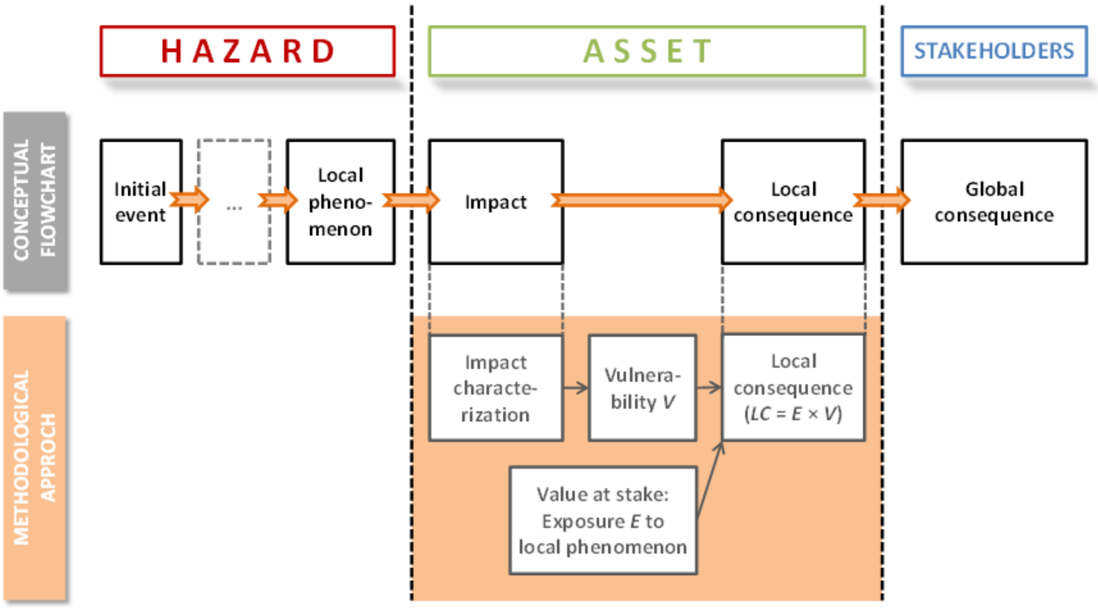

Figure 6 - Asset vulnerability assessment for a specific impact and its relation with the asset exposure in the overall context of the research project

3.5 Infrastructure Characterization for Vulnerability Assessment

The methodology described in the previous section for assessing the vulnerability of the infrastructures requires a characterization of the various types of infrastructures, namely bridges, tunnels, embankments and cuts, using the relevant factors considered in the methodology.

Based on the experience and fundamental understanding of the behavior of each kind of infrastructure, relevant factors are proposed for the four major categories of factors: structural, natural, traffic and operational.

3.5.1 Bridges

The Figure 6 lists the factors considered relevant from the point of view of the assessment of the physical vulnerability of bridges included in road or rail networks. The vulnerability may be assessed in terms of cost or time of repairing/reconstruction following the occurrence of a specify hazard causing a particular impact. The exposure of the asset should only depend on the same factors listed. For each factor, some examples of categories are proposed, the detail to use in the categorization being specific for each case.

The list includes, with respect to the structural factors, the bridge's construction type, described by the construction system, the cross-section and the material, the major geometric features (span, height and length) and the structural condition. The natural factors considered are the type of foundation and the crossing characteristics, while the traffic factors are those describing the specific characteristics of the local traffic: category, type and volume. The operational factors are the existence and type of centralized systems and also the eventual connection to hubs.

Structural Factors Affecting Physical Vulnerability

Construction Type			Span	Height	Length	Structural condition
System	Cross-Section	Material				
1. Beam bridge 2. Cable Stayed Bridge 3. Suspended 4. Movable Bridge 5. Earth-Covered Bridge 6. Other	1. Solid 2. Hollow 3. Truss	1. Concrete 2. Steel 3. Composite 4. Prestressed Concrete	1. Span < l1 2. l1 < Span < l2 3. Span > l2	1. Height < h1 2. h1 < Height < h2 3. Height > h2	1. Length < L1 2. L1 < Length < L2 3. Length > L2	1. Old/ Poorly Maint. 2. New/ Well Maint.

Location of bridge pillars	Foundation system	Type of Track/Pavement	Auxiliary Structure (rails only)
1. On water 2. On shore	1. Deep foundations 2. Direct foundations 3. Combined	1. Wood/Concrete Sleepers/ Ballastless track 2. Asphalt/Concrete/Bituminous	1. Overhead Line 2. No overhead line

Natural Factors Affecting Physical Vulnerability	
Geological/Geotechnical Foundation Conditions	**Crossing Characteristics**
1. Hard Rock 2. Soft Rock/Hard Soil 3. Soft Soil	1. River 2. Lake/Small River 3. Sea / ocean 4. Plain ground 5. Mountain valley

Traffic Factors Affecting Physical Vulnerability			
Traffic Category	**Traffic Category under the bridge**	**Traffic Type**	**Traffic Volume**
1. Highway 2. Normal Road 3. High-Speed Railway 4. Normal Railway	1. Ship (sea) 2. Ship (river) 3. Road 4. Rail	1. Passengers 2. Freight (cargo) 3. Mixed Traffic	1. annual daily average 2. rush-hour

Factors Affecting Operational Vulnerability		
Additional Systems (next to the infrastructure)	**Systems Category**	**Hubs**
1. Yes	1. Centralyzed Systems (affecting other i.f. of the network)	1. Connected
2. No	2. Operational/Energy Systems exclusive to the infrastructure	2. Not connected

Figure 7 - Factors governing physical vulnerability of **bridges** (roads and railways) irrespective of the impact considered

3.5.2 Tunnels

The factors governing the assessment of the physical vulnerability of tunnels, which make part of road or rail networks, are listed in Figure 7. The vulnerability may be assessed in terms of cost or time of repairing/reconstruction for any particular impact, the exposure of the asset depending also exclusively on the same factors listed. Some examples of categories are proposed for each factor, the adequate detail required in the categorization of the tunnels being case specific.

The list includes, with respect to the structural factors, the tunnel's construction type (construction system and cross-section), the major geometric features (length, cross-sectional area and cover depth) and the particular features that may affect its performance under some of the hazards considered: drainage and ventilation systems, fire protection and emergency detection systems and structural condition. The natural factors considered are the geological/geotechnical and the hydrological characteristics of the site, in the latter case both at and below the surface. The traffic factors describe the specific characteristics of the local traffic (category, type and volume) that may severely influence the effects of the occurrence of a specific impact. The operational factors are the existence and type of centralized systems and also the eventual connection to hubs.

