

# **Measuring Climate Resilience for Transport - Deliverable 2.1**

Report addressed to The Department for  
Transport

June 2025

This page left intentionally blank for pagination.

Mott MacDonald  
10 Fleet Place  
London EC4M 7RB  
United Kingdom

T +44 (0)20 7651 0300  
mottmac.com

# **Measuring Climate Resilience for Transport - Deliverable 2.1**

Report addressed to The Department for  
Transport

June 2025

This document is issued for the party which commissioned it and for specific purposes connected with the above-captioned project only. It should not be relied upon by any other party or used for any other purpose.

We accept no responsibility for the consequences of this document being relied upon by any other party, or being used for any other purpose, or containing any error or omission which is due to an error or omission in data supplied to us by other parties.

This document contains confidential information and proprietary intellectual property. It should not be shown to other parties without consent from us and from the party which commissioned it.

---

KPMG was a Subcontractor to Mott MacDonald for this study and contributed to stakeholder engagement to inform the research and analysis.

# Contents

Executive summary	1
<b>1 Introduction</b>	<b>4</b>
1.1 Project and Workstream Background	4
1.1.1 Policy Context	4
1.1.2 Project Objectives	4
1.1.3 Overview of Workstreams	4
1.1.4 Workstream 2 Purpose	5
<b>2 Methodology</b>	<b>6</b>
2.1 Overview	6
2.2 Interface with workstream 1	7
2.3 Literature review	7
2.3.1 Identification of literature	7
2.3.2 Recording of literature review findings	7
2.4 Interviews	8
2.4.1 Interviewees and questions	8
2.4.2 Recording interview results	9
2.5 Notable DMLs	9
2.6 Data limitations	10
<b>3 Literature Review and Stakeholder Interviews</b>	<b>11</b>
3.1 Overview	11
3.2 Initial hypotheses preceding the literature review	11
3.3 Identified metrics and associated data	12
3.3.1 Hazard metrics	13
3.3.2 Asset level outcome metrics	16
3.3.3 Operational outcome metrics	19
3.3.4 Features of a resilient system	23
3.3.5 Summary of literature review and stakeholder interview findings	27
3.4 Discussion	32
<b>4 Conclusion and Next Steps</b>	<b>35</b>
<b>5 Appendices</b>	<b>37</b>
Appendix 1: List of Interviewed Organisations	37
Appendix 2: List of additional sources of data, metrics and indicators	38
Appendix 3: Interview questions	39
Appendix 4: Supporting graphics	41

## Tables

Table 1 - Metric categories, sub-categories and definitions	8
Table 2 - Interview key findings - Hazard Metrics	14
Table 3 - Summary of notable hazard DMIs	15
Table 4 - Interview key findings - Asset-level outcome metrics	17
Table 5 - Summary of notable asset-level DMIs	18
Table 6 - Interview key findings - Operational outcome metrics	20
Table 7 – Summary of notable operational DMIs	22
Table 8 - Interview key findings - Features of a resilient system	24
Table 9 - Summary of notable features of a resilient system DMIs	27
Table 10 - Summary of notable DMIs	31
Table 11 - Performance Datasets	44

## Figures

Figure 2.1: High level overview of WS2	6
Figure 2.2: Conceptual diagram of systems-based approach	8
Figure 3.1: Breakdown of DMIs identified by category and sub-category	12
Figure 3.2: Placement of metrics in a systems-based approach	12
Figure 3.3: Breakdown of hazard metric sub-categories by transport mode	13
Figure 3.4: Breakdown of asset-level outcome metric sub-categories by transport mode	16
Figure 3.5: Breakdown of operational outcome metric sub-categories by transport mode	19
Figure 3.6: Breakdown of the features of a resilient system metric sub-categories by transport mode	23
Figure 3.7: Hazards measured by Hazard DMIs by sector	28
Figure 3.8: Asset DMIs by sector and mode	29
Figure 3.9: Operational DMIs by sub-sector and mode	30
Figure 5.1: Breakdown of metrics by category	42
Figure 5.2: Breakdown of metrics and sub-metrics by sector	42
Figure 5.3: Use of hazard and UKCP18 DMIs by mode	44
Figure 5.4: Change in number of organisations reporting through ARP by mode	45
Figure 5.5: Identified DMIs with temporal aspects by mode	45

## Abbreviations

ADEPT	Association of Directors of Environment, Economy, Planning & Transport
ANSP	Air Navigation Service Provider
ARP	Adaptation Reporting Power
BAG	British Aviation Group
CAA	Civil Aviation Authority
CAPEX	Capital Expenditure
CCA	Climate Change Act
CCAR	Climate Change Adaptation Report
CCC	Climate Change Committee
CCIA	Climate Change Impact Assessment
CCRA	Climate Change Risk Assessment
DARe Hub	Decarbonised, Adaptable and Resilient Transport Infrastructures
DEFRA	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
DMI	Data, Metrics, and Indicators
EA	Environment Agency
EWR	East West Rail
FOD	Foreign Object Debris
HS1	High Speed 1
HS2	High Speed 2
ICT	Information and Communication Technology
IDB	Inter-American Development Bank
ITF	International Transport Workers' Federation
LRF	Local Resilience Forum
MAG	Manchester Airports Group
NaFRA	National Flood Risk Assessment
NAP	National Adaptation Programme
NATS	National Air Traffic Services
NCA	National Climate Assessment
NIC	National Infrastructure Commission
NRW	Natural Resources Wales
OPEX	Operational Expenditure
ORR	Office of Rail and Road
RA	Risk Assessment
RQ	Research Question
RSSB	Rail Safety and Standards Board
SEPA	Scottish Environment Protection Agency

SRN	Strategic Road Network
TfGM	Transport for Greater Manchester
TfL	Transport for London
TfWM	Transport for West Midlands
UKCP18	United Kingdom Climate Projection 2018
UKRLG	UK Roads Leadership Group
WMCA	West Midlands Combined Authority
WS	Workstream

## Definitions<sup>1</sup>

Asset criticality	Measure of the consequence of asset failure on an organisation
Asset Level Outcome	The impact of a hazard on a (transport) asset
Climate hazard	A climate-related physical event that has the potential to cause harm
Climate resilience	Ability of a system to anticipate, prepare for and respond to the impacts of climate change
Data	Information collected by transport organisations that can be used to inform understanding of climate change resilience
Dataset	A collection of related sets of information composed of separate elements that can be used to inform understanding of climate change resilience
Features of a resilient system	Processes, activities or outputs that can be used to indicate climate change resilience
Ideal metrics	Metrics identified at WS1 as optimal for the assessment of climate hazard impacts outcomes and system resilience
Incidence	The frequency or rate of occurrence of a climate hazard
Indicator	An observed value of a variable used to signal a state, often used within organisations to track performance against a benchmark
Interdependence	The dependence of two or more systems, modes or organisations on each other
Lagging metric	A metric that offers insights into past results or performance
Leading metric	A metric that offers insights into future results or performance
Magnitude	The size or extent of a climate hazard event
Metadata	Data that provides information about other data
Metric	The measurement of climate change resilience performance using input data or information
Notable metrics	Data, metrics or indicators that demonstrate potential to be deployed and effective at a sector level.
Operational Level Outcome	The impact of a hazard on a (transport) system's operations
Priority hazards	Hazards identified as priorities for modes at WS1
Priority impacts	Impacts (asset level and operational) identified as priorities for modes at WS1
Service provision / Expected level of service	A measurable, defined target for the performance of a service
Threshold	A defined point past which there is a change (e.g in consequence severity, response action, etc.)
Transport Mode	A subdivision of the transport sector with multiple organisations (e.g. aviation mode, rail mode)

