WP5 Report

Preparation and elaboration of an all-hazard guide for transport infrastructure

The following report summarizes the results of Work Package 5 – Preparation and elaboration of an all-hazard guide for transport infrastructure of the EU CIPS Project AllTrain.

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1. Introduction

The AllTraIn project is funded by the European Commission – DG General Home Affairs under the *Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks* Program (CIPS). During the two-year course of the project, several work package reports will be issued, including the present report on WP4 – Approach for Assessment.

**Background & work-package structure**

The project AllTraIn is divided into 7 work packages:

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

Figure 1 illustrates the work-package structure of the AllTraIn project.
• Work Package 1 identifies the state of the art regarding security research. Focus is given to already existing methodologies and approaches which could potentially be used or adapted within the AllTrain project. Work Package 2 deals with the identification of all possible hazards to transport infrastructures. These include (but are not limited to) man-made hazards (intentional and unintentional) as well as natural hazards. The outcome is a substantial list of possible hazards which are potentially relevant for transport infrastructure. Work Package 3 aims to identify and develop criteria for the identification of relevant infrastructure types and sub-types that can play a role in terms of susceptibility to different hazards. Work Package 4 develops a methodological approach for the assessment of hazards and assets, combining the information of the previous work packages. Work Package 5 aims to develop a practicable and user-friendly all-hazard guide for transport infrastructure, which is demonstrated and validated in Work Package 6. Work Package 7 deals with the dissemination and management activities within the project.
2. All-Hazard Guide
All-Hazard Guide for Transport Infrastructure
All-Hazard Guide for Transport Infrastructure
Providing security to its people is one of the most important tasks of a government. The relevant authorities have to constantly adapt to the ever-changing global environment and shifting paradigms that influence security. In particular, the increased interlinkage between different societal sectors, dense infrastructure networks and the urbanization of the population have fostered dependence on a reliable, safe and secure transport infrastructure. Any impairment, disturbance or failure of that interlinkage would have a substantial impact on the (nation-) state, the economy and major segments of the population.

The All-Hazard Guide contributes to the development of a secure, effective and functional transport network across Europe by identifying and assessing all possible hazards to transport infrastructure. By considering major road and rail infrastructure, it covers the interconnectivity of transport across Europe by enabling owners and operators of transport networks to obtain an indication as to which of their infrastructure systems might potentially be susceptible to a specific hazard and which specific hazard might potentially have the biggest impact on their diverse structures.

The All-Hazard Guide was developed as a result of the research project AllTraIn - All-Hazard Guide for Transport Infrastructure, with the financial support of the Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks Programme (CIPS) of the European Commission – Directorate-General Home Affairs.

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## DEFINITIONS

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>Asset</td>
<td>A relevant infrastructure element or section.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Hazard</td>
<td>A potential event which can compromise the security and/or availability of traffic infrastructure assets.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Initial event</td>
<td>Top-level hazard events, defined as: Human actions, failure of man-made items, meteorological events, geophysical events.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Local phenomenon</td>
<td>Lower-level hazard events evolving at the asset location.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Impact</td>
<td>The way in which a hazard acts on a given asset (e.g. water height, applied forces).</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Exposed value</td>
<td>Defines the value of the infrastructure in terms of replacement cost and time, which is subject to the impacts of the local phenomenon. It depends solely on the asset characteristics.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Vulnerability</td>
<td>The characteristics and circumstances of [...] an asset that makes it susceptible to the damaging effects of a hazard.</td>
<td>UNISDR</td>
</tr>
<tr>
<td>Local consequence</td>
<td>The unwanted condition of an asset inflicted by an impact, expressed as physical damage or disruption (out-of-service time). Quantified in terms of repair cost and disruption time: Local consequence = Exposed value x Vulnerability</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Global consequence</td>
<td>Consequences from the perspective of owner, operator and society. Quantified in terms of repair cost, loss of revenue and detour cost. Depends e.g. on the number of affected users and the network configuration.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Criticality</td>
<td>The relevance of an infrastructure element or section to the availability of a traffic infrastructure network.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Safety</td>
<td>The protection of transport infrastructure against unintentional events such as accidents, covered by relevant standards.</td>
<td>SecMan</td>
</tr>
<tr>
<td>Security</td>
<td>The preparedness, prevention and preservation of a transport infrastructure against exceptional man-made and natural hazards.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
<td>Source</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Indeterminacy of some of the elements that characterize a situation or of the outcomes of a process, due to limited or lack of knowledge (epistemic reducible uncertainty) or due to the intrinsic or natural variability of a process (aleatory and irreducible uncertainty).</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Likelihood</td>
<td>Qualitative description of the uncertainty of the occurrence of an event. Can be quantified as frequency or probability.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Frequency</td>
<td>The number of times a specified event occurs within a specified interval (e.g. accidents per year).</td>
<td>PIARC</td>
</tr>
<tr>
<td>Return period</td>
<td>1/Frequency, i.e. the expected number of time units between two occurrences of an event.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Probability</td>
<td>Likelihood that an event will occur, expressed as a number between 0 and 1.</td>
<td>PIARC</td>
</tr>
<tr>
<td>Risk</td>
<td>The combination of the likelihood of an event and its negative consequences.</td>
<td>Based on UNISDR</td>
</tr>
<tr>
<td>Obstruction</td>
<td>The unannounced physical presence of volumes of foreign objects that wholly or partially occupy the useful space for the traffic in the infrastructure. Examples: snow falls or rock blocks and landslides. These foreign objects can also collide with vehicles.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Operational impact</td>
<td>The reduction, more or less significant, of the infrastructure equipment functionality essential to the traffic flow. Example: damage to a traffic control system caused by lightning.</td>
<td>AllTraIn</td>
</tr>
<tr>
<td>Structural impact</td>
<td>Additional (static, dynamic) load on infrastructure and/or reduced structural resistance. Example: excessive vehicle weight may lead to the infrastructure element’s failure.</td>
<td>AllTraIn</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

