International Coalition for Sustainable Infrastructure

Position Paper

Implementing resilience in critical transport infrastructure systems

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Abstract

Critical transport infrastructure systems play a pivotal role in supporting society through provision of essential connectivity services to end-users, alongside enabling economic growth. To be able to deal with an increasingly complex and interconnected world and uncertain future, critical transport systems need to be made more resilient. Being able to preserve critical services in ordinary as well as extraordinary circumstances is the resilience value ultimately delivered to customers. This paper argues that to be successfully implemented, resilience needs to be built/enhanced/embedded across the whole infrastructure lifecycle. It presents a summary of international research undertaken to identify tangible, practical and relevant actions, tools, approaches, physical measures, and useful resources that decision-makers and practitioners can turn to when looking to implement infrastructure resilience. Finally, it is argued that a value-driven approach focussing on the resilience value delivered by infrastructure is needed to build the business case for resilience implementation.

Keywords: resilience; transport; critical infrastructure; system; whole lifecycle; value chain

1. Introduction

Transport infrastructure is vital to support society by delivering critical services to end users, alongside economic growth. Many disruptions can cause cascading impacts including, limiting or preventing access to jobs, education and leisure, and essential services such as freight and healthcare.

The Trans-European Transport (TEN-T) networks are the core European transportation corridors. However, most of this infrastructure was constructed in the 1960-70s and designed for a working life of ~50 years. These networks are now often subjected to stresses due to increased congestion, ageing, and changes in climate that they were either not designed for or are no longer able to withstand; such risks are becoming increasingly dynamic and emerging. This can result in significant physical damage to our transport infrastructure, impeding travel and causing safety concerns. Ultimately, in the absence of serious injuries and fatalities, the real impacts of these events are economic and social. The World Economic Forum recently identified the *'failure of critical*

infrastructure' as a key global economic risk (World Economic Forum, 2017).
Transport networks are highly interconnected. Not only are they multimodal (e.g., highways, rail, ports), but they rely on other integrated infrastructure systems (e.g., energy, telecommunications and water) to deliver critical transport functions or services that are dependent in ordinary as well as extraordinary circumstances (see Figure 1).

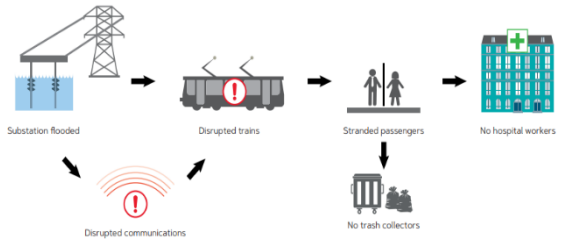

Fig 1. Example of interdependent urban infrastructure systems causing cascading failures (Arup/Mian et al. in: World Bank, 2018)

We do not routinely design, deliver and operate our critical infrastructure systems for resilience. However, in a world that is increasingly volatile, uncertain, complex and ambiguous there is a need to increase their resilience. The UN Sustainable Development Goal 9, 'Build resilient infrastructure, promote sustainable industrialization, and foster innovation' (United Nations, 2016), has emphasised this need. We have defined resilience as the ability to prepare for identified shocks and stresses, to respond to and recover positively from those events that you cannot predict or avoid and adapt to changing conditions. Resilience must focus on the ability of the system to continue to function, considering technical resilience alongside community and organizational resilience (e.g., Kim and Ross, 2019).

The concept of infrastructure resilience can often seem intangible and difficult to apply to the real world and is made more difficult by critical infrastructure typically being planned, designed, and operated in silos, with no single organisation responsible for all components of a system, let alone in a system-of-systems or multimodal context.

This paper presents a summary of international research undertaken into strategies, approaches and tools that allow and enable implementation of resilience in critical infrastructure systems. It argues that a lifecycle approach is needed to successfully build or enhance infrastructure resilience and it presents useful resources for decision-makers and practitioners looking to take well-informed action towards more resilient transport (and wider) infrastructure systems. Considerations on the value of resilience are made, highlighting the need to link the concepts of resilience and value strengthen the business case for resilience implementation.