---

<sup>1</sup> The definitions provided have been used within this project

# Executive summary

While there is considerable existing information available about how climate change impacts transport sector organisations and their individual networks, there is limited information available on how to measure these impacts over time at a transport mode (road, rail, aviation and maritime) or system level. A project has been undertaken to understand and collate the data that transport stakeholders capture on weather and climate related disruption and costs to provide an understanding of the available data for measuring transport system resilience and adaptation. The project consists of three workstreams to address these requirements and to ultimately support the monitoring and evaluation of the outcomes and impacts of DfT's climate policies.

**The objective of Workstream 2 (WS2) was to identify existing data, metrics and indicators (DMIs) being used to measure key weather and climate risks, and their impact on the transport system.** To address this brief, a desktop study of relevant literature was conducted to understand the DMIs currently being measured by organisations, and structured stakeholder interviews were held to gain richer insights into organisational data. This report records the process, outputs and findings of the activities undertaken as part of WS2.

Overall, the workstream has found that there are many data points and metrics collected in relation to climate resilience (504 DMIs collected, 113 of which were identified as 'notable'<sup>2</sup>). Some organisations also have other performance data sources available that could be used to inform or measure climate resilience (e.g. Network Rail Schedule 8 Data, or National Air Traffic Services weather-attributed performance data). However, there are internal capability and capacity challenges faced by organisations, as well as resource limitations for data collection, reducing their ability to measure climate resilience. Additionally, there are challenges (such as inconsistent approaches and no mechanism for compiling data from different organisations) that limit the extent to which currently collected data can be used to inform or measure climate resilience at a transport sector or modal level.

Categories of metrics were established at WS1 as; hazard metrics; asset-level outcome metrics; operational outcome metrics; and features of a resilient system<sup>3</sup>. WS2 found that while transport organisations across modes collect DMIs for each of these categories, significant variation exists across modes in terms of what, how, and why it is measured, limiting comparability and aggregation. While operational metrics like delays are widely tracked, they are not often attributed to weather or climate impacts. Similarly for asset-level and resilience metrics, while they are sometimes available, they have been found to be inconsistent between organisations, qualitative, or not directly linked to climate impacts. Relative uniformity in data sources of weather and climate data was observed across transport modes, although aggregating this data to a sector-level would be challenging because different organisations are interested in different hazards, frequencies, severities and thresholds depending on how they are impacted by climate change.

Analysis of the collected DMIs identified some for their potential to be deployed at a sector level as a means of measuring resilience. These were termed 'Notable DMIs' and were identified across all four categories of: hazards; asset-level outcomes; operational outcomes; and features of a resilient system. These notable DMIs will be considered further within WS3.

---

<sup>2</sup> **Notable metrics** are those which demonstrate potential to be deployed and effective at a sector level.

<sup>3</sup> **Features of a resilient system** are processes, activities or outputs that can be used to indicate climate change resilience.

Based on the information and insights collected from the literature review and interviews, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis has been conducted for the transport sector as a whole, focusing on the ability of the sector to develop appropriate metrics and collect relevant data to assess the impact of climate change and weather events on the sector.

The key organisational strengths associated with assessing the resilience of assets and operations to weather events and climate change include:

- **Hazard data:** Organisations across modes are already collecting a range of data to assess the hazards that are most relevant to their operations (e.g. Met Office weather data, UKCP18 projections).
- **Some relevant operational data:** Many organisations are already collecting operational data at a granular level, while some are also analysing the financial impact of this operational data (e.g. revenue loss due to delays, number of cancellations).
- **Some investment in features of resilience:** Organisations across the transport system are investing in measures that could help them become more weather and climate resilient (e.g. Climate change risk assessments, asset risk ratings).

The organisational weaknesses associated with assessing the resilience of assets and operations to weather events and climate change include:

- **Lack of capacity:** Organisations indicated they do not always have the contractual arrangements or systems in place to access relevant data, or the capacity and resources to collate it effectively or even form a consolidated view of how best to use it to inform their approach to climate resilience.
- **Lack of 'leading metrics':** The asset and operational data collected by organisations is not always linked to weather data to create leading metrics, impeding their ability to develop forward-looking operational responses or asset management strategies in response to specific weather events.
- **Variation in climate resilience maturity:** Across the transport sector there is large variation in climate resilience maturity which may impact the extent to which some organisations can report against climate resilience metrics.
- **Asset data:** There are a range of challenges which limits the availability of asset related data including: differences in asset management maturity; the type of data often required to measure asset performance (inspection data or qualitative data); and the challenges of linking weather or climate impacts to asset performance (e.g. degradation over time).

At a system or modal level, these are opportunities for organisations within the transport sector to leverage. This will be considered in Workstream 3:

- **Defining the metric purpose:** Before setting a metric, it is important that its purpose or objective is clearly defined along with how it is intended to be used. This helps to ensure that the chosen metric will measure what is required. The challenge associated with this is increased by the complex stakeholder landscape.
- **Defining expected levels of service:** Organisations highlighted that for weather attribution for operational metrics to be relevant and useful, it is necessary to define an 'expected level of service' under different weather conditions. While defining expected levels of service or supporting the definition of expected levels of service for different modes, asset types, geographies and weather conditions is challenging, it is a critical step in measuring resilience.
- **Metric progression:** Given the range of climate resilience maturity across the transport sector, there is the potential to progressively develop and implement metrics over time, starting with simple metrics that require less data and resources to report.

- **Asset criticality:** There is an opportunity to focus resilience efforts on the most important parts of the system potentially based on the level of redundancy of the asset and the importance of the socio-economic services it supports.
- **Measuring the features of system resilience:** Whilst organisations are investing in specific measures to improve their weather and climate resilience, there is an opportunity to determine the different ways this is being undertaken, to track them over time and link them to the outcomes to be achieved.
- **Assessing and measuring interdependencies:** There is an opportunity to support organisations to share data and information within and across transport modes, as well as between sectors (e.g. energy and water). This was pointed out as a key opportunity.

These are some sector or system-wide challenges that might be barriers for the sector in developing appropriate metrics and collecting relevant data. Again, this will be considered further in Workstream 3.

- **Challenge of attributing causality:** It is challenging to attribute causality to specific weather events or long-term climate change when assessing asset damage or operational challenges.
- **Variations in data collection and reporting:** Aggregating, compiling and comparing data across modes and the sector is made more difficult by the wide variation in the type and format of data collected between organisations.

