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The need for data management plans to enable the resilience analysis of transport infrastructure systems

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Abstract

To be helpful in developing recommendations to support the standardization of infrastructure resilience assessment, members of the FORESEE project have studied the data requirements of a case study through its lifecycle phases, and asset management perspectives. This paper introduces key results in these analysis, including concepts and objectives for infrastructure data management plans, to accomplish future resilience governance optimizations and enable the broad variety of assessment methods.

Keywords: Infrastructure resilience; asset management; governance; data management plan; machine learning; structural health monitoring.

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1 Introduction

Among transport infrastructure research and development communities, there is currently no globally agreed way to assess the level of “resiliency”. The wide range of resilience definitions, the varying scope of factors, and the different disruptive events and their effects makes it difficult to generalize. However, the growing levels of hazard intensity, frequency and uncertainty, strongly suggest that it is important to build better governance frameworks that would facilitate the overall transport infrastructure asset management, in particular with regards to their resilience analysis.

According to United Nations Office for Disaster Risk Reduction (UNISDR), resilience is the ability of a system exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. Therefore, measuring resilience for a transport system should be a combination of measuring its toughness to withstand difficulties, and measuring the capacity to recover quickly from them. So what would be more resilient: a tough bridge able to withstand severe earthquakes, which has no short-time rebuilding solution, or a flexible bridge that needs to be shut down for much smaller earthquakes, which is able to provide service soon after? Is it more resilient to invest in early warning systems to avoid ice hazards, or to strengthen the winter road maintenance crew resources? If an infrastructure is able to predict/detect an accident affecting the level of service, what would keep the resiliency higher: an ITS system able to warn all users a small distance in advance, or a new Intelligent Transport Systems (ITS) system able to broadcast to the interconnected users with enough time to reroute their path? There are many different types of factors, and levels of complexity to analyze in detail.

While many transport infrastructure assets are designed, built and managed with functionality and cost-effectiveness in mind, it is clearly important to be able to incorporate some resilience idea into the equation, if we are to reduce the growing uncertainty and ensure optimal governance frameworks. Transport infrastructures are long-term assets, with many stakeholders and a high impact on society, if we believe change is coming, it is in our best interest to adapt the decision making process. Such frameworks not only have to apply the transport systems experience and way of thinking, but also should allow to incorporate the new type of analysis that machine learning techniques offer to address these complex questions.

The FORESEE project aims to develop a toolkit to provide resilience schemes for rail and road transport infrastructures, with the objective of reducing the impact that disruptive events produce. It is formed by a multidisciplinary team of experts working in a consortium towards facilitating the use of innovative multimodal methodologies that will deploy cutting-edge technologies able to offer long-term asset management strategies. Part of the project is devoted to assessing the resiliency of transport infrastructure throughout their lifecycle, i.e. in the planning, design, construction, operation and maintenance phases (Adey et al., 2019). Another part is devoted to investigating ways that Machine Learning, e.g. Neural Networks, can be used to help decision makers during the resiliency assessments. Machine learning can be used to learn how to identify/classify/clusterize/detect defects/patterns/objects/risks through reinforcement learning using a large number of examples. In this way, they are able to develop an abstract concept that is more and more precise, as the training process and example dataset improves.

Decision makers, designers, builders, operators and maintainers all have vast amounts of different data, information, knowledge and criteria to perform their duties. However these are not often all available in the same place, less often traceable and rarely interconnected, perhaps due to the long-term periods between the life-cycle phases or due to the lack of standards to follow throughout the phases. The slow process development on the infrastructure sector and the large variety of stakeholders involved, makes it difficult to incorporate holistically data management concepts like: data interoperability, re-usability and accessibility, into governance frameworks, public tenders, supply chain contracts, or even monitoring systems, like Traffic Control Centers, ITS and Structural Health Monitoring (SHM) Systems.