Structural Factors Affecting Physical Vulnerability				
Construction Type		Length	Cross-section Area	Cover Depth
System	Cross-Section			
1. NATM 2. TBM 3. Cut&Cover	1. Single Tube 2. Double Tube	1. Length < L1 2. L1 <Length< L2 3. Length > L2	1. Area < A1 2. A1 < Area < A2 3. Area > A2	1. Shallow tunnel 2. Deep tunnel

Drainage Systems	Ventilation Systems	Fire Protection	Emergency /Detection	Structural condition
1. High Capacity 2. Low capacity	1. Existent 2. Non-exist	1. Existent 2. Non-exist	1. Existent 2. Non-exist	1. Old/ Poorly Mair 2. New/ Well Main

Lining	Type of Track/Pavement	Auxiliary Structure (rails only)
1. Single shell 2. Dual shell 3. In-situ concrete 4. Shotcrete 5. No lining	1. Wood/Concrete Sleepers/ Ballastless track 2. Asphalt/Concrete/Bituminous	1. Overhead Line 2. No overhead line

Natural Factors Affecting Physical Vulnerability		
Geological/Geotechnical Foundation Conditions	Hydrological conditions	
	Surface	Groundwater
1. Hard Rock	1. Submerged	1. Below tunnel invert level
2. Soft Rock/Hard Soil	2. Under flood lev	2. Above tunnel invert level
3. Soft Soil	3. Above flood level	

Traffic Factors Affecting Physical Vulnerability		
Traffic Category	Traffic Type	Traffic Volume
1. Highway	1. Passengers	1. annual daily average
2. Normal Road	2. Freight (cargo)	2. rush-hour
3. High-Speed Railway	3. Mixed Traffic	
4. Normal Railway		

Factors Affecting Operational Vulnerability		
Additional Systems (next to the infrastructure)	Systems Category	Hubs
1. Yes	1. Centralyzed Systems (affecting other i.f. of the network)	1. Connected
2. No	2. Operational/Energy Systems exclusive to the infrastructure	2. Not connected

Figure 8 - Factors governing physical vulnerability of **tunnels** (roads and railways) irrespective of the impact considered

3.5.3 Embankments

Figure 8 presents the factors supposed to govern the physical vulnerability (in terms of cost or time of repairing/reconstruction) of embankments included in road or rail networks. These factors allow the vulnerability assessment of an embankment subject to a specify hazard, causing a particular impact, as well as evaluation of the asset exposure. The examples of categories proposed for each factor may need to be adapted to reflect the level of detail adopted in the analysis.

The list of factors proposed for embankments includes the construction type, the major geometric features and the drainage systems as structural factors. The other factors considered match those taken into for tunnels, namely the geological/geotechnical and the hydrological characteristics of the site, at and below the surface, with respect to the natural factors, and the traffic category, type and volume, with respect to the traffic factors. The operational factors are the existence and type of centralized systems and also the eventual connection to hubs.

Structural Factors Affecting Physical Vulnerability

Construction Type	Lateral Slopes	Height	Drainage Systems
1. Simple Embakment 2. Side-Benched Embakment 3. Embankment with Light Ground Improv. 4. Embankment with Extensive Ground Improv.	1. Slope < s1 2. s1 < Slope < s2 3. Slope > s2	1. Height < h1 2. h1 < Height < h2 3. Height > h2	1. High Capacity 2. Medium Capacity 3. Low capacity

Structural condition	Type of Track/Pavement	Auxiliary Structure (rails only)
1. Old/ Poorly Maint. 2. New/ Well Maint.	1. Wood/Concrete Sleepers/ Ballastless track 2. Asphalt/Concrete/Bituminous	1. Overhead Line 2. No overhead line

Natural Factors Affecting Physical Vulnerability

Geological/Geotechnical Foundation Conditions	Hydrological conditions		Water sensitive Foundation Soil
	Surface	Water table	
1. Hard Rock 2. Soft Rock/Hard Soil 3. Soft Soil	1. Under flood leve 2. Above flood leve	1. Shallow 2. Deep	1. Yes 2. No

Traffic Factors Affecting Physical Vulnerability

Traffic Category	Traffic Type	Traffic Volume
1. Highway 2. Normal Road 3. High-Speed Railway 4. Normal Railway	1. Passengers 2. Freight (cargo) 3. Mixed Traffic	1. annual daily average 2. rush-hour

Factors Affecting Operational Vulnerability		
Additional Systems (next to the infrastructure)	**Systems Category**	**Hubs**
1. Yes	1. Centralyzed Systems (affecting other i.f. of the network)	1. Connected
2. No	2. Operational/Energy Systems exclusive to the infrastructure	2. Not connected

Figure 9 - Factors governing physical vulnerability of **embankments** (roads and railways) irrespective of the impact considered

3.5.4 Cuts

The factors considered to govern the assessment of the physical vulnerability of cuts found in road or rail networks, in terms of cost or time of repairing/reconstruction for any particular impact, are listed in Figure 9. The exposure of a cut can also be assessed based only on the same factors listed. Some examples of categories are proposed for each factor, the suitable detail required in the categorization being again case specific.

The structural factors describing the cut include the construction type, the major geometric features (lateral slopes and depth) and the drainage systems. The other factors considered match those also taken into account for tunnels and embankments, namely the traffic category, type and volume, with respect to the traffic factors, and the geological/geotechnical and the hydrological characteristics of the site, at and below the surface, with respect to the natural factors. An additional natural factor is included in this case, in order to characterize the natural slope. The operational factors are the existence and type of centralized systems and also the eventual connection to hubs.

Structural Factors Affecting Physical Vulnerability			
Construction Type	**Lateral Slopes**	**Depth**	**Drainage Systems**
1. Simple Cut 2. Side-Benched Cut 3. Cut with Light Ground Improvement (GI) 4. Cut with Extensive GI / Retaining Walls	1. Slope < s1 2. s1 < Slope < s2 3. Slope > s2	1. Depth < d1 2. d1 < Depth < d2 3. Depth > d2	1. High Capacity 2. Medium Capacity 3. Low capacity

Structural condition	Support structure	Type of Track/Pavement	Auxiliary Structure (rails only)
1. Old/ Poorly Maint. 2. New/ Well Maint.	1. Not required 2. Required, not efficient 3. Required, efficient	1. Wood/Concrete Sleepers/ Ballastless track 2. Asphalt/Concrete/Bituminous	1. Overhead Line 2. No overhead line

Natural Factors Affecting Physical Vulnerability

Geological/Geotechnical Foundation Conditions	Natural Slope	Hydrological conditions	
		Surface	Water table
1. Hard Rock 2. Soft Rock/Hard Soil 3. Soft Soil	1. Slope < ns1 2. ns1 < Slope < ns2 3. Slope > ns2	1. Under flood level 2. Above flood level	1. Below excavation base 2. Above excavation base

Traffic Factors Affecting Physical Vulnerability

Traffic Category	Traffic Type	Traffic Volume
1. Highway 2. Normal Road 3. High-Speed Railway 4. Normal Railway	1. Passengers 2. Freight (cargo) 3. Mixed Traffic	1. annual daily average 2. rush-hour

Factors Affecting Operational Vulnerability

Additional Systems (next to the infrastructure)	Systems Category	Hubs
1. Yes	1. Centralyzed Systems (affecting other i.f. of the network)	1. Connected
2. No	2. Operational/Energy Systems exclusive to the infrastructure	2. Not connected

Figure 10 - Factors governing physical vulnerability of **cuts** (roads and railways) irrespective of the impact considered

4. Pratical Examples of Methodology Application

It would be important for the future development of the project to include at this stage examples showing practical use of the methodology proposed. The main question at this stage may be whether the examples should be carried out including realistic impacts, derived in accordance with the methodology proposed within previous research Work Packages.

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Annex I – Review of Projects and Methodologies

Previous research in this field was carried out within various projects, using different methodologies. Even if the aims of these projects are considerably different, which strongly affects the suitability of the methodology used, it is important to review different cutting-edge alternatives recently considered for this type of analysis. The different alternatives proposed in previous research projects must be assessed in view of the particular objectives of each project, including but not limited to the wide range of threats considered and the diversity of infrastructure types taken into account. As examples a few research projects are presented.