2. A lifecycle approach to implementation of resilience

It is common for those working in infrastructure to focus only on the one point in the asset's life with which they are presently concerned; this can result in less resilient practices. Instead, we recommend a whole life cycle perspective is adopted. This would consider each action taken in the context of the entire lifecycle from the initial conception and design, through its operational life until eventual decommission or renewal.

It is vital that whole life considerations are in planning, design, construction, operation and maintenance of transport infrastructure. The collapse of the Morandi Bridge in Genoa in the summer of 2018 (Pollock, 2018) is a tragic, but important opportunity to adapt and learn to allow better future planning and procedures (NIAC, 2010) around the whole life management of infrastructure.

Risk-based management has been appropriate for dealing with known and predictable threats but has proven more difficult and is potentially prohibitively costly in managing less known or unpredictable events (Bostick et al. 2018). This is important, as some have argued that focus in risk management is primarily on discrete events rather than the build-up of gradual chronic stresses (Pettit et al. 2019). Taking into account future conditions is particularly relevant because of the long lifespan of transport infrastructure.

Covering all stages of the asset lifecycle, resilience can help addressing the complexity and uncertainty that our increasingly interconnected and globalized world is faced with. Resilience should be developed as an integral part of transport organizations and systems-based thinking is key to identifying

both critical interdependencies within the transport system and between infrastructure systems. Although the concept of infrastructure resilience has become more widely accepted and a significant body of research exist on this topic, guidance on how to implement resilience in practice is scarce.

In 2018, the World Bank commissioned extensive research on infrastructure resilience strategies, approaches, tools, and case studies of past disasters or near misses as part of the Urban Rail Development Guidebook (Arup for the World Bank, 2018). The chapter on resilience to natural hazards and climate makes the case for implementation of resilience across the infrastructure lifecycle and provides useful guidance for decision makers and practitioners on how to do this. Examples of tangible and practical actions that can be taken at each stage of the infrastructure lifecycle are given in Figure 2. The infographics in Figure 3 present a useful summary of the natural and climate hazards that can have an adverse impact on urban rail infrastructure as well as examples of physical prevention/mitigation measures identified from a wide array of international case studies.

The Resilience Shift programme, a global initiative funded by the Lloyd's Register Foundation, conducted research into identification and categorization of risk and resilience-based tools and approaches for resilience.

Findings from this research indicated that many tools and approaches to assess, build or enhance infrastructure resilience already exist but they are not widely disseminated or accessible to potential users. The Resilience Shift Toolbox is a useful resource that aims to improve accessibility to and promote adoption of tools and approaches for resilience. It provides important information on each tool or approach that includes defining at what stages of the infrastructure lifecycle it is best used (Resilience Shift, 2019). Some high-level examples of tools and approaches are included in Figure 2 below