1.1 Background

The transport network in Europe is probably one of the most important systems for European economy and society. Trans-European transport routes play a vital role in the traffic of goods and the supply and mobility of people. Although most of the passenger and freight transport in the EU uses land transport, as yet no coherent approach for the security of these transport modes is in place. Any disturbance of these structures could lead to negative consequences for the population of the affected region and the economy as a whole.

Currently, there are many different approaches to identifying hazards specific to transport infrastructure. Most of these approaches focus on single modes or specific hazards and no comprehensive, integrated compilation of all the hazards to multi-modal transport infrastructure in Europe is available. Owners and operators of these infrastructures are facing a large number of hazards and need to decide on the priorities for allocating funds to measures that increase the availability and/or the security of their structures. Ongoing and completed projects have identified the need for a common European approach to assessing these hazards in a structured and comparable way. In particular, research projects have shown the need for a comprehensive all-hazard catalogue for critical transport infrastructures, based on an integrative approach. Thus, the main objective was to develop a practicable and user-friendly All-Hazard Guide for land transport infrastructure, thereby facilitating a structured Trans-European and holistic security-risk-management approach.

For this purpose, the All-Hazard Guide lists all relevant hazards for transport infrastructure in Europe. Furthermore, criteria for the classification of transport infrastructure according to hazard vulnerability have been developed. By combining the information gathered on hazard and infrastructure characteristics, a methodological approach to the assessment of structures and impacts of hazards has been established. This has been achieved by setting up a qualitative assessment procedure to evaluate the vulnerability of various different transport infrastructures to a set of different hazards.

The development of the All-Hazard Guide was funded by the European Commission – DG General Home Affairs under the Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks Programme (CIPS).

1.2 Basic concepts

1.2.1 Security vs. safety

The All-Hazard Guide deals with the security of road and rail infrastructure. In the present context, security is understood as the preparedness, prevention and preservation of a transport infrastructure against exceptional man-made and natural hazards.

This definition of security is complementary to that of safety, which is defined as the protection of transport infrastructure against unintentional events such as accidents and is covered by relevant standards. Thus, the key distinction between security and safety is that

- safety deals with events covered by relevant standards, while security focuses on exceptional hazards;
- safety deals with unintentional hazards (man-made and natural), while security additionally includes intentional events (man-made).

Safety is not part of the scope of the All-Hazard Guide.
1.2.2 Assets

Any transport infrastructure consists of a number of elements that are aligned one after another. Any hazard analysis needs to address these elements separately, according to their type (e.g. embankment, bridge etc.) and specific characteristics (length, height etc.).

In this guide, infrastructure elements or sections are generally referred to as assets.

1.2.3 Hazards

Hazards are defined as potential events which can compromise the security and/or availability of transport infrastructure assets. As discussed above (1.2.1 Security vs. safety), the All-Hazard Guide covers the following types of events:

- intentional man-made hazards,
- (exceptional) unintentional man-made hazards
- (exceptional) natural hazards.

1.3 The AllTrain approach

1.3.1 The dual-entrance approach

The idea behind AllTrain is to combine all types of hazard with all types of road and rail infrastructure (assets). To implement this idea, the dual-entrance approach has been conceived, as illustrated in Figure 1. The principle of the dual-entrance approach is to allow the user to:

- enter a specific asset and receive information about relevant hazards (first entrance),
- enter a specific hazard and receive information about specifically susceptible types of assets (second entrance).

Figure 1 – The dual-entrance approach
1.3.2 The sequence chain

Apart from the dual-entrance approach, a second guiding concept of AllTrain is the sequence chain. The prime purpose of the sequence chain is to establish a general framework for linking hazards to infrastructure elements (assets). This goal is achieved by introducing a set of global concepts with links between these concepts.