The benefits of incorporating these concepts into the governance procurement requirements would be that the analysis, and therefore the decision making process throughout the different life cycle phases, would increase in quality and efficiency. Not only would the real-time end-users and infrastructure operator benefit, but also the designers and the decision makers could enrich their decision if they had these tools available. For example, the

disruptive event used during the Operation & Maintenance phase, could be correlated with the Level of Service data from the traffic models or the On-Service threshold levels from the structural design models. This would allow the different disruptive levels to be correlated with hidden/non-obvious context patterns and use later with the previously acquired intelligence as predictive warning tools, in such a way that not only will help operators manage the infrastructure more efficiently, but also it would help designers make better empirical decisions. More importantly, it would also facilitate the identification of risks affecting the system (e.g. Hackl et al., 2018) and the analysis of the potential resilient upgrades that could be applied on any given phase.

The potential of these techniques is enormous, but the age of some infrastructure records, the traditionally low digitalization of the disruptive events and the lack of data management plans (DPM), has not provided enough momentum to benefit from them as much as in other faster-data generating sectors. It can be imagined that if the data existed in abundance in the correct form, Machine learning techniques such as neural networks could be exploited to help make better infrastructure decisions. It, therefore, seems logical to discuss how this should be promoted and facilitated, specifically for the transport infrastructure sector.

This paper starts this discussion by analysing the difference between data, information, knowledge and wisdom throughout the life cycle of transport infrastructures, to be able to address the resiliency assessment with current and future techniques during the complete lifecycle infrastructures. The purpose is to find common ground on the long-term infrastructure data management requirements, acknowledging the challenging different scales, aggregation levels and frequency characteristics of data, but also exploring through examples the benefits this effort could provide at different strategic, tactical and operational levels. By suggesting a resiliency focused data management plan throughout the different phases to be institutionalized through the governance frameworks, the paper tries to start a discussion on the potential recommendations for future infrastructure data driven standardization activities.

2 Resiliency

Resilience comes from an old Latin word 'resilire', which means to spring back. Even though its usage has changed, many Roman roads still exist, despite the time and hazards they have suffered. It is clear that the experience and wisdom of the Roman engineers helped them develop and improve resilient solutions for their transport systems. It would be interesting, not only to build upon their knowledge, but also upon the data collected through time. If we would had a record of all considered data throughout infrastructure history, we could un-doubtedly apply the new data driven analysis to understand better the requirements needed when assessing the resilience of any transport infrastructure system at their different detail levels and phases. Since we do not enjoy such records, but we are evolving into a data driven society that faces growing disruptive uncertainties, the question would be what can we do to improve the current available frameworks.

There are many resilience assessment frameworks, models and tools for transport infrastructure. Some of them consider resilience as an outcome, and some others as a process, but most of them are focused mainly on the exploitation phase (asset management frameworks). Some economic frameworks (Vugrin et al., 2010) study not only the robustness but also the restoration effort or recovery behaviour of the systems. Some others consider a resilient system has four attributes known as the four R's (R4): robustness, redundancy, resourcefulness and rapidity (MCEER, 2005). The FORSEE project identified a lack of resilience considerations, especially for the long term transport infrastructures, due to the inability to understand and monetize resilience for the investment decisions process. It agreed that the transport infrastructure resilience definition could be summarized as the ability to continue providing service if a disruptive event occurs (Adey et al., 2019). The subsequent FORESEE discussion concerning the methods to assess the resilience targeted and open variety of different possible service measurements (i.e. Travel time, Trips, Accidents, etc..) to be compared with/without the effect of the disruptive event, whether calculated through simulations or using indicators.

According to the review of resilience assessment approaches by Seyedmohsen et al. (2016) there are two main types: qualitative and quantitative approaches. The qualitative assessment approaches are considered to include both conceptual frameworks and semi-quantitative methods. Conceptual frameworks or expert judgement being the ones that provide insights about the notion of resilience, but without any quantitative value. While the semi-quantitative methods would involve the aggregation of expert opinion along multiple dimensions into key performance resilience indicators. The quantitative assessment methods, on the other hand, are characterized as either general resilience measures or simulation models. General resilience measures would assess the resilience

by comparing the performance of a system before and after the disruption effects. Additionally some general resilience measures include the recuperation periods, adding a time-dependent perspective into the system performance, while others take into account aleatoric and uncertainty factors while using stochastic approaches. Simulation model based approaches emphasize the structure or characteristics of a particular system to derive a measure of its resilience.