The findings and insights collected through this workstream will be considered further within WS3 to characterise the barriers and opportunities to improve the measurement of climate change impacts on the transport system and provide high-level recommendations to close those gaps.

---

KPMG was a Subcontractor to Mott Macdonald for this study and contributed to stakeholder engagement to inform the research and analysis.

# 1 Introduction

## 1.1 Project and Workstream Background

### 1.1.1 Policy Context

Under the Climate Change Act (2008), the UK Government is required to assess the risks and opportunities posed by climate change, and how to best adapt to them. The act mandates the publication of a UK Climate Change Risk Assessment (CCRA) every five years, with an accompanying National Adaptation Programme (NAP) in response. The Climate Change Act also gives powers to the UK to request that certain organisations report on how they are adapting to climate change through the Adaptation Reporting Power (ARP).

Insights provided by ARPs as well as other publications including sector-specific and organisational reports and government publications are integral to the understanding of climate change effects, responses and the outcomes of policy across the transport sector. Within ARP reports, reporting organisations are required to lay out the current and projected effects of climate change on their organisation, as well as their plans for adapting to climate change. These reports are therefore crucial to the Government's ability to monitor the effects of weather and climate change as well as the effects of mitigation and adaptation policy on critical infrastructure.

DfT maintains numerous strategic priorities related to the Climate Change Act. Its focus is on delivering greener transport by tackling climate change, improving air quality by decarbonising transport, and managing the risks to, and opportunities for, transport from climate change. In support of this DfT has developed a draft Transport Adaptation Strategy that was published in April 2024 and underwent consultation. It is currently undergoing a refresh following feedback and the July 2024 change in government<sup>4</sup>.

### 1.1.2 Project Objectives

This project will provide an understanding of the data that transport stakeholders capture to measure the overall impacts of climate related costs, damage and disruption to the transport network. It looks to understand how to measure the impact of climate change on the transport system across the whole life cycle, and the sector's resilience and adaptation. Understanding the extent and quality of climate information and data repositories will act to inform monitoring and evaluation of the outcomes and impacts of policy and provide insight into areas of information deficit. While there is considerable existing information available about how climate change impacts the transport sector and its individual networks, there is limited information available on how to measure these impacts over time at a transport mode (road, rail, aviation and maritime) or system level. Addressing these requirements will support the monitoring and evaluation of the outcomes and impacts of DfT's climate policies.

### 1.1.3 Overview of Workstreams

To address the requirements described in Section 1.1.2, the project has been broken down into three workstreams:

---

<sup>4</sup> This report was created in June 2025, and does not take into account any developments after that time period.

- **Workstream 1 (WS1):** Literature review of key weather and climate risks to / impacts on the transport system.
- **Workstream 2 (WS2):** Identifying existing DMIs used to measure key weather and climate risks to / impacts on the transport system, and
- **Workstream 3 (WS3):** Gap analysis and potential next steps for addressing gaps.

#### 1.1.4 Workstream 2 Purpose

The objective of WS2 was to identify existing DMIs being used to measure key weather and climate risks, and their impact on the transport system. To address this brief, data collected during the WS1 desktop study was supplemented by a desktop study of further relevant literature at WS2 to form the WS2 evidence base. This evidence base was used to understand the DMIs currently being measured by organisations. The evidence gathered during the desktop studies was supplemented by structured stakeholder interviews to gain richer insights into organisational data. WS2 was informed by conclusions reached at WS1, which addressed research questions (RQs):

1. What are the key weather and climate risks which impact the transport system **(RQ1.1)** and what impact do they have **(RQ1.2)**?
2. What metrics should ideally be collected to assess these **(RQ2)**?

WS2 employed the evidence collected through desktop-based study and 1-2-1 interviews to address RQ3:

3. What DMIs are transport sector organisations currently collecting to measure weather and climate risks? **(RQ3)**

The purpose of this report is to summarise the key findings of WS2, notably the DMIs used by organisations to measure priority hazards and impacts.

WS3 will use the outputs of WS2 (current data and metrics) and WS1 (future use of metrics) to identify gaps and outline potential next steps for improving the measurement of resilience of the transport sector.

KPMG was a Subcontractor to Mott MacDonald for this study and contributed to stakeholder engagement to inform the research and analysis.

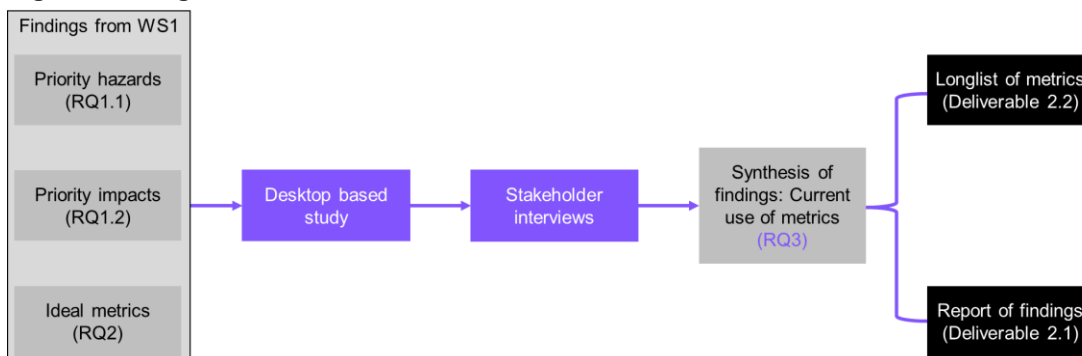
## 2 Methodology

### 2.1 Overview

Section 2 provides an overview of the methodology followed through WS2 (Figure 2.1). WS2 was conducted as follows:

- 1. Review of findings from WS1:** Findings from WS1 were considered during the method design and analysis of results at WS2. WS1 provided a conceptual framework for considering the different aspects of climate resilience. This framework has been used to group and categorise the different DMIs collected in relation to climate resilience. WS1 also provided useful context for the writing of stakeholder interview scripts.
- 2. Literature source scoping, identification & desk-based review:** Building on the source material collected at WS1, a scoping of sources of potential interest was conducted, with particular focus on collecting ARP4 reports and emerging inputs to the UK CCRA4 Technical Report (currently in preparation in support of the UK's fourth national Climate Change Risk Assessment). Twenty-three ARP4 reports were provided by DfT and were reviewed to build the evidence base for RQ3. Literature and findings from WS1 facilitated data collection and the categorisation of DMIs currently used to measure hazards and their impacts and outcomes.
- 3. Collect data:** Categorised DMIs identified through Step 2 were combined to form a longlist for Deliverable 2.2.
- 4. Stakeholder interviews:** Organisations from across the transport modes were selected for interview and an interview topic guide was prepared based on the information collected up to that point. Interview findings were recorded and collated for synthesis with findings from step 2.
- 5. Synthesis of findings:** Findings from Step 3 and stakeholder interviews were analysed to address RQ3 and inform WS3. The analysis consists of three main parts:
  - Assessing the categorised the DMIs to identify themes and trends.
  - Identifying Notable DMIs which have the potential to be used at the sector level – See Section 2.5 for further information.
  - Performing a SWOT analysis based on the information collected throughout the workstream.