Figure 2 – The dual-entrance approach

Figure 2 introduces the sequence chain forming the logical backbone of the All-Hazard Guide:

- An initial hazard event (e.g. rain) causes a local hazard phenomenon (e.g. a debris flow). The causal link can be direct (rain causes debris flow) or indirect. The latter case is symbolized by the grey box with dashed contours in the figure. In principle, there can be multiple intermediate steps. However, the approach is to focus on the initial cause and its final, local result progressing next to the asset at stake. In some cases, initial event and local phenomenon can even be the same.
- The next step links the local phenomenon (the way in which the hazard materializes next to the asset) to the impact (the way in which the hazard acts on the asset). If the local phenomenon is debris flow – to stick with the same example – the impact would be obstruction, structural impact or operational impact (as outlined in Chapter 3).
- While impact refers to the phenomena that act on the structure, it says nothing about the consequences. Whether there are any consequences and their degree of severity depend on the vulnerability and exposed value of the asset. The model focuses on local consequences, i.e. the damage inflicted directly and locally on the asset. They include repair and reconstruction costs as well as out-of-service time of the specific asset at stake.
- Local consequences can lead to global consequences, i.e. impaired capacity of the transport network causing travel delay costs and loss of toll revenues. Global consequences are displayed in the sequence chain for the sake of completeness, but they are not within the scope of the project.
The methodological approach linking impact to local consequence is displayed in the lower part of Figure 2. However, the focus is on the upper part, i.e. the sequence chain, which ties the main concepts together. The methodological approach and other detailed considerations is part of the assessment methodology described in Chapter 4. Figure 3 shows the concise definitions of the respective elements of the sequence chain and also illustrates the debris flow example mentioned above.

**Figure 3 – Sequence chain: Definitions and example**

**1.4 Structure of the Guide**

Based on the dual-entrance approach presented in Figure 1, the All-Hazard Guide is structured as follows:

- identification of relevant hazards (Chapter 2);
- categorization of infrastructure with respect to its susceptibility (Chapter 3);
- linking hazards to susceptible types of infrastructure: Establishment of the assessment methodology, corresponding to the “Alltrain methodology” in Figure 1 (Chapter 4);
- introduction of strategies to implement the measure(s) (Chapter 5).

In addition to this guide, an app (AllTrain Tool) has been developed. The AllTrain Tool is a practicable and user-friendly option for applying the All-Hazard Guide online. The AllTrain Tool, along with a short manual, can be found online (www.alltrain-project.eu).
2. HAZARDS TO ROAD AND RAIL INFRASTRUCTURE

2.1 Initial events

As defined in the introduction, initial events are top-level events, including:

- intentional and unintentional man-made events (e.g. sabotage, theft etc.),
- meteorological events (e.g. extreme wind, rainfall, snow, icing etc.),
- geophysical events (e.g. earthquake, tsunami, lava flow etc.),
- gravitational events (e.g. avalanche, debris flow, rock fall etc.),
- hydrological events (e.g. river flood, lake overflow, urban flood etc.),
- other events (e.g. magnetic storms, wildfires, toppled trees etc.).

Each of these events can be broken down into more specific elements; as an example, meteorological events can be broken down into cold and warm fronts, cyclonic storms, local wind systems, rain, snow hail, icing etc. However, as this example list already indicates, it can be difficult to completely separate these phenomena from each other (rain can follow on from a cold front, etc.). In the context of the All-Hazard Guide, it is not necessary to untangle these interdependencies, since the methodological centre piece of the model is local (hazard) phenomena and their impacts rather than their sometimes remote root causes. Local phenomena are discussed in more detail below.

2.2 Local phenomena

When the array of possible local hazard phenomena is broken down into a list, a major difference can be made between man-made hazards and natural hazards.

All the hazards listed below are described in detail in separate Hazard Fact Sheets that can be found online (www.alltrain-project.eu).
2.2.1 Man-made hazards

Table 1 presents the list of man-made hazards, divided into those due to intentional and unintentional action. Many hazards can be the consequence of either intentional or unintentional action (e.g. fire). The scope of the All-Hazard Guide is limited to security issues as defined in in the introduction (exceptional man-made and natural hazards). Thus, ordinary vehicle accidents are disregarded. However, ramming (intentional) and the threat posed by excessive vehicle dimensions or weight are exceptional hazards that are not covered by design codes.

