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# An Assessment Tool for Enhancing Railway Organization Resilience Against Unexpected External Events

Siew Chee Wong[1], Hongrui Wang[1], Alfredo Núñez[1], Niels van Oort[1]

[1] Delft University of Technology, 2628CN Delft, The Netherlands
Corresponding Author: Hongrui Wang (H.Wang-8@tudelft.nl)

## Abstract

Railway systems are increasingly vulnerable to unexpected external events, such as extreme weather caused by climate change, cyber-attacks targeting critical infrastructure. These disruptions threaten the continuity of railway operations and underscore the necessity for railway organizations to enhance their overall resilience. Various studies have looked into the assessing the infrastructure resilience, however, having a resilient infrastructure is insufficient. The back-end decision making or organizational resilient is also essential and it should also be considered. This paper presents a semi-qualitative assessment tool that integrates both technical and organizational attributes identified against the established 4R Resilience Framework: Robustness, Redundancy, Resourcefulness, and Rapidity. The tool employs a structured five-stage cycle, combining expert voting, Rank Ordered Centroid-Technique for Order of Preference by Similarity to Ideal Solution (ROC-TOPSIS) methods to evaluate and determine the resilience level of each resilient attribute. Through surveys, the tool was validated for its relevance and practicality: over 60% of respondents affirmed the applicability of its resilience attributes and evaluation criteria, while 97% considered the tool at least moderately useful. The assessment process identifies low-performing attributes, which serve as guide for resilience-building initiatives and strategic planning. This work contributes an actionable approach to resilience assessment and planning that is adaptable for both national and international railway systems/organizations facing increasingly complex operational risks, and perhaps a universal assessment guideline.

Keywords: railway resilience, risk management, organizational preparedness, assessment tool

## 1. Introduction

Railway systems are critical infrastructures essential to human mobility and countries economic development. Their resilience, defined as the ability to withstand, absorb, adapt to, and recover from ‘internal’ and ‘external’ disruptions, is critical. These disruptions inconvenient railway users, leading to loss in service confidence and decline in revenue. Hence, railway organizations continuously put in effort to reduce the occurrence of disruptions that are within their means to prevent. Traditional risk management frameworks in the railway sector focus primarily on system failures. However, recent disruptions driven by ‘external’ events such as climate events (e.g., flooding and heatwaves) [Pörtner & Roberts, 2023], cybersecurity incidents (e.g., ransomware attacks) [ENISA, 2023], pandemic [Z. Zhang et al., 2023] underscore the need to assess the resilience against external, often uncontrollable, threats as their occurrences are unpredictable.

While existing resilience studies emphasize infrastructure robustness, it is essential to note the operation and management of these infrastructure also plays a pivotal role in crisis anticipation and response. This paper, based on the MSc thesis by Wong [Wong, 2023], proposes a semi-qualitative assessment tool that allows railway organizations to evaluate and improve their preparedness for unexpected external events through a framework.

## 2. Challenges, Related Work, and Research Gap

Rail transport faces ongoing challenges from unexpected severe weather disruptions due to climate change and cyber-attacks that compromise railway operation. While significant efforts have been made to reduce the risk of predictable system failures, the unpredictable nature of external events presents a unique challenge. This

research considers two challenges faced by railway organizations in maintaining operational resilience:

- Impact of Climate Change on Infrastructure: Extreme weather events such as floods and heatwaves pose significant risks to railway infrastructure, causing damage and service disruptions that are difficult to predict and manage.
- Vulnerability to Cybersecurity Threats: As rail systems increasingly rely on digital technologies, they face growing risks from cyber-attacks, which can compromise critical operations like signalling system and ticketing systems, leading to severe service interruptions.

Resilience in transportation has been studied across multiple domains using frameworks such as the 4R model: Robustness, Redundancy, Resourcefulness, and Rapidity [Tierney & Bruneau, 2007]. Railway resilience is defined as the '*ability of a railway system to provide effective services in normal conditions, as well as to resist, absorb, accommodate and recover quickly from disruptions or disasters that inevitably happens*' [Bešinović, 2020]. Most studies focus on quantifying asset vulnerability or modelling infrastructure robustness during disruptions, often through simulation or optimization techniques [Yin et al., 2023; Knoester et al., 2023]. These studies overlook the part of how the railway system can accommodate and recover quickly during such situations, which involves human intervention and with limited resources. The need for a holistic tool that includes both technical and organizational elements is recognized but underdeveloped in current literature [Sun et al., 2020]. This gap motivates the development of a multi-dimensional assessment tool that can provide strategic-level insights for decision-makers.