I.1 CAPTA Methodology and CAPTool Implementation

The CAPTA (Costing Asset Protection: An All Hazards Guide for Transportation Agencies) methodology allows one to perform a high-level assessment of threats and hazards and the potential consequences based on generic attributes of the transportation asset. It was developed by the National Cooperative Highway Research Program (NCHRP). The overview is based on the CAPTool user's guide developed by John A. Volpe National Transportation Center (2013).

The methodology encompasses nine steps, seven of which are performed in CAPTool, a Microsoft Excel spreadsheet. The two initial steps are performed outside the CAPTool and consist in identifying and collecting data. The nine steps are:

1. Identify Assets
2. Collect Data
3. Identify Threat / Hazard Asset Classes
4. Establish Consequence Thresholds
5. Describe Infrastructure Assets
6. Identify Critical Assets Across Modes
7. Identify Countermeasure Opportunities
8. Generate Summary Report
9. Re-run CAPTool with Updated Assumptions, Budget Realities or New Assets

I.1.1 Step 1 – Identification of Assets

The CAPTool user's guide indicates that this step identifies the assets to be considered in the methodology, which should be aggregated into the following eight major asset categories: road bridges, road tunnels, transit/rail stations, transit/rail bridges, transit/rail tunnels, administrative and support facilities, ferries and fleet.

I.1.2 Step 2 – Collection of Data

This step gathers information for each of the infrastructures identified in Step 1. According to the respective asset category, the information required is defined in Table I as retrieved from the user's guide. This data completes the input infrastructure characterization data of the CAPTA methodology.

I.1.3 Step 3 – Identification of Threat / Hazard Asset Classes

In this step a double entry matrix (threat, asset category) defines which threats can have an impact on each of the eight asset categories listed above, in a yes/no based decision. The CAPTool user's guide indicates that this should be established through various inputs such as past experience, judgment and/or vulnerability assessment. It further indicates that the threats identified determine the type of countermeasures suggested later in the CAPTA methodology.

	Category							
Required Data	Road Bridges	Road Tunnels	Transit/Rail Stations	Transit/Rail Bridges	Transit/Rail Tunnels	Admin & Support Facilities	Ferries	Fleets
Identification of asset or asset class	•	•	•	•	•	•	•	•
Quantity	•	•	•	•	•	•	•	•
Annual average daily traffic	•	•						
Length (ft.)	•	•		•	•			
Travel lanes	•	•						
Detour length to nearest available crossing	•	•						
Type of construction	•			•				
Replacement cost	•	•	•	•	•	•	•	•
Maximum train capacity (occupancy)			•	•	•			
Knowledge that structure is below grade/above grade			•					
Knowledge that station is a transfer point			•					
Percentage of total ridership using the tunnel (or bridge)				•	•			
Square footage of facility						•		
Maximum occupancy of facility						•		
Maximum occupancy (persons)							•	
Maximum occupancy (vehicles)							•	•
Average cost per vehicle								•

Table I- Information required for assessing potential consequences on transportation assets according to CAPTA methodology.

I.1.4 Step 4 – Establishing Consequence Thresholds

In this step, the user should define the threshold beyond which the entity (asset owner, operator or system user) would consider investing in countermeasures to prevent losses or mitigate consequences. Three thresholds are defined in each case for: life loss, property loss and mission disruption. These are defined as follows:

"**Potentially Exposed Population (PEP):** This category is expressed in terms of potential casualties. It represents a range of casualties for each threshold level. The CAPTool uses the phrase "potentially exposed population" because the analysis assumes that this is the upper bound on harm to people associated with the maximum threat rather than an estimate of the actual casualties resulting from the hazard or threat.

Property Loss: This category is expressed in terms of asset replacement costs. The expression is in millions of dollars across the cost range.

Mission Importance: This category is expressed in terms of loss of function and/or transport delays and is relevant to specific assets or asset classes, including the relative importance of assets to the transportation network as indicated by their system role (e.g., Interstate Highway System, National Highway System designation) and the volume of use (e.g., Average Daily Traffic (ADT)) across a volume range. For road bridges, the CAPTA uses the product of ADT and detour distance as a surrogate for mission or function impact. The user can set the values of this factor based on local data. For purposes of illustration, this CAPTool example uses the 75, 85 and 95 percentile of this product based on bridges in the National Bridge Inventory.

Note that other major consequences may also occur, such as loss of specific government services, delays to emergency response, and impediments to military deployment. However, such consequences tend to be highly correlated with the primary consequences that capture loss of life; loss of property; and disruption of functions and related economic, government, military and emergency response activities.

It is highlighted that these thresholds, as defined, indicate the exposure to the hazards rather than infrastructure vulnerability: maximum loss of life possible rather than an estimation of the actual loss of life for a given hazard affecting a given asset class and replacement costs assuming total asset destruction instead of a partial repair cost corresponding to an intermediate damage degree.

I.1.5 Step 5 – Describing Infrastructure Assets

This step determines the asset capacity to exceed the threshold consequence levels determined in the previous step. This CAPTool determination is based on predefined equations such as the following examples: a multiple of maximum rail car capacity (for PEP), a linear cost per asset type (for replacement cost) and user input percentage of ridership that regularly uses the transit/rail transportation asset. For each asset category, the maximum exposure is determined (analogously to the preceding examples) and compared with the thresholds in the previous step.

I.1.6 Step 6 – Identify Critical Assets across Modes

This step is a summary of the three previous steps, as the capacity of an asset to exceed the threshold consequence levels define the assets criticality. In this summary step, all definitions from previous steps can be reviewed and an opportunity for manual override exists. Threats can be added to or removed from particular asset classes, assets can be manually overridden to critical and consequence thresholds can be reevaluated if deemed necessary.

I.1.7 Steps 7, 8 and 9 - Identification of Countermeasure Opportunities, Generation of Summary Report and Re-running the CAPTool

In Step 7 the CAPTool lists countermeasures rated by effectiveness which the user can choose, based on an embedded database and for each threat selected for each asset category. Step 8 compiles a budget summary, including the countermeasure options of step 7. Step 9 is a re-run of all previous steps for an iterative reevaluation of all assumptions and assessments by the user, as needed.

I.2 SecMan

The SecMan (Security Risks Management Processes for Road Infrastructures) project addresses security risks for road bridges and tunnels for the identification of critical infrastructures and adequate protection measures. Bridges and tunnels are categorized in order to achieve a systematic approach of practical applicability in a European context. The project was developed with funding of the CIPS program. The present overview is based on the final version of the manual available at http://www.secman-project.eu/.

I.2.1 Steps considered in SecMan methodology

The methodology encompasses 4 steps:

1. Step 1 identifies the part of the network to be investigated through a pre-selection criticality and attractiveness assessment;

2. Step 2 is defined as an object-specific vulnerability assessment for bridges and tunnels for certain threats;

3. Step 3 is the combination of the outputs of steps 1 and 2 in a criticality-attractiveness-vulnerability matrix and

4. Step 4 provides the user decision support for the selection of protection and mitigation measures.

The project manual states it is based on expert judgment and default values have been set through internal and external expert workshops. This overview focuses on SecMan's Step 2.