One of types of techniques being investigated by the FORESEE project is Machine Learning (ML). ML techniques are data analytics techniques that teach computers to learn from experience. They “learn” information directly from data, information or knowledge without relying on a predetermined equation as a model,. The algorithms adaptively improve their performance as the number of samples available for learning increases, meaning that is beneficial to have all types of decisions interlinked and correlated with the data they used.

Exactly which techniques are used in the assessment of resilience will depend the purpose of the assessment. If the purpose is to compare the resilience of a transport infrastructure if different alternative management strategies are followed, we need to define the strategies and determine the level of information detail required. Since both “the ability of the system to resist being damaged” and “the ability of the system to recover quickly from being damaged” are used in the assessment of resilience, there are generally two different types of strategies are “prevention strategies” and “contingency strategies”. The prevention strategies are the ones that create a set of barriers that strengthen the transport systems with respect to major disruptions, while the contingency strategies provide response and recovery plans or emergency mechanisms that reduce the adverse consequences of damage and the resulting service disruptions.

The prevention strategies often include the use of monitoring systems, enabled with connected sensors and action capabilities, whether to inform of the probability of occurrence and intensity of hazards or to directly act upon them, for example ice warning systems or mechanisms that deliver anti-icing agents that prevent snow, ice and frost would be a typical prevention strategy. The prevention strategies may also include passive mitigation measures, i.e. ones that are not monitored and controlled. , e.g. a passive slope stabilization system able to mitigate landslide risks.

The contingency strategies combine a set of response and recovery procedures that make use of many different interconnected resources to minimize the effects of the disruptive hazards, from emergency programmes to crisis management, operational procedures and transport system continuity. For example a resiliency contingency plan developed for winter maintenance to deal with heavy snowfalls would include ice/snow removal protocols and resources. A mitigation strategy developed to deal with landslides would include re-routing procedures and rescue protocols to limit the effect on the level of service and recover the capacity as soon as possible.

3 Governance

Transport and infrastructure governance refer to the processes, tools and norms of interaction, decision-making and monitoring used by governmental organisations, asset owners or stakeholders and their counterparts, with respect to making infrastructure services available to the public. It thus relates to the interaction between governmental institutions internally, as well as their interaction with the private sector, as well as with the end users. It relies on the transport sector policy-makers and stakeholders to provide a transparent, responsive, efficient and resilient framework and guidelines to achieve optimal interactions. An important aspect of the governance is that it covers the entire life-cycle of the asset, and though it is often referred to only the delivery modality contracts, it covers all the previous and subsequent phases, therefore affecting very long periods. The impact this sector has on the economy and the high level of investment required, demands a constant exercise to review and strengthen the analysis methodologies, and to provide procedures and processes that help them operate more successfully and efficiently through time.

The governance decision process that would benefit from resilience assessments, contain in general three types of decisions:

- Strategic decisions - mostly made during the Evaluation & Decision phases by the infrastructure owner, but also during the Design & Construction and Operation & Maintenance phase. They often decide the balance between prevention and contingency strategies, based on the available resources and the acceptable resilience levels. These type of decisions require experience, knowledge, information and data that span large periods of time, e.g. years and is aggregated. It is relatively difficult to obtain and analyse.

- Tactical decisions - heavily made during the Design & Construction phase, but needed during the whole lifecycle when determining prevention and contingency strategies. The resilience assessment for this type of decision requires knowledge, information and data as with respect to what might happen in the medium term, e.g. multiple months and is somewhat aggregated. It is likely available only for the duration of the decision analysis.
- Operational decisions - used mostly on the Operation & Maintenance phase for the short term control of the day to day activities - involves making decisions that require real time information and data of the conditions affecting the infrastructure and with little or no aggregation. It, in many cases, has to be constantly available.