Figure 2.1: High level overview of WS2



Source: Mott MacDonald. 2025

## 2.2 Interface with workstream 1

WS1 established the key weather and climate risks to the transport sector, their potential impacts on organisations' assets and operations, and the metrics that should be collected to assess these. Findings from WS1 were considered when conducting WS2, including:

- **Priority hazards** – WS1 identified priority hazards and impacts for each transport mode. However, this methodology was critiqued by stakeholders for omitting hazards significant at a local level. The collection of DMIs in WS2 was therefore not constrained by the findings of the WS1 literature review and examines metrics for all climate hazards and their associated outcomes.
- **Interdependencies and metric complexity** – Measuring and understanding interdependencies between organisations and modes was established in WS1 as crucial for building a resilient transport system. Work undertaken during the WS2 desktop study and stakeholder interviews has therefore applied focus to identifying current measures of interdependence and examined how well existing metrics account for interdependencies. Preliminary findings at WS1 identified a lack of uniformity in organisational reporting practices. WS2 has assessed the applicability of identified DMIs for cross-organisational or cross-modal applications.
- **Metric complexity (weather attribution)** – WS1 found that attribution of asset impact or outcome impacts to weather or climate related events can be challenging for organisations. These challenges stemmed from data collection limitations such as there being no data, limited data, or poor quality data demonstrating the cause of the impact. For example, asset damage may occur during a storm, but was it related to high wind speeds or poor maintenance, or a combination of the two. Or there may be weather or climate related subcontractor performance delays, but the subcontractor may not be required to report on the reason for their overruns. These challenges have been explored further during stakeholder interviews conducted at WS2.
- **Performance level** – At WS1, expected levels of service were discussed by stakeholders as unclear in some circumstances, yet crucial for the use of metrics in assessing organisational performance. WS2 has therefore endeavoured to collect information on performance metrics to understand how organisations perceive and measure their service provision against baselines.

## 2.3 Literature review

### 2.3.1 Identification of literature

The core evidence base for WS2 was collected from 27 publications, including 23 ARP4 reports (list of sources in Appendix 2: List of additional sources of data, metrics and indicators). Additionally, relevant data from the literature review conducted at WS1 was used to address research questions at WS2 (Deliverable 1.1: Appendix 1). This data was combined and used to characterise the current reporting of metrics by the transport sector in assessing climate hazards and their impacts.

### 2.3.2 Recording of literature review findings

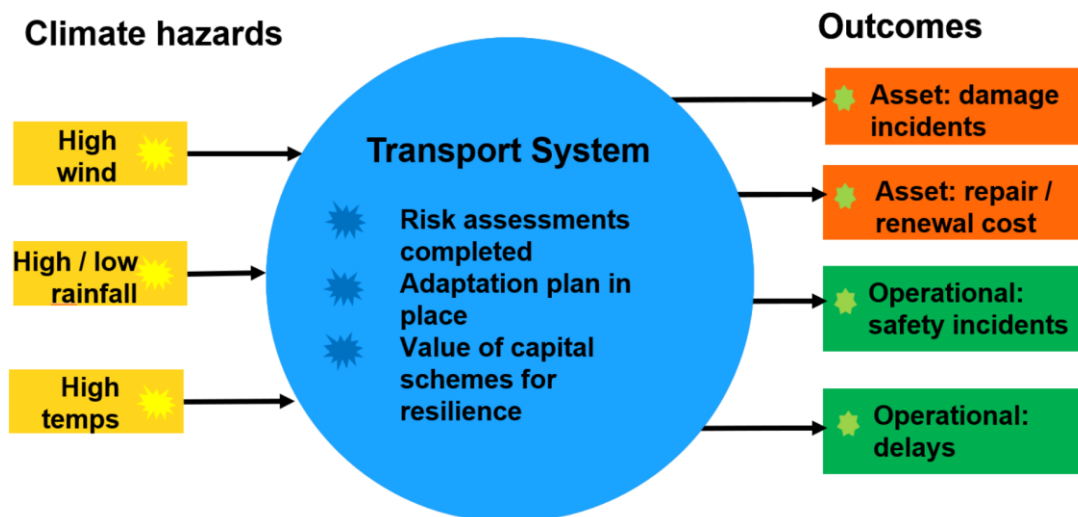
DMIs were extracted from source literature reviewed at both WS2 and WS1. A full list of DMIs identified at WS2 is contained in Deliverable 2.2. The DMI description was recorded verbatim from the sources reviewed along with the mode, report type, organisation and climate hazard in reference. This process produced a longlist of 416 DMIs, which were then categorised as relevant to either hazard metrics, asset-level outcome metrics, operational outcome metrics or feature of a resilient system metrics (Table 1) These categories of metrics were developed and

presented within WS1 in line with a systems-based approach which considered measures of climate hazards, their impacts on transport system asset and organisational outcomes, as well as features of a resilient system (Figure 2.2). Where the data, metric or indicator recorded was highly specific to an organisation (i.e. to its location assets or operations), this was noted.

**Table 1 - Metric categories, sub-categories and definitions**

Metric Category	Definition <sup>5</sup>
Hazard	Measures the extent (temporal / spatial) of climate hazards (Subcategories: <i>Incidence / Magnitude / Threshold exceedance</i> )
Asset level outcome	Measures the impact on transport assets of a hazard occurring (Subcategories: <i>Repair cost / other costs / asset condition / damage</i> )
Operational outcome	Measures the operational impact of the hazard occurring (Subcategories: <i>operational cost / delay / safety / environment / revenue / service provision</i> )
Feature of a resilient system	Measures that quantify attributes of a resilient system. Likely to be process metrics. (Subcategories: <i>risk assessment / adaptation planning / governance / investment plans</i> ) <sup>6</sup>

**Figure 2.2: Conceptual diagram of systems-based approach**



Source: Mott MacDonald, 2025

## 2.4 Interviews

### 2.4.1 Interviewees and questions

Interviewees were selected from organisations with input from DfT. A full list of interviewed organisations is in Appendix 1: List of Interviewed Organisations. The stakeholders selected represented organisations from each of the four modes. The questions were formulated to address RQ3, and therefore focused on:

<sup>5</sup> Definitions of metric subcategories are held within the glossary.

<sup>6</sup> It is recognised that these sub-categories are not exhaustive. This point is captured within Section 4 for further consideration in WS3.