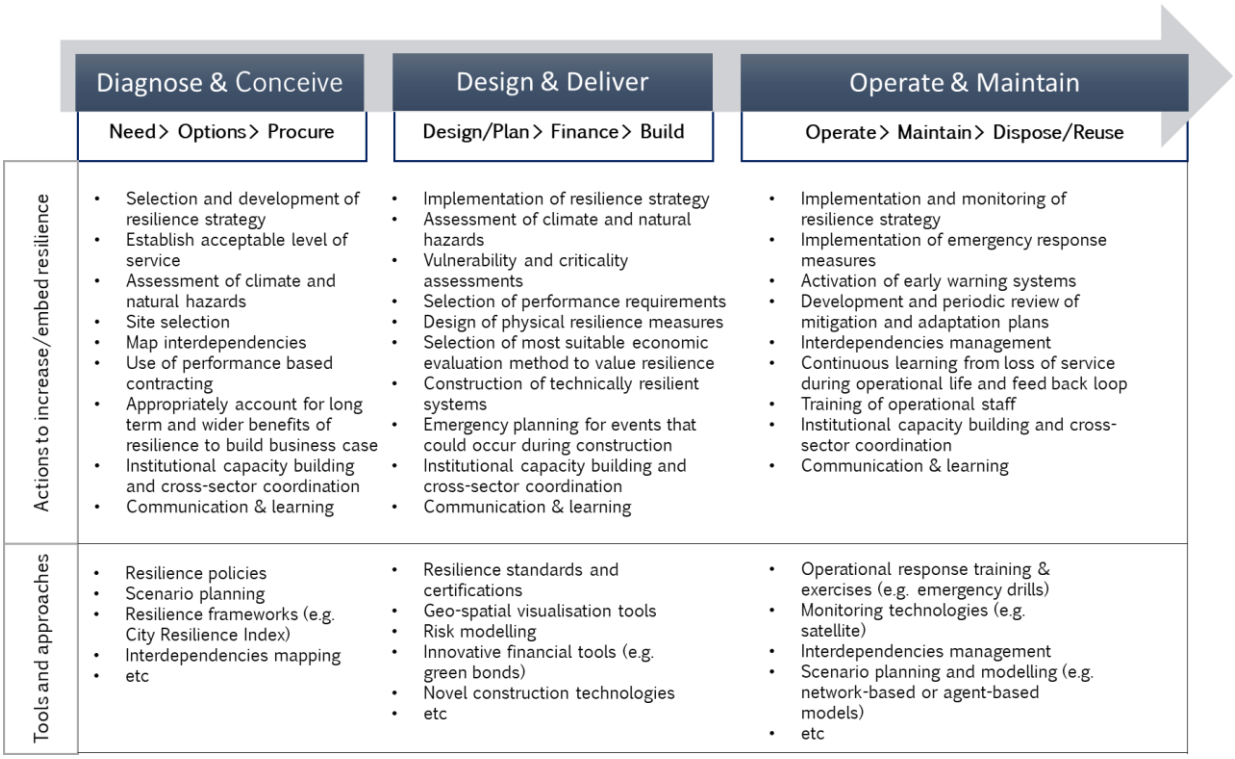

Fig. 2 Examples of actions that can be taken to improve resilience at each stage of the infrastructure lifecycle (adapted from Arup/Mian et al. In: World Bank, 2018 and Resilience Shift, 2018). Examples of tools and approaches are also given (after Carluccio et al, 2019).