Despite when they are mostly used, governance decisions of all types are present within the different lifecycle phases. However, unlike other sectors, the typical lifecycle of the transport infrastructure is quite long. The time between the Evaluation & Decision phases, the Design & Construction phases and the Operation & Maintenance phase can be measured in years, therefore there is a clear risk of disengagement between phases and by relation between decision types. The stakeholders interests from one phase, can be biased and very different from the next. Sometimes the information used to make decisions pertaining to resiliency are often never re-used, the records they were based on are not available and there is a lack of data continuity. This is something a good governance framework can improve. The benefits of establishing a common constant data base for analysis purposes would raise the decision process efficiency, by enabling infrastructure resilience assessments end to end.

It is interesting to consider how the best practice asset management standards (ISO 55000 is an international standard covering management of assets of any kind) could not only be applied to specific transport infrastructure, but considering the growing-in-importance-Data as an asset, we could manage data following the same guidelines. This would mean that the data should be collected to ensure that all the needs of the stakeholders are met, in order to make more effective asset management decisions. The data, despite the external or internal origin, should be assessed with regards to completeness, accuracy, timeliness, accessibility and consistency quality, as well as to the collection, analysis and evaluation procedures.

As governance affects all phases of the life-cycle, e.g. the administration and management of contracts, the determination of the budget, the monitoring of expenditures, the completion of financial and technical audits, the management of the information systems, and procurement processes, the governance framework affects the type of data, information and knowledge required to meet by statutory or legal reporting and record-keeping obligations for each transport infrastructure stakeholder, e.g. owner, designer, constructor, operator. Traditionally governance frameworks refer principally to the records, whether they are public or private, and how they help to ensure that infrastructure meets legal and regulatory requirements. They seldom refer to how records are documented, their interoperability and how the information contained in them are to be reused for other decisions.

4 Montabliz case study

4.1 Viaduct

The infrastructure used in this paper is the Montabliz dual carriageway viaduct transport infrastructure, located at the 149 kilometre point of the 178 kilometre long A67 highway, between the towns of Molledo and Pesquera, Cantabria, Spain. It is known for being the highest concrete beam bridge in Spain and the sixth in Europe, with 146 meters in height (highest pier) over the river Bisueña. The viaduct connects a tunnel to the other side of a valley with a curved and sloped configuration, that helps link the high altitude plains of Spain to the northern coast, through a mountainous area. The height and location of the Montabliz Viaduct exposes it to climate hazards, e.g. strong winds, snow storms and fog. To understand better the time periods involved it is worth mentioning that the highway A67 was started in 1984. Six years later, the first 23 kilometres had been completed. The works were stopped for another 6 years, until resumed and the next sections opened in 2004. The viaduct project itself was designed and built between 2004 and 2008. The last section of the A-67 was opened in 2009, linking for the first time the region of Cantabria with Madrid using a highway.