Table 1 – List of local phenomena: Man-made hazards

<table>
<thead>
<tr>
<th>Type of action</th>
<th>Local phenomenon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only intentional</td>
<td>Ramming</td>
</tr>
<tr>
<td></td>
<td>Sabotage</td>
</tr>
<tr>
<td></td>
<td>Theft</td>
</tr>
<tr>
<td></td>
<td>Cyber attack</td>
</tr>
<tr>
<td>Only unintentional</td>
<td>Excessive vehicle dimensions</td>
</tr>
<tr>
<td></td>
<td>Excessive vehicle weight</td>
</tr>
<tr>
<td>Intentional/unintentional</td>
<td>Blockade</td>
</tr>
<tr>
<td></td>
<td>Fire</td>
</tr>
<tr>
<td></td>
<td>Explosion</td>
</tr>
<tr>
<td></td>
<td>Hazardous release</td>
</tr>
</tbody>
</table>
2.2.2 Natural hazards

Table 2 introduces the list of natural hazards. The hazard category in the left column is based on the conventions applied within natural hazards research. Hazard categories are not congruent with the concept of initial events listed above. Avalanches, for instance, are categorized as gravitational hazards. Gravity, however, is not the trigger or initial event or trigger in the sense of the sequence chain.

As indicated in Section 2.1 (initial events), many local phenomena are not triggered by a single initial event, but by a number of conditions. Thus, a local phenomenon can have both man-made and natural components at the same time, e.g. the case of a dam failure. In this specific case, it was decided to treat dam failure in the same way as other types of floods for the sake of methodological simplicity (i.e. as a natural hazard).

Table 2 – List of local phenomena: Natural hazards

<table>
<thead>
<tr>
<th>Hazard category</th>
<th>Local phenomenon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteorological hazards</td>
<td>Extreme wind</td>
</tr>
<tr>
<td></td>
<td>Extreme rainfall</td>
</tr>
<tr>
<td></td>
<td>Extreme snowfall</td>
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<tr>
<td></td>
<td>Snow drift</td>
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<tr>
<td></td>
<td>Sand drift</td>
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<tr>
<td></td>
<td>Storm surge</td>
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<tr>
<td></td>
<td>Icing</td>
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<tr>
<td></td>
<td>Lightning</td>
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<tr>
<td></td>
<td>Sandstorm</td>
</tr>
<tr>
<td></td>
<td>Fog</td>
</tr>
<tr>
<td></td>
<td>Hail</td>
</tr>
<tr>
<td></td>
<td>Extreme high temperatures</td>
</tr>
<tr>
<td></td>
<td>Extreme low temperatures</td>
</tr>
<tr>
<td>Geophysical hazards</td>
<td>Earthquake</td>
</tr>
<tr>
<td></td>
<td>Ground deformation/displacement</td>
</tr>
<tr>
<td></td>
<td>Ground subsidence</td>
</tr>
<tr>
<td></td>
<td>Soil liquefaction</td>
</tr>
<tr>
<td></td>
<td>Sinkhole</td>
</tr>
<tr>
<td></td>
<td>Tsunami</td>
</tr>
<tr>
<td></td>
<td>Lava flow</td>
</tr>
<tr>
<td></td>
<td>Lahar</td>
</tr>
<tr>
<td></td>
<td>Ash cloud</td>
</tr>
<tr>
<td>Gravitational hazards</td>
<td>Avalanche</td>
</tr>
<tr>
<td></td>
<td>Debris flow</td>
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<tr>
<td></td>
<td>Shallow landslides</td>
</tr>
<tr>
<td></td>
<td>Deep-seated landslides</td>
</tr>
<tr>
<td></td>
<td>Rock fall</td>
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<tr>
<td></td>
<td>Rock collapse</td>
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<tr>
<td></td>
<td>Cliff fall</td>
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<tr>
<td>Hydrological hazards</td>
<td>River flood and lake overflow</td>
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<td></td>
<td>Flash flood</td>
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<tr>
<td></td>
<td>Urban flood</td>
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<td></td>
<td>Groundwater flood</td>
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<td></td>
<td>Outburst flood</td>
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<tr>
<td>Other hazards</td>
<td>Toppled trees</td>
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<tr>
<td></td>
<td>Wildfire</td>
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<tr>
<td></td>
<td>Magnetic storm</td>
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<tr>
<td></td>
<td>Blackout</td>
</tr>
<tr>
<td></td>
<td>Rodents</td>
</tr>
<tr>
<td></td>
<td>Crossing animals</td>
</tr>
</tbody>
</table>
3. INFRASTRUCTURE CATEGORIZATION AND SUSCEPTIBILITY TO SPECIFIC HAZARDS

3.1 Infrastructure types

According to the basic conceptual scheme adopted in the sequence chain, after the characterization of potential events (hazards) that could compromise the security and the operational capability of the infrastructure follows the assessment of local consequences induced by the impacts on each type of infrastructure.

The overall goal is to identify the type of potential susceptibilities associated with the vulnerabilities of each infrastructure element, taking into account the type of impact. The impacts can also induce other consequences for the stakeholders and the community in general (global consequences), which are not taken into account.

Within the scope of the methodology, a set of asset types was selected:

1. bridges,
2. tunnels,
3. embankments,
4. cuts,
5. centralized systems.