I.2.2 The definition of Vulnerability

SecMan considers risk, in a safety context, as the product of the probability of an event times the consequences of that same event. When establishing the transition to security, SecMan considers vulnerability as the product of the feasibility of an attack (transitioned from safety's probability of an event) times the damage potential (transitioned from safety's consequences).

To determine the vulnerability, as defined above, step 2 identifies man-made threats relevant to road tunnels and road bridges. The feasibility of each attack is then assessed with a binary variable, distinguishing things such as the easiness and difficulty of attack implementation. The damage potential is a measure of the damage caused to the infrastructure and the reconstruction time required. The assessment of the damage potential is based on the categorization of the bridges and tunnels.

I.2.3 Categorization of the infrastructure

The bridges and tunnels are aggregated in a number of representative object types with relevance for the damage potential. Although each infrastructure has unique differentiating parameters, such an approach is required for a systematic and comprehensive approach.

Tunnels are categorized based on five criteria (in addition to ventilation systems and local operation systems):

- Predominant Geotechnical conditions
- Construction Method (conventional/NATM, TBM)
- Hydro-Geological Conditions
- Single Shell vs. Dual Shell
- Single Cell vs. Multiple Cells

Bridges are categorized based on four criteria:

- System
- Span or Height
- Construction Material
- Superstructure Cross-Section

Based on the above criteria, 20 types of tunnels and 19 types of bridges are identified and the damage potential is evaluated for each type and for each threat. The categorization criteria represent the infrastructure characteristics that influence the damage caused to the infrastructure and/or the reconstruction time required. These are evaluated for each of the relevant threats affecting each infrastructure. For each of the relevant threats, descriptive and detailed scenarios are formulated.

I.3 SeRoN

The SeRoN (Security of Road Transport Network) project aims at investigating the impacts of man-made attacks to bridges and tunnels, namely regional and supra-regional impacts on transport links and their economic impacts. This overview is based on the deliverables available at http://www.seron-project.eu/.

The project is structured in the following 4 steps:

1. Step 1 - Road corridor selection and identification of potentially critical infrastructure objects
2. Step 2 - Calculation of network importance
3. Step 3 - Risk assessment without measures
4. Step 4 - Measure analysis

I.3.1 Step 1 - Road corridor selection and identification of potentially critical infrastructure objects

Step 1 is described as a first "filter" in identifying the potentially critical infrastructure objects (bridges and tunnels) for the road corridor. The selection of the corridor depends on the entity using the SeRoN methodology (infrastructure owners, operators or political and private stakeholders). The TEN-T network corridors are suggested as a starting point. Threshold values for criteria such as the Average Daily Traffic or Heavy Goods Vehicle volume are used for identifying criticality.

I.3.2 Step 2 - Calculation of network importance

Step 2 aims at further identifying the top critical objects, by ranking them according to their network importance. The network importance is measured by the consequences of the unavailability of the bridges and tunnels considered, comparing a scenario of standard operating conditions and complete cut-off disruption. In the subsequent steps 3 and 4 complex and detailed analyses are performed. Step 2 aims at further limiting the infrastructure objects to be studied in the detailed stages.

I.3.3 Step 3 - Risk assessment without measures

Risk assessment is carried out for the bridges and tunnels selected in step 2. Detailed scenarios are defined for the relevant bridge and tunnel man-made threats. Then, both a probability analysis, estimating the probability of the attack, and a consequence analysis, estimating the direct and indirect consequences, is performed. Direct consequences include fatalities and structural damages which are estimated with simulation software, including the use of detailed Finite Element Method based approaches.

Annex II – Definitions of the factors proposed

II.1 BRIDGES

II.1.1 STRUCTURAL FACTORS

Bridge structural factors group the characteristics of the infrastructure governing its physical vulnerability, including its geometry and structural characteristics, from the construction type to its foundations, as well as the type of pavement, for roads, and the type of track and auxiliary structure for trains.

CONSTRUCTION TYPE

System

This factor describes the type of construction system used, ranging from simple beam bridges to more complex cable-stayed and suspended bridges.

Cross-section

This factor refers to the cross-section of the bridge, which can be of the following types: solid section, hollow section (usually more efficient than solid sections because they are lighter) and truss (which consist of linear members only, connected by nodes where the loads are applied, organized so that the assemblage as a whole, comprising different configurations that are often triangular, behaves as a single object).

Material

This factor considers the material used in the bridge, allowing for the most common materials used in modern bridge construction to be used (stone or wood is not commonly used in modern days as a material for bridges in modern land transportation systems).

SPAN

The bridge span is taken as the length of its main span, i.e. the length of suspended roadway/railway between two intermediate supports for the bridge

HEIGHT

The bridge height refers to the height over land or water, measured as the distance from the bridge deck to the lowest point in the land or water below, the limits being defined so that the effects of floods or possible ship ramming, amongst others, can be incorporated.

LENGTH

The length describes the total bridge length, taken as the total construction involved in building the bridge and measured from the last section of embankment, cut or tunnel before the bridge, to the first section of embankment, cut or tunnel after the bridge

STRUCTURAL CONDITION

This factor designates the current condition of all the bridge components, including its foundations, which reflects the bridge's age as well as the level and quality of maintenance during its lifetime.

LOCATION OF BRIDGE PILLARS

Bridge pillars can be located on water or on shore, which significantly affects the bridge vulnerability to some hazards.

FOUNDATION SYSTEM

This factor is related to the type of foundation, which may include deep (piles, piers, drilled shafts and caissons, or similar) or shallow/direct (footings, slabs, etc) foundations, as well as foundation systems combining these two main types (piled slabs, e.g.).

TYPE OF TRACK/PAVEMENT

Pavements can be made of asphalt, bituminous or concrete mixtures, while rail tracks may be formed by wood or concrete sleepers or may even be of the ballastless type, which may consist of a continuous slab of concrete supporting directly the rails and, despite being initially more expensive, can greatly reduce maintenance requirement (mostly used in new very high speed routes and in tunnels)

AUXILIARY STRUCTURE

This factor describes the possible existence of overhead lines or overhead wire, which are used to transmit electrical energy to rail vehicles in railways and that, where existing, are a critical and sensitive component of the system.

II1.2 NATURAL FACTORS

Bridge natural factors include the characteristics of the natural environment where the infrastructure is located that can influence the infrastructures behaviour in relation to the impacts, namely the geological/geotechnical foundation conditions and the crossing characteristics.

Geological/geotechnical foundation conditions

This factor describes the geological and geotechnical conditions found under and around the bridge's foundations, ranging from hard/solid rock to soft/compressible soil.

Crossing characteristics

The crossing characteristics of a bridge refers, in this context, to the characteristics of the ground (plain ground or mountain valley) or water (river, lake/small river or sea/ocean) under the bridge.

II1.3 TRAFICC FACTORS

Traffic factors are used to describe the main characteristics of traffic operating on the bridge, in order to incorporate in the analysis the importance of the traffic category, type and volume, and also to describe the main characteristics of the traffic category operating under the bridge. In addition, these factors are used to identify sections that are part of a hub, in order to take into account the additional negative effects of different hazards on these locations.

Traffic category

The traffic category distinguishes between highway and normal road, for roads, and between high-speed railway and normal railway, for railways.

Traffic category under the bridge

The traffic category under the bridge considers the sort of traffic operating under the bridge, which can vary from ship (sea or river) to road or rail, as it can affect the bridge above in considerably different ways.

Traffic type

This factor describes the type of traffic operating on the road/rail, ranging from passengers to freight traffic and including mixed traffic.