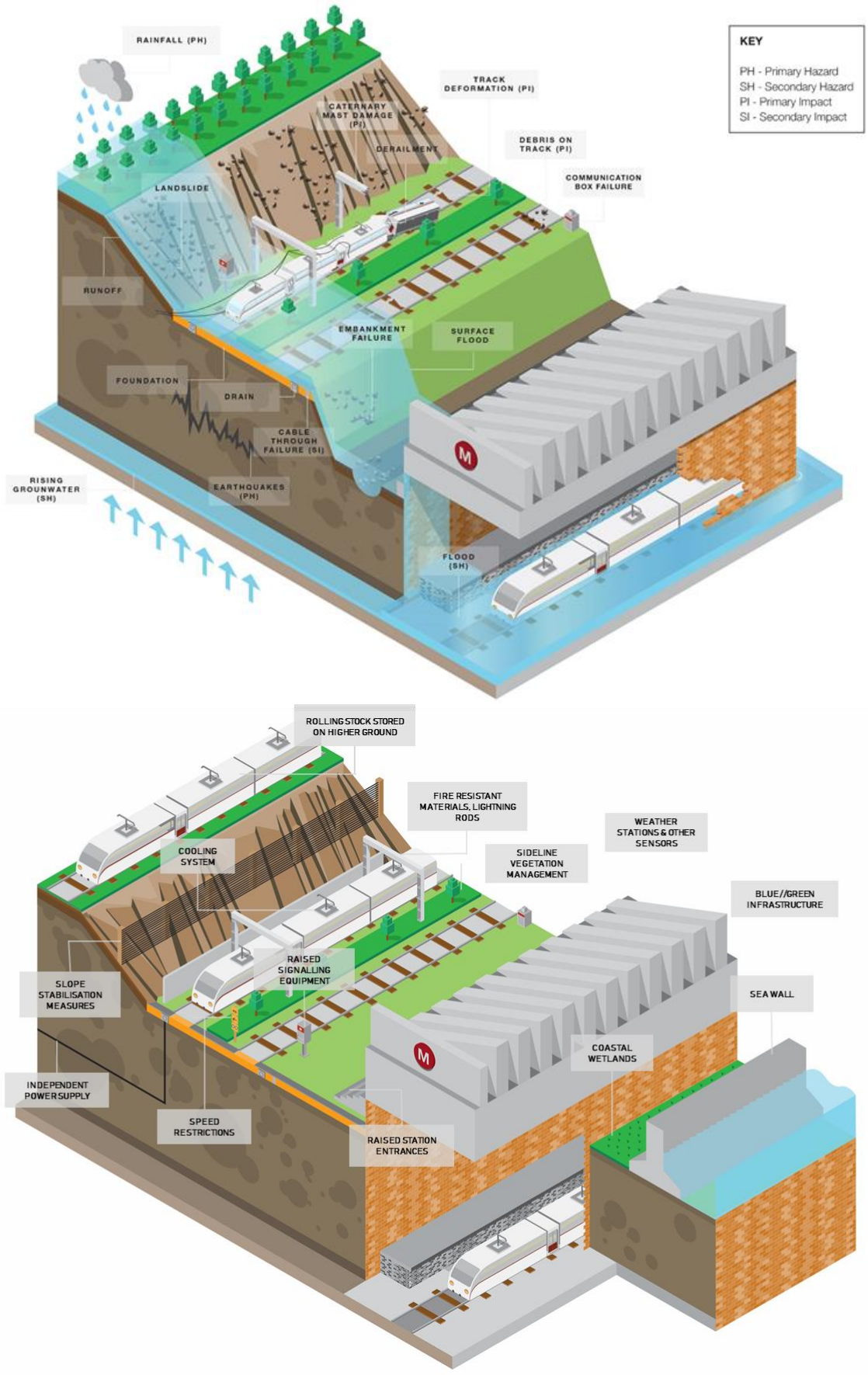

Fig. 3 Graphical representation of natural and climate hazards that can have an adverse impacts on urban rail and examples of prevention/mitigation measures (© Arup)

3. Making the case for resilience implementation: a value-driven approach

Taking a proactive approach to investing in resilience, rather than simply reacting to events after they occur, also reduces the opportunity cost of an incident (Mian et al, World Bank 2018). Customers pay for both disruptions that occur because resilience measures were not taken, but also for measures that are taken to prevent disruption. However, making the case for long-term resilience is not easy, particularly when infrastructure investment cycles are short-term and financial resources are finite.
We define the critical functions of infrastructure as the ability to sustain societal needs through protecting, connecting and/or providing essential services (e.g., in the case of transport, the essential service provided to end-users is connectivity). Ensuring that these are delivered and maintained in the face of shocks and stresses is what we define as resilience value (see Figure 4 below).

Research done by the Resilience Shift program found that a value-driven approach could be used to support resilience implementation and strengthen the business case for resilience. The central idea of this approach is that the critical infrastructure value chain (Figure 5) can be extremely useful for connecting the concepts of resilience and value in the context of the infrastructure lifecycle, which is a familiar framework to everyone working on the design, delivery and operation of transport infrastructure systems (Carluccio et al, 2019). Value chains are traditionally used in business contexts, but Linkov et al. (2019, publication in progress) have also argued the case for joining value chain and resilience, supporting it over the supply chain resilience approach that has been more frequently utilized in the past.
The critical infrastructure value chain (Figure 5) can help focussing resilience thinking and efforts as explained below.