- Indicators
- DMIs that are **currently** collected
- DMIs that **could** be collected
- Cross-modal and cross-sector data
- Attributes of a resilient system

**2.5 Respondents were given at least two weeks' notice of their interview, to allow time to collate relevant information from across their organisations so that they could respond to the questions holistically. Information from relevant ARP4 reports supported some interviews, as well as early responses received from stakeholders to the interview questions issued before the interview. The interviews were dynamically structured according to the relevance of each section to the organisation in question. A full list of interview questions can be found in Appendix 3: Interview questions**

### **2.5.1 Recording interview results**

Interview results were recorded for each of the questions asked in an interview template (Appendix 3), noting the DMIs referenced by interviewees. Interviewers summarised their findings in a shared format, highlighting key findings and takeaways and followed up after the interviews to try to obtain the underlying metadata.

In this report, interview findings have been synthesised to specifically respond to RQ3, and split into:

- **Current metrics:** Metrics and data that are currently being collected by organisations to assess weather or climate resilience
- **Potential metrics:** Wider metrics or data being collected by organisations for other purposes that they think could be used to assess weather and climate resilience

More general insights into organisational and modal gaps will be reported in the gap assessment within Deliverable 3.

### **2.5.2 Caveats on interview approach and findings**

- **Representation across modes:** 20 interviews were conducted – 7 from rail, 6 cross-modal, 3 from strategic roads, 1 from local roads, 2 from maritime, and 2 from aviation. This skew was expected because of the complexity of the rail industry and the value in interviewing cross-modal stakeholders given they could provide insights on multiple modes. However, fewer responses were received from maritime and aviation organisations than expected.
- **Metadata limitations:** Whilst participants had been given two weeks' notice to allow time to collate relevant information from their organisations, they noted that they did not have the time or resource to exhaustively collect all the information/metadata requested as the information sits across their complex organisations. Therefore, the information presented within Deliverables 2.1 and 2.2 should be treated as indicative, and more extensive research would have to be conducted to detail this further.
- **Representation within organisations:** Most interviewees were from climate resilience or environmental sustainability teams, although occasionally they were joined by asset management teams. None of the participants were from operational teams responsible for day-to-day operational resilience. Therefore, whilst the general finding was that most organisations collect operational rather than asset-specific data related to weather events, the metadata is therefore not as detailed for asset data as might be possible with wider involvement of asset managers and operational staff.

## 2.6 Notable DMIs

Following the completion of the literature review and interviews, the DMIs were assessed for their potential efficacy as sector-level metrics. This process identified 113 DMIs – termed Notable DMIs – suitable for potential deployment at a sector level. While criteria for suitability varies across metric categories, Notable DMIs have the potential to be used beyond a single organisation, either across the transport sector more widely, in their current form or through further generalisation. Examples and descriptions of the character of notable DMIs across metric categories is provided in Section 3.

## 2.7 Data limitations

It is important to recognise the data limitations that have been encountered during WS2. While a significant volume of publicly available documentation was reviewed, and extensive stakeholder engagement was undertaken, the volume and detail of data and information that was expected at the beginning of the project has not always been found or made available.

It was originally intended that the metadata related to DMIs would be collected and analysed to support the activities within workstream 3. However, due to less data and information being publicly available than had been expected, and stakeholder constraints limiting the information they were able to share, it has not always been possible to meet original expectations. This has resulted less metadata related to DMIs captured within D2.2.

Nevertheless, as a result of the work undertaken within this workstream, there is a much better understanding of the DMIs being collected, and the challenges and opportunities associated with collecting, analysing, and reporting them. This increased level of understanding is key to the activities that will be reported under workstream 3 and will support the development of roadmaps and potential next steps.

## 3 Literature Review and Stakeholder Interviews

### 3.1 Overview

Section 3 presents findings from the WS2 literature review in the context of findings from WS1. The findings are based on the full list of DMIs that are provided in Deliverable 2.2 and the stakeholder interviews that have taken place.

Section 3.2 provides initial hypotheses informed by the findings from WS1. Section 3.3 summarises findings on existing DMIs using the metric categories identified in WS1 supplemented by modal insights from the interviews. Section 3.4 provides a discussion of results.

### 3.2 Initial hypotheses preceding the literature review

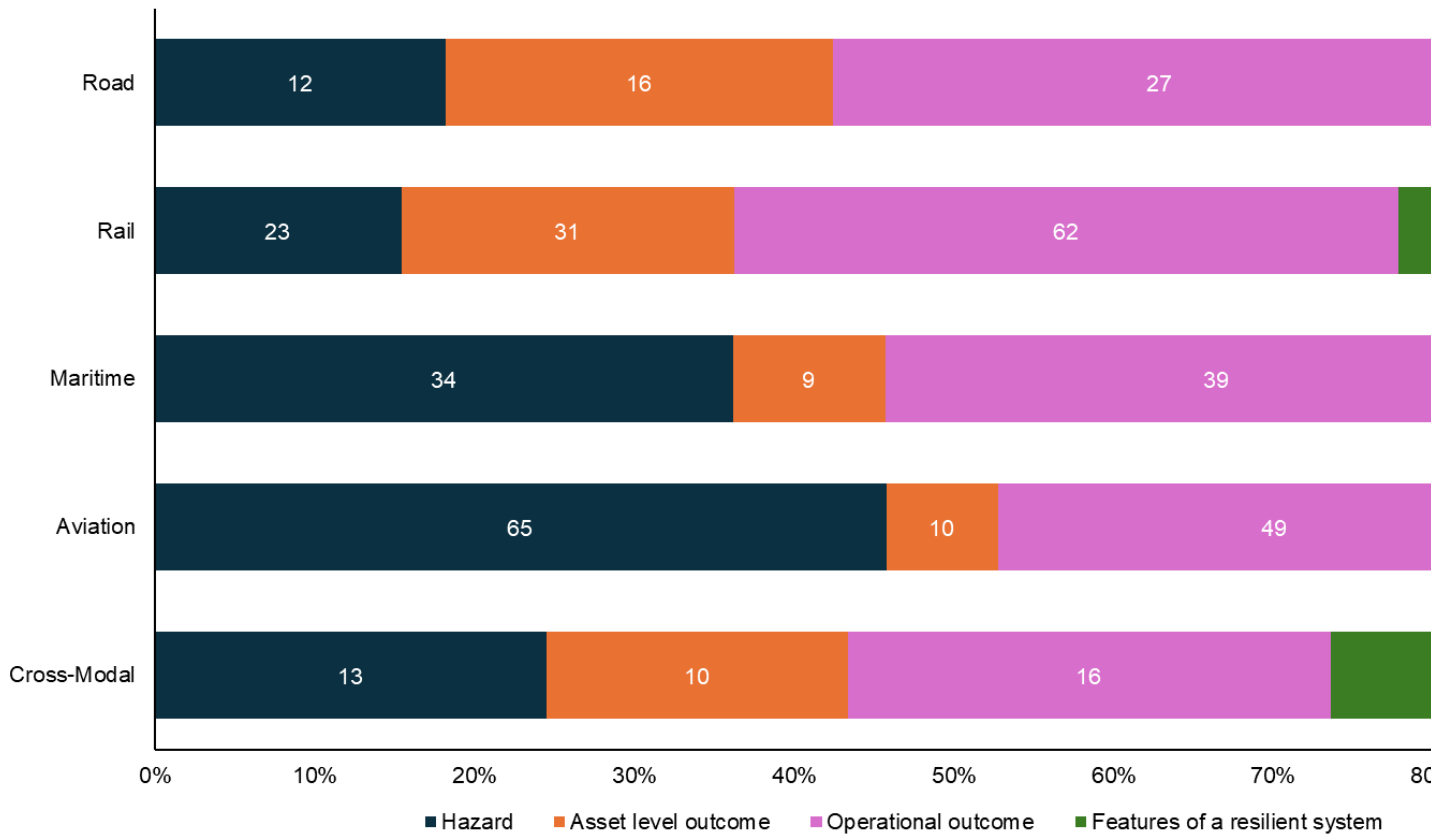
Findings from WS1 informed hypotheses preceding the WS2 literature review. A summary of these expectations can be found below:

- **Interdependence is not widely measured by organisations:** At WS1, stakeholders expressed significant interest in improving metric and data collection to facilitate assessments of interdependence between transport organisations and across modes. Based on this feedback, it was expected that the DMIs identified at WS2 would not readily present opportunities for comparison and assessment of interdependence, due to non-uniform methods of collection and reporting across the transport sector.
- **Granular weather attribution of impacts is challenging:** Organisations collect a wealth of asset-specific and operational data; however, this is not always attributable to weather events or climate change due to the challenges of attributing causality, as well as limited resources and budget.
- **Expected levels of service provision are not clearly defined:** WS1 stakeholders discussed challenges in understanding expectations of acceptable baseline performance level and acceptable performance levels during non-standard conditions such as extreme weather. Given this feedback, we did not expect metrics to provide understanding of, or standard adjustments to, baseline service expectations.
- **Metrics are organisation specific:** Due to both the natural focus of organisations on their priority climate hazards and outcomes and the significant variance of priorities across modes, geographical locations, asset types *et cetera*, current metrics were expected to be very specific at an organisational level. In association with this, metrics were also expected to be significantly varied within and between transport modes.

### 3.3 Identified metrics and associated data

Figure 3.1 shows a breakdown of the metric categories and sub-categories identified, and how they map to the systems-based approach (Figure 3.22). A full breakdown of categories and sub-categories by sector is shown in Appendix 4: Supporting graphics (Figure 5.1 and

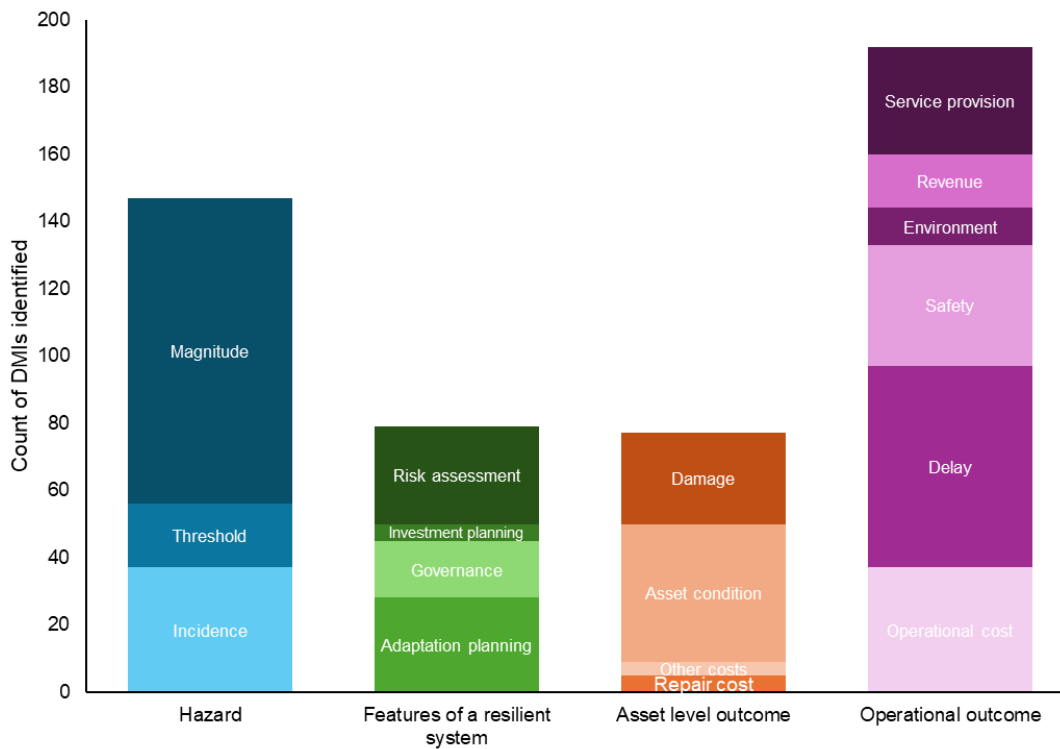
**Figure 5.1: Breakdown of metrics by category**



Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

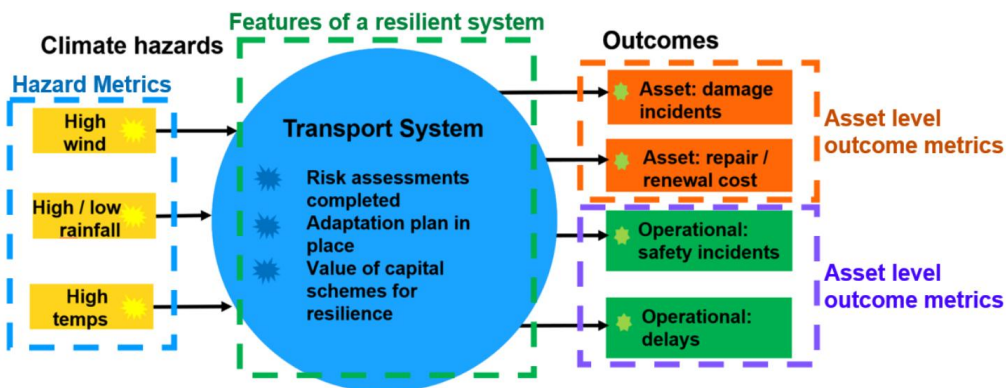
Figure 5.2Figure 5.2).