The first four asset types considered (bridges, tunnels, embankments and cuts) can be generally described as structural, considering that these form the hard physical part of the transportation infrastructure (Figure 4). Tunnels and bridges are used to cross different types of barriers. Tunnels are underground or underwater passageways, excavated below the surface (usually in mountains or urban/sensitive areas), while bridges are structures built to span physical obstacles, including bodies of water, valleys or roads. Cuts and embankments are used to adapt the natural terrain to the requirements of the road/rail profile. In general, open road and rail sections can be categorized as either cuts or embankments or a succession of both. Cuts require the excavation of the natural ground to lower the surface level, while embankments are earthworks used to raise the surface level. All these asset types can be embedded in road, rail or mixed transport systems.

A centralized system is a system shared by more than one asset which is of great important since it has an essential function for the asset’s operability, in particular, communications, monitoring or traffic control, security or even energy supply in the case of railway systems. Although these are not infrastructure types as such, they can be affected individually by all the hazards considered within this Guide. The occurrence of any hazard in a centralized system has similar impacts on one or more of the infrastructure elements defined, their potential negative consequences being more serious in the case of railways.
3.2 Basic conditions and main factors

The infrastructure categorization is based on the analysis of existing operational transportation infrastructures. The infrastructure characteristics are considered for assessing hazard vulnerability through a common methodology. The mitigation and/or prevention measures already implemented at the time of the analysis are regarded as characteristics of the infrastructure. Also, when the measures are non-existent or insufficient, advice is given at the end of the analysis on which measures could be implemented to mitigate or prevent the impacts of a specific hazard. These measures are addressed in the hazard fact sheets (see Section 5.2).

The infrastructure categorization process prepares the information required for the next step, which is the assessment of the local consequences. According to the new methodology, this characterization is the result of the combination of two main groups of factors:

- **Type of impact on the infrastructure.** Three types of impacts are considered: obstruction (to traffic), operational impact and structural impact.

  - **Obstruction:** the unannounced physical presence of volumes of foreign objects that wholly or partially occupy the useful space for the traffic in the infrastructure. Examples: snow falls or rock blocks and landslides. These foreign objects can also collide with vehicles.

  - **Operational impact:** the reduction, more or less significant, of the infrastructure equipment functionality essential to the traffic flow. Example: damage to a traffic control system caused by lightning.

  - **Structural impact:** Additional (static, dynamic) load on infrastructure and/or reduced structural resistance. Example: excessive vehicle weight may lead to the infrastructure element’s failure.

- **Type of Local Consequence on the Infrastructure.** Two fundamental types were considered: damage, requiring repair and incurring replacement costs and interruption of service (or, out-of-service time).

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

  - **Out-of-service time:** total or partial interruption of traffic or normal service of the infrastructure, as part of a transport infrastructure network. This effect will cause different damage to users and the community, as well as to the entity that manages the infrastructure, and is thus a component of Global Consequence whose evaluation is beyond the scope of the methodology.

  For practical purposes, the analysis only considers the out-of-service time because this is an easier parameter to estimate than reconstruction costs, being less dependent on scale and country and also, in most cases, there is a correlation between the two types of local consequences. Therefore, it is assumed that out-of-service time is suitable to represent local consequence as a whole.

The relationship between these two sets of factors depends on several vulnerabilities associated with each asset type and each hazard type. These vulnerabilities were grouped in a small set of factors:

- **Structural factors,** including the vulnerability characteristics considered significant associated with the physical structure, the mechanical system that constitutes the infrastructure element. These cha-
racteristics will affect its susceptibility to the considered Impacts. Example: the type of structural material.

- Natural factors, including the characteristics of the natural environment where the infrastructure element is situated and considered as significant in its impact-induced behaviour. Example: the geological characteristics of the site.

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

- Local operational factors, indicates the existence or not of a system of communications monitoring the infrastructure element or the traffic control, a security or energy supply system in the case of railway networks linked to a centralized system.

### 3.3 Categorization

Based on the experience and fundamental understanding of the behaviour of the infrastructure elements, relevant points are considered for the four major categories of vulnerability factors: structural, natural, traffic and local operational factors. The aspects provided describe the assets for a comprehensive analysis of local consequences in terms of cost and time, although the analysis in this case only considers one aspect, time.

The following pages describe a number of factors that have been used for categorizing each of the five asset types. A more detailed and comprehensive list of factors can be found online (www.alltrain-project.eu).
**Embankments**

The factors governing the physical vulnerability of embankments included in road or railway networks include the construction type, the major geometric features and the drainage systems as structural factors. The type of track or pavement and the existence of any auxiliary structure for railway system are also considered. The other factors are the same as those used for tunnels, i.e. 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, and connection to a hub with respect to the traffic factors. Local operational factors identify the possible existence of systems adjacent to the infrastructure that are connected to other sections of the road/railway.