## 3. Methodology: The Semi-Qualitative Resilience Assessment Tool

This section outlines the design of the proposed resilience assessment tool. It begins by introducing the concepts grounded in the 4R Resilience Framework, followed by a step-by-step explanation of a five-stage resilience evaluation cycle. The methodology integrates technical and organizational perspectives, offering a practical guide for railway organizations to assess, score, and improve their resilience in a structured and repeatable manner.

### 3.1 Conceptual Framework

The tool is built upon the 4R Resilience Framework to identify the resilience attributes, which are categorized into two key domains as shown in Figure 1:

- **Technical Domain**: Encompassing hardware (e.g., rolling stock, signalling system) resilience and software (e.g., railway asset software safety integrity, cybersecurity protection provision) resilience.
- **Organizational Domain**: Encompassing internal resilience and external resilience of an organization in preparing themselves to ensure continuous operation when face with any external events.

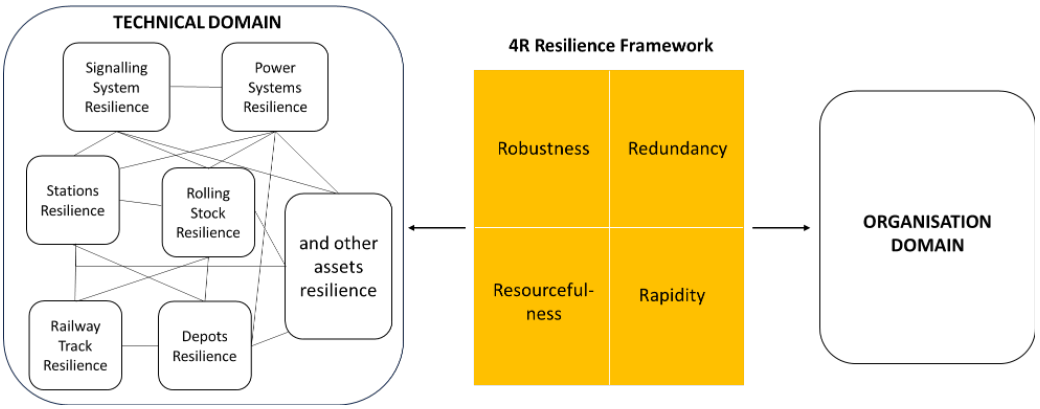


**Figure 1:** Two key domains considered to represent railway resilience

### 3.2 Five-Stage Assessment Cycle

The assessment approach follows a five-stage assessment cycle as shown in Figure 2, and it is repetitive.

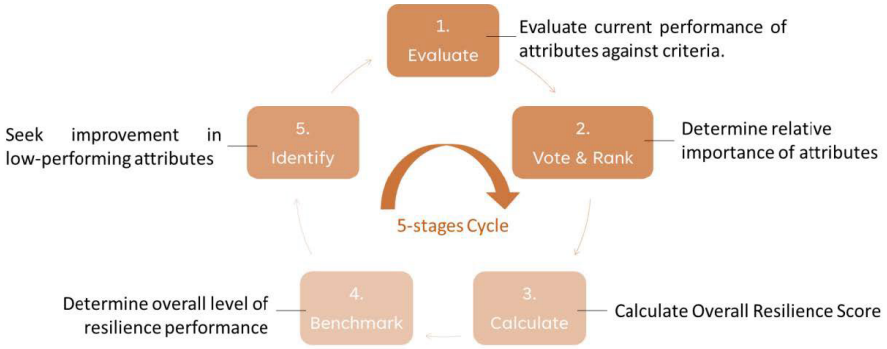


**Figure 2:** Five-stage assessment cycle

1. **Evaluate**: Identified resilience attributes from the two domains are evaluated against pre-defined set of evaluation criteria.
2. **Vote and Rank**: Relative importance of each attribute towards the resilience building in the organization business model is determined by stakeholders or decision-makers.
3. **Calculate**: The overall resilience score which will provide the resilience performance indication to the decision-makers at the strategic level, is calculated.
4. **Benchmark**: The overall resilience score obtained in Stage 3 is compared against a resilience heat band to provide qualitative indication at strategic level.
5. **Identify**: Attributes with low resilience can be further identified for resilience-enhancing measures.