**Figure 3.1: Breakdown of DMIs identified by category and sub-category**



Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025<sup>7</sup>

**Figure 3.22: Placement of metrics in a systems-based approach**

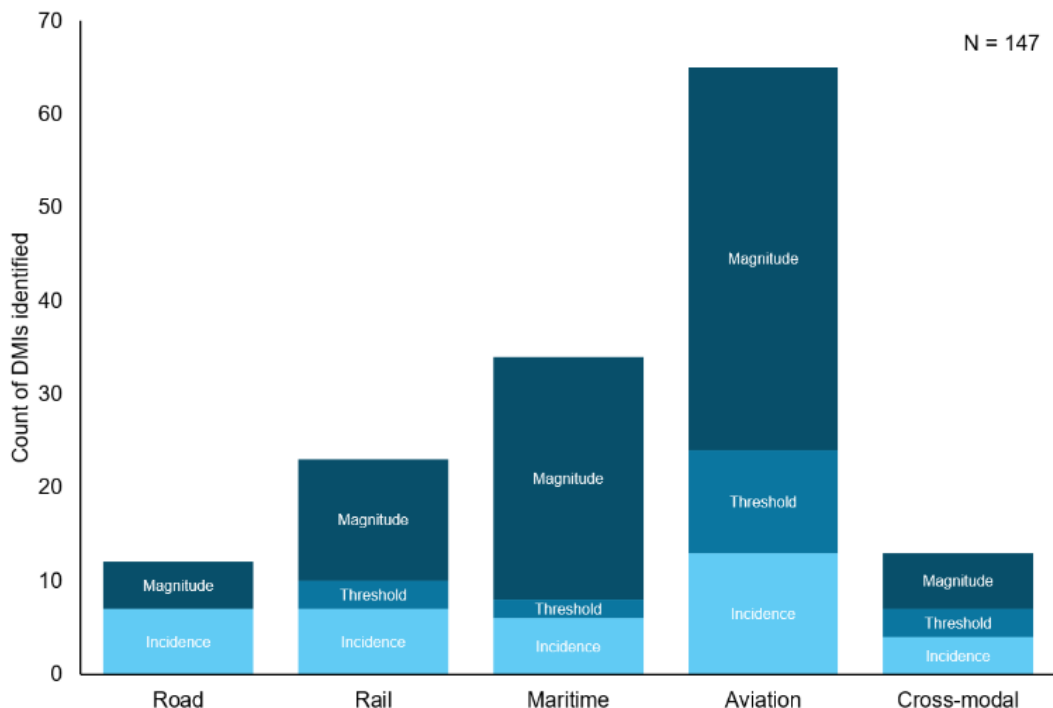


Source: Mott MacDonald, 2025

<sup>7</sup> 'Count' quantifies the total number of distinct DMIs (i.e. the number of individual DMIs from different organisations).

### 3.3.1 Hazard metrics

**Figure 3.3: Breakdown of hazard metric sub-categories by transport mode**



Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

The 147 hazard DMIs (Figure 3.1) collected demonstrated efforts by organisations to measure hazards on both spatial and temporal scales. To enable analysis, hazard DMIs were further categorised into measures of incidence, magnitude or threshold exceedances (Figure 3.3). Magnitude and threshold exceedance metrics provide organisations and policymakers with an understanding of the severity of the hazard in a set period but on their own do not provide any indication of the hazard’s impact (e.g. precipitation rate). Incidence metrics measure hazards over time and can facilitate cross-modal comparisons (e.g. number of heatwaves per year, or number of storm events per year). However, this is of limited value as individual assets, locations, and organisations need to monitor different thresholds depending on their specific vulnerabilities.

Metrics measuring the magnitude of hazards were atemporal, providing a measure of a hazard in time (e.g. windspeed, precipitation rate, temperature). Organisations used these measures in reports to describe past events, present climatic states and speculate on future conditions. The threshold exceedance metrics collected were often associated with a magnitude metric, assigning a modal- or organisation-specific threshold that, when exceeded, initiated a consequence, impact or action. These metrics were often highly specific at a regional or site level and therefore had limited utility for comparison between modes and organisations. For example: building temperature at a site location, or wind speed resulting in a port specific action.

Incidence metrics, measuring the frequency or how often a climate hazard occurs, were used by organisations to draw comparisons on a temporal scale. Incidence metrics allowed the tracking of climate hazards, most often by measuring the incidence of a threshold exceedance. These metrics, where non-specific, could be used to facilitate cross-organisational and modal

comparisons of hazards over time. However, depending on the threshold set, it may only be of significance to a limited number of assets, asset types, organisations or sub-set of organisations, limiting the value of collecting the same threshold across organisations or modes. For example, recording the number of days over 30°C could theoretically be collected by all organisations, but if only one asset has a vulnerability over 30°C, there is very limited utility in all organisations collecting that metric. Additionally, when only using current data, this type of metric is a lagging metric because it only provides information on the past. However, it could be recorded over time to see trends, or it could be coupled with climate projection data to see whether the incidence frequency increases under different climate scenarios, which would provide an indication of how conditions may change in the future.

Table 2 provides specific insights from interviews with organisations in each transport in relation to current and potential metrics related to hazards.

**Table 2 - Interview key findings - Hazard Metrics**

Road
<p><b>Current metrics:</b> Across the road transport mode, hazard metrics collected are often part of operational monitoring and planning around seasonal weather changes. In particular, winter planning constitutes a large part of the hazard level monitoring both for the Strategic Road Network and for local roads – based on weather data provided by the Met Office and specialised third parties. For the SRN, the metrics captured include air temperatures, road surface temperatures as well as forecast data from the Met Office. Alongside this data, wind data is captured at specific areas (such as bridges) that are susceptible to extreme winds. Some local authorities collect weather data which is specific to the relevant weather condition in their areas – for example, on flood warnings. However, the relevance of hazard metrics for different local authorities depends on the specific geography and topography.</p> <p><b>Potential metrics:</b> For both the SRN and local roads, some experts felt that hazard metrics could potentially be combined with other operational or asset level metrics to generate insights into weather or climate resilience for example, how weather events specifically impact road conditions like potholes or drainage.</p>
Rail
<p><b>Current metrics:</b> Several organisations within the rail transport mode, in particular rail asset managers, collect some data on weather events as part of their operational planning and asset management – flooding risks and high temperatures were noted as the most relevant hazards.</p> <p><b>Potential metrics:</b> The rail transport mode is increasingly recognising the need to develop more comprehensive hazard data collection systems to understand the long-term impacts of climate change on infrastructure, assets, and operations. This may include additional training for staff on reporting of weather-related incidents or increasing asset-monitoring capabilities.</p>
Maritime
<p><b>Current metrics:</b> Across the maritime industry, stakeholders were keen to highlight that as part of regular operations, maritime organisations and ports regularly track weather hazards and adjust operations accordingly. These are not currently part of explicit climate resilience planning but are integral to day-to-day adjustments and operational considerations. Both port organisations that were engaged for this work indicated that ports track weather hazards including temperatures, wave heights, wind speeds and directions and tide flows, among others. Typically, there is more attention on sea level rise and storm events, and less on extreme heat and rainfall.</p> <p><b>Potential Metrics:</b> All of the weather data currently tracked and recorded within the mode can be leveraged within wider climate resilience planning. Alongside surface weather and conditions, bathymetry (underwater depth of sea floor) and geological assessments of riverbeds and change over time can form part of longer-term climate change assessment.</p>
Aviation
<p><b>Current metrics:</b> Given the criticality of weather to aviation mode operations, Air Navigation Service Provider (ANSP) stakeholders track data on extreme summer temperatures, wind speed, and flooding events, directly from the Met Office. Given the significance of historic weather-related events to the sector (such as flooding), effort has been expended by airports to monitor hazards with plans in place if certain conditions are reached.</p> <p><b>Potential metrics:</b> While airports are using live weather data in their day-to-day operations, this data and the impacts it has on operations is not necessarily stored and analysed over time. There is the potential for this data to be leveraged further by analysing trends to understand the implications and impacts of weather and climate phenomena.</p>

As part of the desktop study, sources of climate projection and hazard data were also identified. These are provided in Deliverable 2.2. At a national level, several key sources of climate hazard data have been identified. These include: the United Kingdom Climate Projection 2018

(UKCP18) dataset; the National Flood Risk Assessment (NaFRA) flooding datasets; the Future Drainage project; the UK Climate Risk Indicators (CRI) tool; and the Future Flows and Groundwater Project. While the NaFRA dataset has only recently been published, it is expected to be used by the transport sector where relevant, alongside UKCP18 which is already routinely used across the transport sector.