Traffic volume

The traffic volume, which can be expressed in terms of annual daily average or rush hour, measures the total volume of vehicle traffic of a road or railway for a certain period of time, which is a useful and simple measurement of how busy the road or railway is.

Hubs

This factor identifies the possible existence of hubs, in which case the effects of a certain hazard will be amplified by a specified factor.

II1.4 LOCAL FACTORS affecting operational vulnerability

These factors solely identify the possible existence of centralized systems that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure.

Additional Systems (next to the infrastructure)

It identifies if there are centralized systems that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure

Systems Category

This factor describes the category of the system, namely if they are centralized systems and/or operational/energy systems, that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure.

II.2 Tunnels

II2.1 STRUCTURAL FACTORS

Tunnel structural factors group the characteristics of the infrastructure governing its physical vulnerability, including its geometry and structural characteristics, from the construction type to its cover depth, as well as the characteristics of the drainage, ventilation and emergency/detection systems and also the type of pavement, for roads, and the type of track and auxiliary structure for trains.

CONSTRUCTION TYPE

System

This factor describes the type of construction system used, including the New Austrian Tunnelling Method (NATM), the use of tunnel boring machines (TBM) and considering also the cut&cover method, which can be used depending on various circumstances.

Cross-section

This factor refers to the cross-section of the tunnel, which can be of the following types: single tube or double tube, depending on the existence of a single larger tunnel or the existence of two smaller tunnels

LENGTH

The tunnel length is taken as the total length of the tunnel, i.e. the distance between the ends of the tunnel.

CROSS-SECTION AREA

The cross-section area of a tunnel refers to the total open cross-sectional area of the tunnel.

COVER DEPTH

The cover depth establishes the vertical distance from the ground surface above the tunnel to the top of the tunnel, distinguishing between shallow and deep tunnels

DRAINAGE SYSTEMS

This factor describes the efficiency of the tunnel's drainage systems, ranging from high capacity to low capacity systems

VENTILATION SYSTEMS

This factor identifies the existence (or not) of ventilation systems in the tunnel

FIRE PROTECTION SYSTEMS

This factor identifies the existence (or not) of fire protection systems in the tunnel

EMERGENCY/DETECTION SYSTEMS

This factor identifies the existence (or not) of emergency/detection systems in the tunnel

STRUCTURAL CONDITION

This factor designates the current condition of all the tunnel components, which reflects the tunnel's age as well as the level and quality of maintenance during its lifetime.

LINING

The tunnel lining describes the wall of the tunnel, which, when existing, may have different configurations, ranging from simple single shell to dual shell linings (including a sprayed waterproof layer), or using in-situ concrete or shotcrete.

TYPE OF TRACK/PAVEMENT

Pavements can be made of asphalt, bituminous or concrete mixtures, while rail tracks may be formed by wood or concrete sleepers or may even be of the ballastless type, which may consist of a continuous slab of concrete supporting directly the rails and, despite being initially more expensive, can greatly reduce maintenance requirement (mostly used in new very high speed routes and in tunnels)

AUXILIARY STRUCTURE

This factor describes the possible existence of overhead lines or overhead wire, which are used to transmit electrical energy to rail vehicles in railways and that, where existing, are a critical and sensitive component of the system.

SURFACE COMPONENTS

This factor, existing for tunnels only, establishes the possible existence of the so-called surface components of tunnel, like ventilation shafts, emergency exits, etc…

II2.2 NATURAL FACTORS

Tunnel natural factors include the characteristics of the natural environment where the infrastructure is built on that can influence the infrastructures behaviour in relation to the impacts, namely the geological/geotechnical foundation conditions and the hydrological conditions, both at the surface and under the surface (groundwater).

GEOLOGICAL/GEOTECHNICAL FOUNDATION CONDITIONS

This factor describes the geological and geotechnical conditions around the tunnel, ranging from hard/solid rock to soft/compressible soil.

HYDROLOGICAL CONDITIONS

Surface

The surface hydrological conditions describe the position of the tunnel with respect to the water level in the region: it can be submerged and, where above water level, it can be above or below the flood level.

Groundwater

The groundwater hydrological conditions describe the position of the ground water table with respect to the tunnel invert.

II2.3 TRAFFIC FACTORS

Traffic factors are used to describe the main characteristics of traffic operating in the tunnel, in order to incorporate in the analysis the importance of the traffic category, type and volume. In addition, these factors are used to identify sections that are part of a hub, in order to take into account the additional negative effects of different hazards on these locations.

TRAFFIC CATEGORY

The traffic category distinguishes between highway and normal road, for roads, and between high-speed railway and normal railway, for railways.

TRAFFIC TYPE

This factor describes the type of traffic operating on the road/rail, ranging from passengers to freight traffic and including mixed traffic.

TRAFFIC VOLUME

The traffic volume, which can be expressed in terms of annual daily average or rush hour, measures the total volume of vehicle traffic of a road or railway for a certain period of time, which is a useful and simple measurement of how busy the road or railway is.

HUBS

This factor identifies the possible existence of hubs, in which case the effects of a certain hazard will be amplified by a specified factor.

II2.4 LOCAL FACTORS affecting operational vulnerability

These factors solely identify the possible existence of centralized systems that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure.

ADDITIONAL SYSTEMS (NEXT TO THE INFRASTRUTURE)

It identifies if there are centralized systems that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure

SYSTEMS CATEGORY

This factor describes the category of the system, namely if they are centralized systems and/or operational/energy systems, that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure.

II.3 Embankments

II3.1 STRUCTURAL FACTORS

Embankment structural factors group the characteristics of the infrastructure governing its physical vulnerability, including its geometry and structural characteristics, from the construction type to drainage systems, as well as the type of pavement, for roads, and the type of track and auxiliary structure for trains.

CONSTRUCTION TYPE

This factor describes the type of construction system used, including the possible existence of side-benches (lateral berms) or light or extensive ground improvement under and around the embankment.

LATERAL SLOPES

This factor refers to the angle of the lateral slopes of the embankment.

HEIGHT

The height defines the total height of the embankment.

DRAINAGE SYSTEMS

This factor describes the efficiency of the embankment's drainage systems, ranging from high capacity to low capacity systems, including medium capacity.

STRUCTURAL CONDITION

This factor designates the current condition of the embankment, which reflects its age as well as the level and quality of maintenance during its lifetime.

TYPE OF TRACK/PAVEMENT

Pavements can be made of asphalt, bituminous or concrete mixtures, while rail tracks may be formed by wood or concrete sleepers or may even be of the ballastless type, which may consist of a continuous slab of concrete supporting directly the rails and, despite being initially more expensive, can greatly reduce maintenance requirement (mostly used in new very high speed routes and in tunnels)

AUXILIARY STRUCTURE

This factor describes the possible existence of overhead lines or overhead wire, which are used to transmit electrical energy to rail vehicles in railways and that, where existing, are a critical and sensitive component of the system.

II3.2 NATURAL FACTORS

Embankment's natural factors include the characteristics of the natural environment where the infrastructure is built on that can influence its behaviour in relation to the impacts, namely the geological/geotechnical foundation conditions and the hydrological conditions, both at the surface and under the surface (groundwater).

GEOLOGICAL/GEOTECHNICAL FOUNDATIONS CONDITIONS

This factor describes the geological and geotechnical conditions under the embankment, ranging from hard/solid rock to soft/compressible soil.