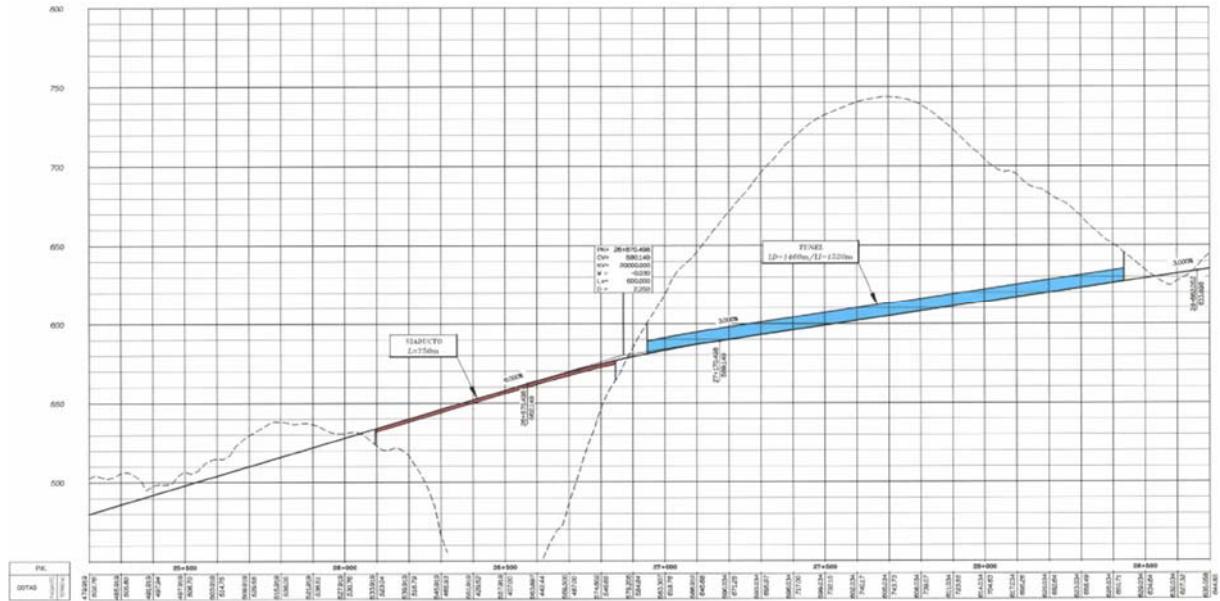


Fig. 2 Longitudinal profile selected during the Montabliz viaduct A67 section feasibility study

4.2 Example decisions through-out the life-cycle

Governance of the Montabliz viaduct requires assessing its resiliency in each lifecycle phase. During the Evaluation phase, for example, the alternatives studied offered different possible layouts and profiles. Some alternatives using the east side of the valley (see ALTERNATIVA ESTE on Fig.3), due to high landslide risks, were considered impractical. Other alternatives using the middle (ALTERNATIVA CENTRO) or west part of the valley, required high slopes and long tunnels, which were incompatible with the budget and the minimum security requirements. In the end, one of the high altitude west side alternatives was selected (ALTERNATIVA OESTE B), as the advantages outweighed the disadvantages. The decision making process made use of, among other things, georeferenced layouts, land-use information data and site specific geological and geotechnical reports.

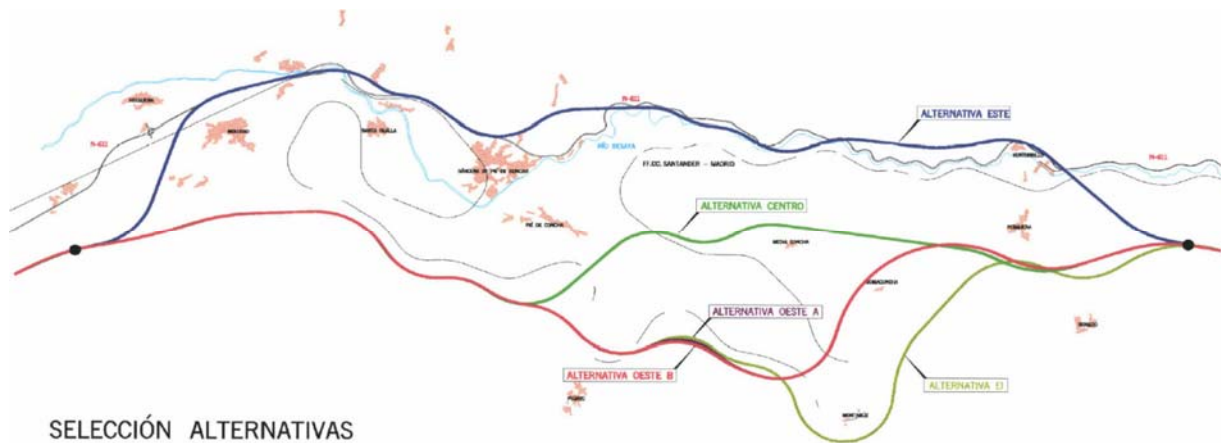


Fig. 3 Alternatives assessed during the Evaluation & Decision phase

During the Design and construction phase, for example, the determination of the viaduct profile and height over the valley required wind tunnel tests to investigate the likely wind effects and resonance issues. The selected alternative was also to have a profile that was especially resistant to snow loads and coupling with this with strict a winter maintenance strategy. Additionally, the piers were thicker than would normally be required to improve the resistance of the viaduct to wildfires, and temperature embedded sensors were installed to be able to better assess damage if they occurred. The decision making process made use of, among other things, information from