**Cuts**

The factors governing the physical vulnerability of cuts in road or railway networks include the construction type, the major geometric features (lateral slopes and depth), the drainage system and the support structure. The structural condition, the type of track or pavement and the existence of any auxiliary structure are also considered. The other factors are the same as those used for tunnels and embankments, i.e. the traffic category, type and volume, and connection to a hub 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 to characterize the natural slope. Local operational factors identify the possible existence of systems adjacent to the infrastructure that are connected to other sections of the road/railway.

**Bridges**

The factors considered for the assessment of the physical vulnerability of bridges being part of road or railway
networks include the bridge’s construction type, described by the construction system, the cross-section and the material, the major geometric features (span, height and length), the structural condition the location of pillars, the foundation system, the type of track or pavement and also the existence of any auxiliary structure (for railway mode). The natural factors considered are the foundation and the crossing characteristics, while the traffic factors are those that describe the specific characteristics of the local traffic: category (on the bridge as well as below the bridge), type and volume, as well as the connection to a hub or not. Local operational factors identify the possible existence of systems adjacent to the infrastructure that are connected to other sections of the road/railway.

**Tunnels**

The factors governing the assessment of the physical vulnerability of tunnels, which make part of road or railway networks include, 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. It is also considered the type of lining as well as the type of track or pavement and the existence of auxiliary structure. 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 are those describing the specific characteristics of the local traffic (category, type and volume) that may severely influence the effects of the occurrence of a specific impact and the existence of a connection to a hub or not. Local operational factors identify the possible existence of systems adjacent to the infrastructure that are connected to other sections of the road/railway.
Centralized systems

The factors governing the physical vulnerability of the centralized systems included in either road or railway networks but located at a distance from any bridge, tunnel, embankment or cutting include both structural, natural and traffic factors. The structural factors describing the centralized systems include the construction type and condition, the foundation system and the possible existence of remote access. The natural factors identify the geological/geotechnical conditions and the ground surface profile at the site. The traffic factors characterize the average volume of traffic that is controlled by or dependent on the centralized system.

Hazard vulnerabilities - Example

As an example of how the tables and vulnerability factors can be used, the vulnerability of a cut to the hazard avalanche is considered. The factors selected are presented in Table 3 and they were identified only for their relevance in terms of out-of-service time.

The magnitude of the impact on out-of-service time caused by the local consequences of an avalanche on a cut depends significantly on certain of the structural factors, which describe the major physical characteristics of the built asset relevant to this specific hazard. These include the lateral slope, the depth of the cut and also the existence of auxiliary structure, for the rail transport mode. On the other hand, the natural slope plays an important role on the occurrence of an avalanche. The traffic category and the existence of additional systems may increase significantly the impact of a possible obstruction.

### Table 3 – Factors describing a cut with respect to avalanche (out-of-service time only)

<table>
<thead>
<tr>
<th><strong>Structural factors</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral slope</td>
<td>It influences the impact of a possible temporary obstruction</td>
</tr>
<tr>
<td>Depth</td>
<td>It influences the impact of a possible temporary obstruction</td>
</tr>
<tr>
<td>Auxiliary structure (rail)</td>
<td>If existent it represents the possibility of a power shutdown</td>
</tr>
<tr>
<td></td>
<td>(overhead line equipment)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Natural factors</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural slope</td>
<td>It influences the impact of a possible temporary obstruction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Traffic Factors</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic category</td>
<td>It influences the impact of a possible temporary obstruction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Local Operational Factors</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional systems</td>
<td>If existent it represents the possibility of a power or control</td>
</tr>
<tr>
<td></td>
<td>shutdown of the infrastructure</td>
</tr>
</tbody>
</table>
4. ASSESSMENT METHODOLOGY – BASICS

4.1 Concept of the assessment methodology

The assessment methodology is the centrepiece of AllTraIn – it corresponds to the box depicted at the centre of the dual-entrance approach in Figure 1. According to the dual-entrance approach, the assessment model will allow the end user to:

- enter a piece of infrastructure and receive information about relevant hazards (first entrance);
- enter a specific hazard and receive information about specifically susceptible types of infrastructure elements (second entrance).

Thus, the task of the assessment methodology is to link hazards (Chapter 2) to assets (Chapter 3) in a meaningful way, i.e. so that reality is represented in a reasonable way and adds value for infrastructure operators. In order to meet this objective, the following steps are required:

- The first step is to establish an understanding of how hazards, impacts and damage are causally linked to each other. The number of possible combinations between hazards, infrastructure sub-types and various conditions is vast. Thus, one of the key challenges of AllTraIn is to establish a model that can accommodate the complexity of this interplay while limiting the number of redundant and irrelevant combinations as far as possible.