HYDROLOGICAL CONDITIONS

Surface

The surface hydrological conditions describe the position of the embankment with respect to the water level in the region: it can be above or below the flood level.

Water table

This factor describes the position of the ground water table with respect to the ground surface and the embankment's base, distinguishing between shallow and deep water table.

Water sensitive foundation soil

This factor identifies cases where the foundation soil is water sensitive.

II3.3 TRAFFIC FACTORS

Traffic factors are used to describe the main characteristics of traffic operating in the embankment, in order to incorporate in the analysis the importance of the traffic category, type and volume. In addition, these factors are used to identify sections that are part of a hub, in order to take into account the additional negative effects of different hazards on these locations.

TRAFFIC CATEGORY

The traffic category distinguishes between highway and normal road, for roads, and between high-speed railway and normal railway, for railways.

TRAFFIC TYPE

This factor describes the type of traffic operating on the road/rail, ranging from passengers to freight traffic and including mixed traffic.

TRAFFIC VOLUME

The traffic volume, which can be expressed in terms of annual daily average or rush hour, measures the total volume of vehicle traffic of a road or railway for a certain period of time, which is a useful and simple measurement of how busy the road or railway is.

HUBS

This factor identifies the possible existence of hubs, in which case the effects of a certain hazard will be amplified by a specified factor.

II3.4 LOCAL FACTORS affecting operational vulnerability

These factors solely identify the possible existence of centralized systems that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure.

ADDITIONAL SYSTEMS (NEXT TO THE INFRASTRUTURE)

It identifies if there are centralized systems that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure

SYSTEMS CATEGORY

This factor describes the category of the system, namely if they are centralized systems and/or operational/energy systems, that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure.

II.4 CUTS

II4.1 STRUCTURAL FACTORS

Cut’s structural factors group the characteristics of the infrastructure governing its physical vulnerability, including its geometry and structural characteristics, from the construction type to drainage systems, as well as the type of pavement, for roads, and the type of track and auxiliary structure for trains.

CONSTRUCTION TYPE

This factor describes the type of construction system used, including the possible existence of side-benches (lateral berms) or light or extensive ground improvement under and around the cut, eventually even considering the existence of retaining walls.

LATERAL SLOPES

This factor refers to the angle of the lateral slopes of the excavation.

DEPTH

The depth of the cut defines the vertical distance between the road/rail pavement and the top of the excavation.

DRAINAGE SYSTEMS

This factor describes the efficiency of the cut's drainage systems, ranging from high capacity to low capacity systems, including medium capacity.

STRUCTURAL CONDITION

This factor designates the current condition of the cut, which reflects its age as well as the level and quality of maintenance during its lifetime.

SUPPORT STRUCTURE

This factor identifies the possible existence of a support structure, which, when existing, can be ranked as efficient or not efficient.

TYPE OF TRACK/PAVEMENT

Pavements can be made of asphalt, bituminous or concrete mixtures, while rail tracks may be formed by wood or concrete sleepers or may even be of the ballastless type, which may consist of a continuous slab of concrete supporting directly the rails and, despite being initially more expensive, can greatly reduce maintenance requirement (mostly used in new very high speed routes and in tunnels)

AUXILIARY STRUCTURE

This factor describes the possible existence of overhead lines or overhead wire, which are used to transmit electrical energy to rail vehicles in railways and that, where existing, are a critical and sensitive component of the system.

II4.2 NATURAL FACTORS

Cuts natural factors include the characteristics of the natural environment where the infrastructure is excavated on that can influence its behaviour in relation to the impacts, namely the geological/geotechnical foundation conditions, the slope of the natural ground and the hydrological conditions, both at the surface and under the surface (water table).

GEOLOGICAL/GEOTECHNICAL FOUNDATION CONDITIONS

This factor describes the geological and geotechnical conditions around the cut, ranging from hard/solid rock to soft/compressible soil.

NATURAL SLOPE

This factor describes the slope of the natural ground above the cut (usually different from the lateral slope of the cut).

HYDROLOGICAL CONDITIONS

Surface

The surface hydrological conditions describe the position of the cut with respect to the water level in the region: it can be above or below the flood level.

Water table

This factor describes the position of the ground water table with respect to the excavation's base: it can be below or above the excavation base.

II4.3 TRAFFIC FACTORS

Traffic factors are used to describe the main characteristics of traffic operating in the cut, in order to incorporate in the analysis the importance of the traffic category, type and volume. In addition, these factors are used to identify sections that are part of a hub, in order to take into account the additional negative effects of different hazards on these locations.

TRAFFIC CATEGORY

The traffic category distinguishes between highway and normal road, for roads, and between high-speed railway and normal railway, for railways.

TRAFFIC TYPE

This factor describes the type of traffic operating on the road/rail, ranging from passengers to freight traffic and including mixed traffic.

TRAFFIC VOLUME

The traffic volume, which can be expressed in terms of annual daily average or rush hour, measures the total volume of vehicle traffic of a road or railway for a certain period of time, which is a useful and simple measurement of how busy the road or railway is.

HUBS

This factor identifies the possible existence of hubs, in which case the effects of a certain hazard will be amplified by a specified factor.

II4.4 LOCAL FACTORS affecting operational vulnerability

These factors solely identify the possible existence of centralized systems that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure.

ADDITIONAL SYSTEMS (NEXT TO THE INFRASTRUTURE)

It identifies if there are centralized systems that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure

SYSTEMS CATEGORY

This factor describes the category of the system, namely if they are centralized systems and/or operational/energy systems, that, if damaged locally, would affect other infrastructures of the network and/or operational/energy systems exclusive to the infrastructure.

II.5 REMOTE CENTRALIZED CONTROL/ENERGY/LOGISTIC SYSTEMS

This infrastructure type (which can have multiple materializations) distinguishes from the local factors affecting operational vulnerability considered before as part of the other infrastructure types due to the fact that this infrastructure type is physically separated from any section under consideration in the previous infrastructure types. Therefore, the type of hazards affecting this infrastructure and the magnitude of its effects may strongly differ from those that would result from the analysis of any section of the physical components of the infrastructure. For example, if in future an Austrian railway is centrally controlled from Lisbon, an earthquake in Lisbon could seriously affect the operation of the railway network, even if the infrastructure itself is built in a non-seismic area and therefore is not locally susceptible to earthquake effects.

II5.1 STRUCTURAL FACTORS

Structural factors in this case group the characteristics of the infrastructure governing its physical vulnerability, including its geometry and structural characteristics, from the construction type to its foundations.

CONSTRUCTION TYPE

System

This factor describes the type of construction system used, ranging from recent design/solid to outdated design/vulnerable construction.

Material

This factor considers the material used, allowing for the most common materials used in modern building construction (wood, masonry and concrete).

STRUCTURAL CONDITION

This factor designates the current condition of the infrastructure, including its foundations, which reflects its age as well as the level and quality of maintenance during its lifetime.

FOUNDATION SYSTEM

This factor is related to the type of foundation, which may include deep (piles, piers, drilled shafts and caissons, or similar) or shallow/direct (footings, slabs, etc) foundations, as well as foundation systems combining these two main types (piled slabs, e.g.).

REMOTE ACCESS

This factor describes the possible existence of remote access to the infrastructure which, where, if existing, is a critical and sensitive component of the system.