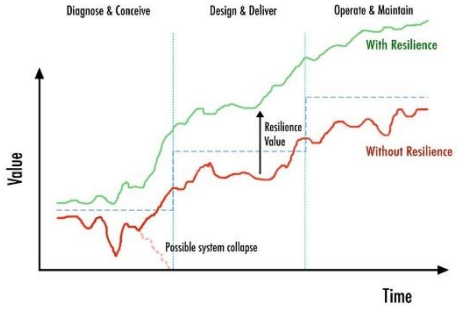

Fig. 5 The critical infrastructure value chain (after Resilience Shift, 2018)

In a typical infrastructure lifecycle, where value creation is ultimately delivered to the end-users of critical infrastructure, resilience value can be created at every stage of the lifecycle. Individual stakeholders along the chain can create and realise the particular value and benefits for themselves. For example, for a designer value may mean reward, recognition, efficiency, or optimal delivery. Through the decisions they make in their day job, everyone along the entire value chain – from those identifying the need to those operating the infrastructure – has a role to play in delivering resilience value. Resilience value is the golden thread that links everyone in the value chain. This thread helps to make decisions around resilience not only matter for individual stakeholders but also for others along the value chain. If this is understood throughout the value chain, this will ensure that resilience is delivered to the benefits of all, leading to a much stronger case for implementation of resilience.

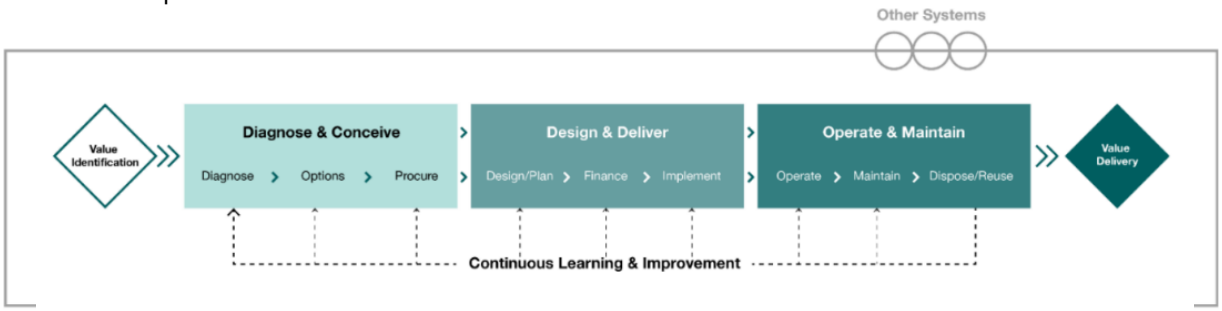

Fig. 4 Value generation in the infrastructure lifecycle under shocks and stresses with and without resilience.

4. Conclusions

Resilience should not be an afterthought, it needs to be embedded across the transport infrastructure lifecycle from the initial conception and design, through its operational life until eventual decommission or renewal. Building resilience into transport and other critical infrastructure systems will allow to prevent or mitigate against known shocks and stresses (e.g. extreme weather events, ageing infrastructure, congestion), to respond better to those events that cannot be foreseen or avoided and to learn and adapt after failures.

Resilience can be implemented more effectively through taking a system-level view. This involves recognizing each mode of transport as part of a larger, interconnected transportation network, which is also interdependent on all other critical infrastructure systems and the society it is integral to.

This paper summarizes research undertaken to identify useful resources that can be used to implement resilience in critical infrastructure systems. Enhancing resilience doesn't always mean hardening the infrastructure, but rather developing and implementing a range of strategies and measures, from fail-safe to adaptive management through to organizational resilience, communication, and capacity building. A range of tools and approaches already exist and there are ongoing initiatives that aim to make them more accessible to decision-makers and practitioners.

A stronger case for resilience can be built through an improved understanding of how resilience value can be created and delivered across the whole value chain of critical infrastructure to the benefit to all those involved, and ultimately, to the society it serves.

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