- After the model had been established and informed, the next challenge was to make the knowledge contained in the model accessible to the end users, i.e. road and rail infrastructure operators throughout Europe. To this end, a software tool was developed to enable users to extract information on relevant hazards for a given piece of infrastructure (first entrance of the dual-entrance approach, described in Section 5.1).

- The second entrance of the dual-entrance approach is selecting a specific hazard in order to obtain information on specifically susceptible types of infrastructure. To make this entrance accessible to the end user, hazard fact sheets were established for each hazard, again based on the assessment model (Section 5.2).

4.2 Concept of the hazard trees

From an end-user perspective (front-end), the AllTraIn model is a tool that can identify relevant hazards for a given piece of infrastructure and vice versa – that can identify types of infrastructure susceptible to a given hazard (see Figure 1).

From a back-end perspective, this requires linking the hazards (local phenomena) listed in Chapter 2 to the infrastructure types described in Chapter 3. Given the multitude of infrastructure characteristics, the number of potential combinations can be very large. To generate the assessment model it is necessary to identify the relevant combinations efficiently. Efficiency is essential in the light of the next work step, where each hazard-infrastructure combination is informed with expert knowledge on possible impacts and consequences.

The selected approach uses the hazards (local phenomena) from Table 1 and Table 2 as a starting point. Its key advantage is that assets (infrastructure elements) are only sub-divided according to structural factors and other factors that are relevant to the specific local phenomenon in question. For example, dividing a
railway embankment into electrified/non-electrified sections is highly relevant if the local phenomenon is icing but less relevant if it is snow drift. This approach can accommodate a discretionary level of detail, while at the same time helping to avoid redundant and void information.

Figure 5 provides a template for generating and informing the assessment model for a given local phenomenon: precursors of the local phenomenon (disposition criteria, triggers, protective measures) are on the left, follow-up events and structural factors are on the right. Precursors can be split into further precursors, follow-up events into further follow-up events. In principle, this approach corresponds to a combined fault-tree and event-tree analysis (FTA/ETA). However, the right hand side of the AllTraIn approach displayed in Figure 5 is not an event tree in the strict sense, since the bifurcations are not based purely on events but on a mixture of structural factors and events. In the context of AllTraIn, the term ‘hazard tree’ is introduced to denote the described approach. A short description of how to set up an hazard tree can be found online (www.alltrain-project.eu) along with some examples.

Figure 5 – General layout of a hazard tree
5. ASSESSMENT METHODOLOGY - APPLICATION

As illustrated in Figure 1, there are two possible ways of putting the AllTraIn assessment methodology to use (dual-entrance approach):

- enter a specific asset in order to receive information about relevant hazards (first entrance);
- enter a specific hazard in order to receive information about specifically susceptible types of assets (second entrance).

The AllTraIn Tool is a user-friendly app that implements the first entrance (Section 5.1).

The AllTraIn Hazard Fact Sheets is an encyclopaedic set of hazard descriptions and corresponds to the second entrance (Section 5.2).

5.1 The AllTraIn Tool

The hazard trees described in the previous chapter contain the information that is needed to identify the relevant hazards and consequences for a given piece of infrastructure (first entrance of the AllTraIn dual-entrance concept). The AllTraIn Tool allows the end user access to this knowledge online at www.alltrain-project.eu along with a short manual.

In general, it can be said that the hazard trees are developed from the centre (hazard) towards the branches (precursors and follow-up events/structural factors). The app enables the user to do the opposite, i.e.

- select a set of structural factors and follow-up events, and
- select a set of hazard precursors (disposition criteria, triggers, protective measures), and receive information on possible hazards and expected consequences. Since a large number of hazard trees are processed each time the user selects a new combination of structural factors and hazard precursors, this process is not trivial.

The AllTraIn tool is a wizard-like recommender mechanism which links assets to relevant hazards. Recommender mechanisms are software tools and techniques that suggest potentially useful items to a user. They are being used increasingly in civil engineering. This is because their users benefit in terms of both time and cost by making more accurate decisions with respect to available domain knowledge.

The app consists of two parts: the first part is an ontology-driven decision-tree learning algorithm which was trained by the resulting ontologies and data included in the hazard trees, and the second part specifies the intrinsic parameters. The user defines the traffic infrastructure, the acceptable impacts, the environmental formations and conditions which can trigger hazards and the acceptable recovery time.

The software is written in HTML5 so that the content can be accessed by any desktop or mobile device, with no installation or compilation necessary on the target device. HTML5 also offers a better user experience with a richer design.

The front end guides the user to develop a feature vector via a wizard-like system by submitting the characteristics of the asset at stake. For the back end, two machine learning decision-tree algorithms were trained using an AllTraIn product translated into machine-readable dictionaries. The machine learning algorithms then eliminate hazards that cannot be classified according to the feature vector produced by the user.
The first algorithm was trained using the characteristics of the assets (infrastructure elements). Data on the type of infrastructure, and various structural and other factors are used in order to eliminate hazards that cannot affect the respective type of infrastructure. The visualized structural factors are also affected by the user-defined infrastructure (feature vector) in terms of whether they are able to affect the elimination of a hazard.