II5.2 NATURAL FACTORS

Natural factors include the characteristics of the natural environment where the infrastructure is located that can influence the infrastructures behaviour in relation to the impacts, namely the geological/geotechnical foundation conditions and the crossing characteristics.

GEOLOGICAL/GEOTECHNICAL FOUNDATION CONDITIONS

This factor describes the geological and geotechnical conditions found under and around the infrastructure's foundations, ranging from hard/solid rock to soft/compressible soil.

GROUND SURFACE PROFILE

This factor describes the characteristics of the surrounding environment, identifying the possible existence of flat, intermediate or mountainous regions.

II5.3 TRAFFIC FACTORS

Traffic factors are used to describe the main characteristics of traffic operating in the network, in order to incorporate in the analysis the importance of the traffic category and average volume on the transportation network.

TRAFFIC CATEGORY

The traffic category distinguishes between highway and normal road, for roads, and between high-speed railway and normal railway, for railways.

TRAFFIC VOLUME

The traffic volume, here expressed in terms of an average for the all network of the annual daily average or rush hour, measures the total volume of vehicle traffic of a road or railway for a certain period of time and the all network, which is a useful and simple measurement of how busy the network is.

Annex III – Relevant factors by Hazard

III.1 Extreme Earthquake

Bridges- almost all structural factors (construction type, geometry and structural condition), e.g. system, cross section, material, height, length, etc

Tunnels- cross section, cover depth and structural condition, as well as geological/geotechnical conditions

Embankments- construction type, lateral slope, height and structural condition

Cuts- construction type, lateral slope, depth and structural condition, hydrological condition

III.1.1 Liquefaction

Bridges- foundation system, geological/geotechnical conditions and crossing characteristics

Tunnels- system, cover depth, geological/geotechnical conditions and hydrological (groundwater) conditions

Embankments- geological/geotechnical conditions and hydrological (water table) conditions

Cuts- geological/geotechnical conditions and hydrological (water table) conditions

III.1.2 Landslide (slide/fall)

Bridges- height, length and geological/geotechnical conditions, auxiliary structure (rails only)

Tunnels- cover depth, length and geological/geotechnical conditions

Embankments- height and geological/geotechnical conditions, auxiliary structure (rails only)

Cuts- geological/geotechnical conditions and hydrological (water table) conditions, auxiliary structure (rails only)

III.1.3 Intense water front

Bridges- height, construction type, namely system and cross section, location of bridge piers, structural condition and crossing characteristics

Tunnels- hydrological conditions (surface), drainage system? Length? structural condition? More?

Embankments- height, structural condition hydrological conditions (surface), drainage systems? More?

Cuts- hydrological conditions (surface), structural condition drainage systems? More?

III.1.4 Ground deformations/displacements

Bridges- foundation system, structural condition, type of track/pavement, geological/geotechnical conditions

Tunnels- system, cover depth, cross-section area, structural condition, type of track/pavement, geological/geotechnical conditions and hydrological (groundwater) conditions

Embankments- construction type, lateral slopes, height, drainage systems, structural condition, geological/geotechnical conditions, hydrological (water table) conditions, traffic category, traffic type and traffic volume

Cuts- construction type, lateral slopes, depth, drainage systems, structural condition, support structure (retaining walls? See construction type), type of track/pavement, geological/geotechnical conditions, natural slope and hydrological (water table) conditions

III.2 Extreme Rainfall

Embankments- structural condition, hydrological conditions (surface), drainage systems? More?

Cuts- hydrological conditions (surface), structural condition, drainage systems? More?

III.2.1 Flood

Bridges- height, crossing characteristics, length, location of bridge pillars, structural condition

Tunnels- hydrological conditions (surface), drainage systems? Length? structural condition? More?

Embankments- height, structural condition, hydrological conditions (surface), drainage systems? More?

Cuts- hydrological conditions (surface), structural condition, drainage systems? More?

III.2.2 Landslide (slide)

Bridges- height, length and geological/geotechnical conditions, auxiliary structure (rails only)

Tunnels- cover depth, length and geological/geotechnical conditions

Embankments- height and geological/geotechnical conditions, auxiliary structure (rails only)

Cuts- geological/geotechnical conditions and hydrological (water table) conditions, auxiliary structure (rails only)

III.2.3 Landslide (flow)

Bridges- height, length and geological/geotechnical conditions, auxiliary structure (rails only)

Tunnels- cover depth, length and geological/geotechnical conditions

Embankments- height and geological/geotechnical conditions, auxiliary structure (rails only)

Cuts- geological/geotechnical conditions and hydrological (water table) conditions, auxiliary structure (rails only)

III.3 Extreme Snowfall

Embankments- Lateral slopes? More?

Cuts- Lateral slope, Natural slope, More? Additional factors required?

III.3.1 Avalanche

Bridges- height, construction type, namely system and cross section, length, location of bridge piers, structural condition, auxiliary structure (rails only) and crossing characteristics

Tunnels- Emergency/detection? More?

Embankments- height, auxiliary structure (rails only) More? Additional factors required?

Cuts- Natural slope, auxiliary structure (rails only). More? Additional factors required?

III.3.2 Snowdrift

Bridges- height?

Tunnels- Emergency/detection? More?

Embankments- height More? Additional factors required?

Cuts- Natural slope. More? Additional factors required?

III.3.3 Toggled trees

Bridges- height, structural condition?, auxiliary structure (rails only) and crossing characteristics (should forest be a possibility?)

Tunnels- Emergency/detection? More?

Embankments- height, lateral slopes, auxiliary structure (rails only) More? Additional factors required? Forest?

Cuts- construction type, lateral slope, depth, natural slope, auxiliary structure (rails only). More? Additional factors required?

III.4 Extreme Hot Weather

Bridges- system, material, structural condition, type of track/pavement and auxiliary structure (rails only). Others?

Embankments- type of track/pavement and auxiliary structure (rails only). Others?

Cuts- type of track/pavement and auxiliary structure (rails only). Others?

III.4.1 Bush Fire

Bridges- system, material, structural condition, height, location of bridge pillars (include forest?), type of track/pavement and auxiliary structure (rails only). Others?

Embankments- type of track/pavement and auxiliary structure (rails only). Others?

Cuts- type of track/pavement and auxiliary structure (rails only). Others?

III.5 Extreme Wind and Storm

Bridges- system, cross section, span, length, height, structural condition and auxiliary structure (rails only). Others?

Embankments- auxiliary structure (rails only). Others?

Cuts- auxiliary structure (rails only). Others?

III.5.1 Storm Surge

Bridges- height, construction type, namely system and cross section, location of bridge piers, structural condition and crossing characteristics

Tunnels- hydrological conditions (surface), drainage systems? Length? Structural condition? More?

Embankments- height, structural condition hydrological conditions (surface), drainage systems? More?

Cuts- hydrological conditions (surface), structural condition, drainage systems? More?

III.5.2 Sand storm

Bridges- traffic category, type and volume? Other?

Embankments- traffic category, type and volume? More? Additional factors required?

Cuts- traffic category, type and volume? More? Additional factors required?

III.5.3 Toggled trees

Bridges- height, structural condition?, auxiliary structure (rails only) and crossing characteristics (should forest be a possibility?)

Tunnels- Emergency/detection? More?

Embankments- height, lateral slopes, auxiliary structure (rails only) More? Additional factors required? Forest?

Cuts- construction type, lateral slope, depth, natural slope, auxiliary structure (rails only). More? Additional factors required?