climate, snow and wind databases, and forest density, structural and material knowledge obtained from written reports.

During the current Operation and maintenance phase, for example, the viaduct is likely to be affected by wind, fog and snow hazards that may result in traffic accidents or level of service reductions. How it is operated and maintained depends on how the operation and maintenance strategy alternatives affect the resiliency of the viaduct. The decision making process during this phase, among other things, will use information from wind anemometers, temperature sensors (embedded in the structure), cameras and traffic sensors.

The example information listed in the three life-cycle phases are summarized in Table 1.

Table 1. Example information used throughout the life-cycle of the Montabliz viaduct, per strategy and decision type

Strategic decisions	Alternatives	Example information
Which route ?	1) A route over the east side of the valley with high landslide risks. 2) A route over the middle of the valley with great affection areas 3) A route over the west side of the valley with more expensive infrastructure and impacts, and 4) a second route over the west side of the valley, with higher altitude and technical challenges and wind risks, but with less impacts	Estimates of technical, environmental, geological and socioeconomic conditions for each route
Tactical decisions	Alternatives	Example information
Which viaduct profile is optimal to deal with wind risks?	1) A strong and expensive profile, with no special emergency plan, 2) A weaker and less expensive profile, with a special emergency plan	Estimates of wind effects and resonance issues based on the results of wind tunnel tests
Which viaduct profile is optimal to deal with snow risks?	1) A profile that satisfies only the legal requirements and a winter maintenance strategy that includes operational and structural ice and snow removal protocols, 2) A profile that is stronger than specified legal requirements and a winter maintenance strategy that includes operational ice and snow removal protocols	Estimates of possible snow loads and frequency of required snow and ice removal
Which viaduct pier design is optimal to deal with wildfire risks?	1) Standard piers according to code, 2) Piers strengthen beyond code requirements and monitored by embedded sensors to take into consideration possible wildfires	Historical events and wildfire risk of nearby forest, forest density and expected evolution.
Operational decisions	Alternatives	Example information
What activities should be undertaken to minimise wind risks if the strength of expected winds increases in the future?	1) Install wind deflectors at the beginning of the viaduct near the end of the tunnel, to reduce the risk 2) Install sensors and a camera to observe vehicle movements during periods of high winds and enable early wind risk warning signs or closing/limiting the viaduct to traffic protocols	Information from nearby wind sensors and cameras, expected condition evolution, as well as accident reports.
What activities should be undertaken to minimise snow/ice/frost risks if their extent increases in the future?	1) Install mechanisms that deliver anti-icing agents that prevent snow, ice and frost, 2) Reinforce the emergency plans to remove snow, ice and frost	Information as to the amount of snow that has fallen or is likely to fall, Information as to the extent of icing, Temperature Extent of salt distributed
What activities should be undertaken to minimise fog risks?	1) Install improved automatic fog detection and warning systems, 2) Install active cat's eye retroreflective safety and illumination devices	Information as to the air moisture content, temperature, and visibility

4.3 Assessing resilience in the different decision situations

In each of the decision situations in Table 1, it is helpful to have estimates of resilience, or in other words, how do the decisions affect the ability of the transport system to provide service if it is affected by one of the stated hazards. Although the resilience of the viaduct as a function of decisions at each level, can be estimated using different approaches, there is a general trend from qualitative estimates to quantitative estimates, when one moves from

strategic decisions to operational decisions. An overview of the resilience assessment approaches based on the overview proposed in Adey et al., 2019, and their suitability for the case study, are shown in Table 2.