Each attribute is evaluated based on expert judgment of the decision-makers. As this evaluation step could be subjective, the scores are then weighted using the ROC-TOPSIS method, in order to obtain a more objective evaluation. These weighted scores are aggregated to compute an overall resilience score, which provides a high-level indication of the organization's preparedness. Resilience heat bands are defined as: low (1.00-1.99), medium (2.0-2.99), and high (3.00-4.00), offering a clear reference for interpretation and prioritization. The aim is to deliver a structured, data-driven approach for assessing the resilience and readiness of railway organizations and their systems in facing unexpected external disruptions.

### 3.3 Implementation

The semi-qualitative assessment tool was implemented in the form of Excel-based application to facilitate practical and easy adoption. The Excel tool automates the five-stage assessment cycle. Its interface allows users to input attribute evaluations and visualize resilience performance instantly through color-coded benchmarking.

As part of the tool's development, rolling stock was selected as an example to determine what are the resilient attributes against extreme weather conditions and cyber-security attacks that can be considered. By understanding how railway asset-specific attributes can be identified, the assessment tool can be further expanded by adding attributes of the other railway assets. This asset-specific consideration will not impact the organizational domain which is related to the intrinsic way of corporate management and governance. Regardless of the types of external threats identified, how an organization manages their resilience should remain the same throughout and should not be tailored to be external event-specific. A set of 34 resilience attributes in the example. This includes 22 technical attributes, 15 related to hardware resilience and 7 related to software resilience. In addition, 12 attributes from the organizational domain were defined, comprising 9 internal resilience (such as enterprise risk management, business continuity, communication) and 3 external

ones (including situational awareness, coordination with emergency responses and railway users). These attributes were subsequently validated with industry experts and served as the basis for the pilot assessment, enabling a structured analysis in determining rolling stock resilience.

Figure 3 shows a snapshot of the Excel-based tool, illustrating how resilience attributes, the evaluation criteria of each attribute, scores, benchmarking are displayed and interpreted. The tool supports transparency in decision-making and provides guidance for identifying areas with low resilience which require immediate attention. It allows addition of attributes where required.


**Figure 3:** Snapshot of the assessment tool

## 4. Validation and Results

To validate the tool, a survey was distributed to 150 respondents, including asset owners, rolling stock manufacturers, and operators. A total of 99 complete responses were received, forming a solid basis for evaluating 2 Goals, i.e. Goal 1 was to evaluate the attributes being identified, and Goal 2 was to evaluate the usability of the tool.

Respondents assessed the relevance of resilience attributes, the clarity of the evaluation framework, and the overall usefulness of the tool. As shown in Figure 4, more than 60% of the responses feedbacked that all the attributes identified for each of the sub-domains are applicable for resilience assessment.

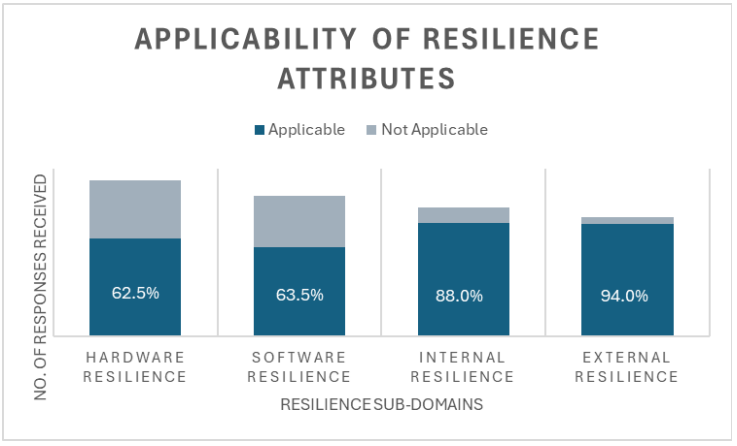


**Figure 4:** Results for applicability of resilience attributes

Most participants found it moderately to highly effective in guiding resilience assessment and strategic planning, i.e. 97% rated the tool as at least moderately useful for resilience assessment. Beyond the numbers, open feedback highlighted the tool's strength in promoting awareness of resilience issues and offering a structured evaluation framework. However, participants noted challenges in evaluating organizational attributes, such as internal coordination and adaptive capacity, due to their intangible nature. This suggests a need for greater

capacity-building to assess non-technical resilience factors. Overall, the validation confirmed the tool's relevance, clarity, and usefulness across a broad range of professional roles.