III.6 Thunderstorm

III.6.1 Lightning

Bridges- auxiliary structure (rails only). Others?

Embankments- auxiliary structure (rails only). Others?

Cuts- auxiliary structure (rails only). Others?

III.7 Volcanic eruption

III.7.1 Lava flow

Bridges- height, construction type, namely system, cross section and material, location of bridge piers, structural condition and crossing characteristics

Tunnels- hydrological conditions (surface), Length? Structural condition? More?

Embankments- construction type, height, hydrological conditions (surface) More?

Cuts- lateral slopes, natural slope, hydrological conditions (surface) More?

III.7.2 Ash cloud

Bridges- traffic category, type and volume? Other?

Embankments- traffic category, type and volume? More? Additional factors required?

Cuts- traffic category, type and volume? More? Additional factors required?

III.7.3 Landslide (slide/fall)

Bridges- height, length and geological/geotechnical conditions, auxiliary structure (rails only)

Tunnels- cover depth, length and geological/geotechnical conditions

Embankments- height and geological/geotechnical conditions, auxiliary structure (rails only)

Cuts- geological/geotechnical conditions and hydrological (water table) conditions, auxiliary structure (rails only)

III.7.4 Landslide (flow)

Bridges- height, length and geological/geotechnical conditions, auxiliary structure (rails only)

Tunnels- cover depth, length and geological/geotechnical conditions

Embankments- height and geological/geotechnical conditions, auxiliary structure (rails only)

Cuts- geological/geotechnical conditions and hydrological (water table) conditions, auxiliary structure (rails only)

III.8 Extreme Cold

Bridges- system, material, structural condition, type of track/pavement and auxiliary structure (rails only). Others?

Embankments- type of track/pavement and auxiliary structure (rails only). Others?

Cuts- type of track/pavement and auxiliary structure (rails only). Others?

III.8.1 Ice storm

Bridges- system, material, structural condition, type of track/pavement and auxiliary structure (rails only). Others?

Embankments- type of track/pavement and auxiliary structure (rails only). Others?

Cuts- type of track/pavement and auxiliary structure (rails only). Others?

III.9 Hail

Bridges- auxiliary structure (rails only). Others?

Embankments- auxiliary structure (rails only). Others?

Cuts- auxiliary structure (rails only). Others?

III.10 Various continuous processes

III.10.1 Landslide (slide/fall)

Bridges- height, length and geological/geotechnical conditions, auxiliary structure (rails only)

Tunnels- cover depth, length and geological/geotechnical conditions

Embankments- height and geological/geotechnical conditions, auxiliary structure (rails only)

Cuts- geological/geotechnical conditions and hydrological (water table) conditions, auxiliary structure (rails only)

III.10.2 Ground subsidence

Bridges- foundation system, structural condition, type of track/pavement, geological/geotechnical conditions

Tunnels- system, cover depth, cross-section area, structural condition, type of track/pavement, geological/geotechnical conditions and hydrological (groundwater) conditions

Embankments- construction type, lateral slopes, height, drainage systems, structural condition, geological/geotechnical conditions, hydrological (water table) conditions, traffic category, traffic type and traffic volume

Cuts- construction type, lateral slopes, depth, drainage systems, structural condition, support structure (retaining walls? See construction type), type of track/pavement, geological/geotechnical conditions, natural slope and hydrological (water table) conditions

III.11 Animals crossing

Embankments- traffic category, type and volume? More? Additional factors required?

Cuts- traffic category, type and volume? More? Additional factors required?

III.12 Explosion

Bridges- almost all structural factors (construction type, geometry and structural condition), e.g. system, cross section, material, height, length, etc, and auxiliary structure (rails only)

Tunnels- cross section, length, cross-section area, cover depth and structural condition, auxiliary structure (rails only), as well as geological/geotechnical conditions and emergency/detection systems

Embankments- any? auxiliary structure (rails only)?

Cuts- construction type, lateral slope, depth, auxiliary structure (rails only) and structural condition

III.13 Fire

Bridges- almost all structural factors (construction type, geometry and structural condition), e.g. system, cross section, material, height, length, type of track/pavement, auxiliary structure etc

Tunnels- length, cross-section area, structural condition, auxiliary structure (rails only), type of track/pavement, as well as ventilation systems, fire protection and emergency/detection systems

Embankments- auxiliary structure (rails only) and type of track/pavement. more?

Cuts- structural condition, support structure, type of track/pavement, and auxiliary structure (rails only)?

III.14 Blockade

Bridges- traffic category, type and volume? More? Additional factors required?

Tunnels- traffic category, type and volume? More? Additional factors required?

Embankments- traffic category, type and volume? More? Additional factors required?

Cuts- traffic category, type and volume? More? Additional factors required?

III.15 Excessive vehicle height

Bridges- height, auxiliary structure, traffic category under the bridge, traffic category, type and volume? More? Additional factors required?

Tunnels- cross-section area, auxiliary structure, traffic category, type and volume? More? Additional factors required?

Embankments- auxiliary structure, traffic category, type and volume? More? Additional factors required?

Cuts- auxiliary structure, traffic category, type and volume? More? Additional factors required?

III.16 Excessive vehicle weight

Bridges- system, material, span, structural condition, type of track/pavement, traffic category, type and volume? More? Additional factors required?

Tunnels- type of track/pavement, traffic category, type and volume? More? Additional factors required?

Embankments- structural condition, type of track/pavement, traffic category, type and volume? More? Additional factors required?

Cuts- type of track/pavement, traffic category, type and volume? More? Additional factors required?

III.17 Hazardous Release

Bridges- material, type of track/pavement, crossing characteristics, traffic category, type and volume? More? Additional factors required?

Tunnels- length, drainage systems, ventilation systems, emergency detection, lining(?),type of track/pavement, hydrological conditions (surface and groundwater), type of track/pavement, More? Additional factors required?

Embankments- drainage systems, hydrological conditions (surface and water table) type of track/pavement, type of track/pavement More?

Cuts- drainage systems, hydrological conditions (surface and water table) type of track/pavement, type of track/pavement More?

III.18 Ramming

Bridges- almost all structural factors (construction type, geometry and structural condition), location of bridge pillars, auxiliary structure (rails only), crossing characteristics, traffic category under the bridge, traffic category, type and volume?

Tunnels- cross-section area, ventilation systems, emergency/detection, lining, auxiliary structure (rails only), traffic category, type and volume?

Embankments- auxiliary structure (rails only), traffic category, type and volume?

Cuts- auxiliary structure (rails only), traffic category, type and volume?

III.19 Sabotage

Bridges- length, type of track/pavement, auxiliary structure (rails only), traffic category, type and volume?

Tunnels- length, ventilation systems, emergency/detection, type of track/pavement, auxiliary structure (rails only), traffic category, type and volume?

Embankments- type of track/pavement, auxiliary structure (rails only), traffic category, type and volume?

Cuts- type of track/pavement, auxiliary structure (rails only), traffic category, type and volume?

III.20 Theft

Bridges- length, type of track/pavement, auxiliary structure (rails only), traffic category, type and volume?

Tunnels- length, ventilation systems, emergency/detection, type of track/pavement, auxiliary structure (rails only), traffic category, type and volume?

Embankments- type of track/pavement, auxiliary structure (rails only), traffic category, type and volume?

Cuts- type of track/pavement, auxiliary structure (rails only), traffic category, type and volume?