Table 2. Illustration of resilience assessment approaches for the Montabliz case study

Resilience assessment approaches	Strategic decisions	Tactical decisions	Operational decisions
Expert judgement	All types of decisions require experts to estimate the resilience based on their experience and wisdom with respect to qualitative environmental/socio-economical aspects (e.g. the effect of alternative routes designed to provide solutions for the future expected level of service requirements on natural forests/areas, easements, land use, eminent domain/compulsory purchase/expropriation requirements, risks and infrastructure lifecycle costs) first in a non-structured way.		
Use of resilience indicators	As a second step, experts could estimate the resilience based on their experience using structured indicators, and estimates of the possible loss of service and additional intervention costs (effects) due to hazard when each alternative is selected.		
	Resilience indicators with no weights, meaning with no estimate of the cumulative effects as they are relatively difficult to estimate	Resilience indicators with equal weights, with estimates of the minimum and maximum cumulative effects as the relationship between each indicator and the effects are relatively difficult to estimate	Resilience indicators with differentiated weights, meaning with estimates of the minimum and maximum cumulative effects per indicator
Use of simulations	As a third step, experts could estimate the resilience using simulations that are built on their experience but make use of models to estimate the losses in service and additional intervention costs. Simulations give considerably more insight into the resilience of transport systems, e.g. as to the effect on the economy of damaged infrastructure, the traffic flow characteristics during the hazards and during the restoration phases, e.g. average annual daily traffic (AADT), average speed and density by scenario, and the costs of the restoration interventions to be executed. The information required as input to the simulations varies depending on the level of decision.		
	Deterministic scenario simulations using past time dependent information or fix projections, such as historical and expected level of service data, hazard intensity data, and hazard consequence data	Probabilistic simulations using stochastic information, such as level of service prospects, hazard probability, or consequence likelihoods	Simulations using real-time data, such as sensor based level of service data, hazard intensity data, and past data from which prediction models have been developed

4.4 Examples of data that would be useful to have through-out the life-cycle

Regardless of the resilience assessment approach used, there is some data that would be useful to have through the life-cycle of the infrastructure. This is summarized in Table 3 and should be stored in common data repositories.

Table 3. Example data sources to estimate resilience through the life-cycle

Example source data	Comments
Level of Service / Demand data	<p>The demand data or Level of Service describe what the transport infrastructures are built for. Transport infrastructure governance use this information to set up the targets to provide the service. The data sources vary from highly aggregated traffic volumes, broad trip generation data, and wide Origin/Destination matrices, to fine detailed, geographically specific and segmented by travel reasons, economic appreciations or travel modes.</p> <p>An example of demand data sources would be the AADT repositories - which for our case study was used on all the life-cycle phases, and is currently available on an annual aggregated level, segmented by heavy/light vehicle types. Other detail data could be obtained from traffic control centers, by using third party statistical information sources (i.e.: mobile phone related data or navigator data) or by conducting specific surveys</p>
Infrastructure description and	The description and context data include information of the areas surrounding the transport infrastructure as well as the infrastructure capacity, elements and network details. The data sources include the asset inventory and network element design details, the digitized terrain, layout and

context data / Offer data	profile models, but also de asset management, the supply chain contracts, the periodic condition analysis reports, the inspection surveys and maintenance works among others.
Hazard conditions / Risk data	<p>The hazard and risk conditions refer both to information about the disruptive events as well as all the information related to their potential consequences. The disruptive events can be related to a wide variety of data sources, from environmental georeferenced observations, to historical disruptions and effects, as well as frequency/probability risk maps and evolution models. The potential consequences vary from broad cause/effect estimates to detailed fragility and vulnerability models that accurately predict the potential consequences of the risk given scenarios.</p> <p>The disruptive data events examples studied for our case study included service closure conditions/decisions as well as traffic incidents related to fog, wind and mainly snow. The related data could be summarized as local climate historical information obtained from third party sources (i.e. the National meteorology agency AEMET), while the real time onsite data can be obtained from the structural health monitoring installed at the infrastructure (the Kinesia SHM managed by the infrastructure operators which reads several anemometer and temperature sensors among others). The level of service consequences are recorded in the incident reports.</p>