| Overall Resilience Score | 2.80 | | | 2.98 |
|---|---|---|---|---|
| **Resilience Domain** | **Sub-Domains** | **Associated Attributes** | **Evaluated Attribute Score** | **Evaluated Attribute Score** |
| Technical (Rolling Stock) | **Hardware Resilience** | | | |
| | Design | System Integrity | 2 | 2 |
| | | System Reliability | 4 | 4 |
| | | Risk Management | 3 | 3 |
| | | Redundancy Level | 4 | 4 |
| | | Resilience Engineering | 1 | 2 |
| | Operation | Interoperability | 2 | 2 |
| | | System Interface (With other railway assets) | 4 | 4 |
| | Maintenance | System Maintainability | 4 | 4 |
| | | Conduct of Maintenance | 3 | 3 |
| | | Conduct of Maintenance Audit | 3 | 3 |
| | | Fault Monitoring and Diagnostic Capability | 1 | 2 |
| | | Adaptability to Changing Environment Conditions | 4 | 4 |
| | Assets Renewal | Asset Performance | 4 | 4 |
| | | Asset Conditions | 4 | 4 |
| | | Availability of Spares | 1 | 1 |
| | **Software Resilience** | | | |
| | Design | Software Safety Integrity | 4 | 4 |
| | | Redundancy Level | 2 | 2 |
| | | Risk Management | 4 | 4 |
| | | Cybersecurity Protection | 4 | 4 |
| | Maintenance | Fault Monitoring and Diagnostic Capability | 1 | 2 |
| | | Conduct of Maintenance Audit | 4 | 4 |
| | | Adaptability to Changing Environment Conditions | 4 | 4 |
| | | Leadership | 1 | 2 |
| | | Resilient Strategies | 1 | 2 |

**Figure 5:** Resilience performance before (left) and after improvement (right)

In addition to survey validation, the tool was piloted using a simulated dataset with the intent to show how before and after improvement results can be shown. The initial assessment highlighted seven low-performing attributes in red. With targeted short-term improvements, an updated assessment showed an improvement in the overall resilience score from 2.80 to 2.98. Figure 5 illustrates the tool's ability to support data-driven resilience planning and benchmarking.

## 5. Conclusion and Future Directions

This paper introduces a semi-qualitative tool that incorporates technical and organizational resilience assessment in the railway domain. By combining structured evaluation with practical implementation, the tool can offer organizations clear pathway to diagnose weaknesses and implement targeted improvements. The insights gained from pilot applications in simulated assessments demonstrate its value for resilience planning, performance monitoring, and decision support. These initial applications support the tool's role in informing resilience-building strategies and highlight its potential for broader integration and improvement.

Building upon these initial applications, several extensions are planned to broaden the tool's impact and improve its comprehensiveness:

- Incorporate economic domain. Cost is a key factor in determining the extent of resilience-enhancing initiatives that an organization can invest in to weigh resilience benefits against cost; and for prioritization of cost-effective improvements.
- Improve on the evaluation criteria for intangible organisational attributes by having proxy indicators such as expected response time in the event of crises, number of emergency drills to be conducted, etc.
- Framework was piloted with rolling stock. Expand the technical domains with broader asset classes (e.g., stations, tracks, IT systems, other railway systems); build modular attribute sets tailored for each of these domains.

- Align the resilience heat bands with international benchmarking initiatives for cross-border resilience assessment or a universal resilience assessment guideline, to better reflect 'real' resilience levels as the heat bands in the study is arbitrary at the moment.
- Whilst the survey validation showed good initial feedback, the sample size to be increased so as to sufficiently represent the global railway industry. Aside to survey, usefulness of the tool can also be assessed by conducting real-world case studies or re and to broaden the tool validation across different railway organisations and regions.
- Excel-based tool may face scalability issues for larger or complex organisation. Web-based or integrated software versions with organisations' risk management systems can be considered.
- The tool has considered that resilience attributes should be universal, instead of tailored to be event specific. It is beneficial to understand from railway practitioners on their views of whether external event-specific resilience attributes should be set for better adaptability, or a universal assessment list would suffice.
- The 'Before-After' improvement case is simulated. Cooperation with agencies, railway organisations would be considered to study the field deployment or retrospective validation against actual railway disruptions encountered so as to validate the criterion. It could be a potential consideration whether the criterion are mature enough to evaluate system-wide resilience without significant customisation.

This approach encourages periodic assessment, integrating resilience as a Key Performance Indicator (KPI) within strategic, tactical and operational management.

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