The second decision-tree algorithm was trained based on critical combinations between different environmental factors and whether they are able to eliminate a hazard. As an example, a steep slope and the absence of a protective forest are critical for an avalanche.

The final visualized hazards are generated by merging the two resulting hazard lists.

5.2 Hazard fact sheets

The second task of the dual-entrance approach is to identify all the characteristics that make an asset susceptible to a given type of local hazard phenomenon (second entrance of the dual-entrance concept). Contrary to the first entrance (all hazards for a given asset), the second entrance is not made accessible to the user in terms of an app, but through fact sheets. These fact sheets give an overview of:

- the general phenomenology (description),
- the disposition criteria of the hazard,
- the internal thresholds (triggering) or external triggers,
- the relevance for different types of infrastructure,
- possible protection measures.

Figure 6 shows the fact sheet for debris flow (natural hazard).
## Local Phenomenon No. 24: Debris flow

**Hazard category:** Gravitational hazards

**Description:**
Debris flow is the downslope mass movement, by either inertial or viscous processes at velocities greater than those of creep or solifluction, of a non-Newtonian slurry of a plastic mixture of water and generally coarse, poorly sorted sediment; debris-flow slurries, depending on the particle-size distribution of the sediment, typically range from 50 to 80 % sediment by volume. Debris flows follow unusually heavy rainfall or the sudden thaw of frozen ground and are capable of carrying large boulders. They commonly cut V-shaped channels, at the sides of which coarser material may accumulate as the more fluid central area moves down-channel. Debris may travel over many kilometers.

**Disposition criteria:**
- Geology
- Potential for debris
- Soil saturation
- Relief
- Type of debris

**Triggering Event:**
- Intense rainfall
- Long-lasting rainfall
- Hail
- Snowmelt

**Relevance for:**
- Bridges
- Embankments
- Tunnels
- Centralized Systems

**Main effects on infrastructure:**
Debris flows can provoke severe structural damage and even the collapse of bridges due to the impact of the mixture of solids (rock blocks) and water. Roads and railways can also be put out of service due to the deposition of large volumes of solid material.

**Measures:**
- Check dams
- Deviating channels
- Water deflecting structure (dyke)
- Debris flow deflecting structures (barrier, shelter and bridge)
- Log erosion barrier

**Picture/scratch:**

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Figure 6 – Debris flow: Fact sheet
6. IDENTIFICATION OF POSSIBLE MEASURES

6.1 Possibilities for measure implementation

The proposed methodology considers that the potential mitigation and prevention measures introduced, whether at the time of construction and/or in place at the time of the analysis, are characteristics of the infrastructure. Thus, the hazard trees include a query about measures right after the establishment of the hazard and before the characterization of the asset (infrastructure element).

6.2 Types of Measures

This chapter has the goal of identifying and defining possible measures to mitigate or prevent the impacts of the hazards defined in this Guide, for every type of transport asset type studied.

The measures presented can be structural, operational or organizational and their goal is solely to prevent or mitigate the hazards or their impacts from the point of view of the local consequences covered by this project: damage to the infrastructure and disruption of the service. In other words, this approach disregards the global consequences as well as any potential human losses.

6.2.1 General measures

There is a group of preventive and mitigation measures that can be applied to all types of infrastructure regardless of the hazard considered. These measures can be regarded as general good practices of broad-spectrum use in the area of transport infrastructure asset management.

- Traffic redundancy
- Installation of (automatic) monitoring systems – CCTV
- Land-use planning
- Early warning systems for natural disasters
6.2.2 Specific preventive and mitigation measures

A list of specific measures was established for each of the studied natural and man-made hazards in order to prevent or mitigate the impacts of each hazard. These measures can be found online at www.all-train-project.eu as part of the following documents:

- the hazard fact sheets (compare Figure 6)
- the Measures Catalogue, where additional details are provided

7. CONCLUSIONS

The All-Hazard Guide is a practical, user-friendly guide which can be used by public and private owners and operators of road and rail infrastructures in Europe, as well as the authorities responsible for the implementation of the regulatory framework for the availability and/or security of transport infrastructures.

The guide identifies, on the one hand the specific hazards that could potentially have a significant impact on a given infrastructure and, on the other hand the infrastructure elements in the network which might be susceptible to a specific hazard.

With the help of the All-Hazard Guide it is possible to qualitatively assess road and rail structures with respect to all possible hazards, including intentional and unintentional man-made hazards as well as natural hazards.

In the medium- and long-term the guide will contribute to a better coordinated strategy for the prevention, preparedness and consequence management of terrorism and other security-related risks for critical transport infrastructures in Europe.
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