4.5 *The need for a data management plan*

Although one currently doesn't exist it is necessary to have a data management plan, i.e. to ensure that data is available in suitable form through out the life-cycle. A data management plan is an organized guide that summarizes the available data, reports on how to find the data, where and how it is stored, whether it will be shared and preserved, and how to access it. The purpose is to use it as a common reference to be able to correlate data with information, information with knowledge and knowledge with the different decision-making processes to learn and improve thereafter.

A transport infrastructure data management plan is a document where:

- To include the requirements along all the transport infrastructure data life cycle phases. The DMP should be a dynamic document, progressively updated taking into account the evolution along the data life cycle.
- To promote efficiency. The DMP should be the repository where all the elements that may influence the transport infrastructure data life cycle be integrated from a global perspective. This way, the resources can be optimized and no-sense or duplicated actions avoided.
- To facilitate data reuse. The transport infrastructure DMP should contain a coherent set of sections describing how the level of service data life cycle is handled. Therefore, the level of service should be able to be tracked along its life, ensuring potential correlations to calculate resilience are possible.
- By ensuring Reproducibility. The DMP would describe all the elements related to the data gathering, pre-processing, and resilience analysis, so that their analysis results can be reproduced and improved in the future with the same techniques or new machine learning ones.

The data management plan would be the single point of reference to each data source, information and knowledge used. It would include:

- Metadata: Describing the infrastructure context, the content and the structure of each dataset.
- Ontology: a formal naming and definition of the types, properties, and interrelationships of the entities and conceptualizations that exist the in the transport infrastructure domain. For example this information would allow the asset management incident reports to be easily processed automatically. An example can be found in Panagiotis et al.
- Digital Object Identifiers (DOI): implementation of a persistent identifier that can be assign to any infrastructure dataset object.
- And the Findable, Accessible, Interoperable, Reusable/Reproducible (FAIR) principles. This refer to the principle of being Findable with uniquely and persistently identifiers. Accessible to ensure that data is and will be reachable and accessible by humans and machines using standard formats and protocols. Interoperable by using the previously mentioned metadata and annotated with resolvable vocabularies/ontologies. Reusable, by being sufficiently well-described to allow the integration with other compatible data sources. and Reproducible, by providing elements related to the data in such a way that this data is identified and relationships are well known (keys, references, times stamps, software, methods, related dataset, etc.).

The benefit of using a data management plan in this way would be to fight the scarcity of historical digital data on the infrastructure sector, to optimize the asset management, to facilitate the resilience evaluation for both the

preventive and the contingency strategies, to improve the life-cycle and risk assessment, and indirectly the governance procurement itself.

5 Conclusion

Resilience analysis is a key part of infrastructure asset management, it allows decision makers to reduce the impact and optimize interventions against different hazards. In order to perform this type of analysis throughout its life-cycle we found that the case study required a wide variety of data collection aggregation and different frequency levels. The available methodologies to evaluate the resilience would benefit of having a long-term holistic approach to gather and record the data in an organized way. By considering the influence the governance framework has and the benefits of promoting efficient data administration to facilitate resilience analysis we realized that infrastructure governance should promote long lasting Data Management Plans (DMP) associated to the complete lifecycle of the infrastructures.

Any research and development project nowadays needs to offer a Data Management Plan (DMP) to provide a reference point to consult and reference the available data. We believe this requirement should be promoted, copied and expand to the transport infrastructure sector through the governance processes. The transport infrastructure data management plan should serve to guarantee that all records, data and information related to the transport infrastructure is discoverable, accessible, assessable, intelligible, usable, and wherever possible interoperable to specific quality standards. In this way making sure all relevant stakeholders can refer to it as single reference, with whatever restrictions required, for the whole infrastructure lifecycle. But also that they update it in the sections and phases they are responsible for/permited to do so.

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