UKCP18 data is available regionally at a resolution of 12km, providing larger area coverage for organisations with linear asset bases (i.e. Road and Rail), and 2.2km resolution for organisations with single site asset bases (i.e. Aviation and Maritime). Probabilistic Projection UKCP18 data is available at 25km resolution. Additional sources of climate hazard data are also provided in Deliverable 2.2 including those that are live compilations of other relevant data sources.

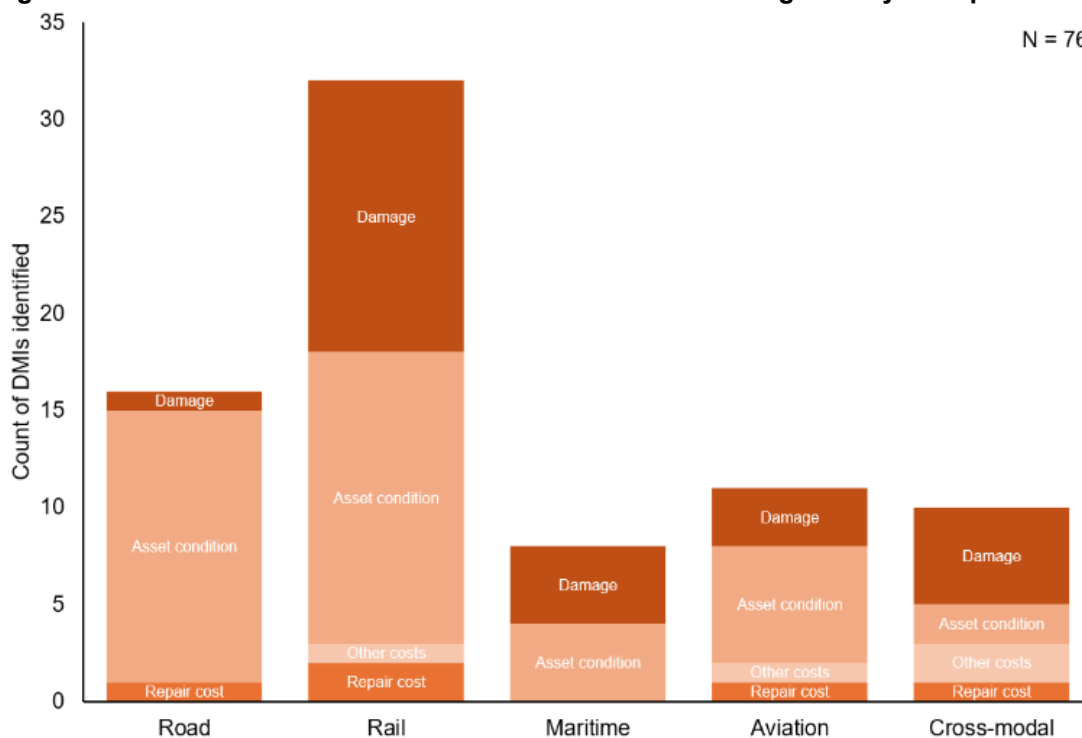
**Notable DMIs** – 12 notable hazard datasets have been identified that cover both historic and projected future climate data. Transport organisations are using data of both types when developing their hazard related DMIs. 50 notable hazard DMIs sourced data from UKCP18 projections and could feasibly be used by organisations across all modes. UKCP18 datasets project future UK climate at a maximum resolution of 12km under different climate scenarios. These datasets are key for transport organisations’ understanding of future weather conditions, their potential impact and outcomes. Projections of *wind speed; temperature increases; sea level rise; and precipitation rates etc.* were collected by organisations and used to understand future scenarios. Some organisations tested projections across different representative concentration pathways (RCPs), assessing resilience under different projections of climate scenario.

**Table 3 - Summary of notable hazard DMIs**

Notable DMI type	Commentary
<p><b>Historic Meteorological &amp; Flooding Data</b></p> <p><i>Examples:</i></p> <p><i>Average annual temperature</i></p> <p><i>Average daily precipitation rate</i></p>	<p>Datasets of historic data are useful for organisations’ understanding of performance under certain weather conditions. These datasets can be used to assess past resilience and frame the need for future adaptation.</p>
<p><b>UKCP18 Climate Projection Data</b></p> <p><i>Examples:</i></p> <p><i>Projected average daily temperature</i></p> <p><i>Projected sea-level rise</i></p>	<p>UKCP18 datasets of projected future climate are key in informing organisations on the magnitude and incidence of future hazards to inform planning and mitigation of potential impacts and outcomes.</p>

### 3.3.2 Asset level outcome metrics

**Figure 3.4: Breakdown of asset-level outcome metric sub-categories by transport mode**



Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

The majority of DMIs collected from the organisations surveyed focused on measuring outcomes at either an operational or asset level. Of these 269 DMIs, 76 measured impacts at an asset-level (Figure 3.22) focusing on quantifying repair costs, asset conditions, damage and other costs (Figure 3.4). The granularity of the metrics here differed significantly between organisations, where some organisations aggregated asset metrics to asset groups (e.g. damage to piers or stations) while others reported on individual assets (e.g. damage to bollards or track). While it would be possible to compile aggregable data on assets such as repair costs, asset conditions, damage and other costs up to a transport mode or sector level, guidance would be required to ensure uniformity in information collection and reporting practices across organisations.

Asset condition metrics were generally measured for individual assets through qualitative assessments appraising asset conditions from ‘poor’ to ‘good’, or indices ranking asset conditions on percentage scales. Qualitative asset condition metrics described asset conditions and were often aggregated to provide organisation wide insights (e.g. percentage of pavement in ‘good’ condition). Indices were also used to measure asset conditions on a 100-point scale, rating assets on their quality and condition (e.g. road quality surface condition index and structure condition index). While these asset condition metrics are useful for organisations to record and track at an individual organisational level, it may not be possible to aggregate them at a transport mode or sector level and it is unclear how their aggregation would support the determination of climate resilience without also understanding the relationship between asset condition and climate variables.

Organisations’ measurement of asset level damage metrics mainly focused on measuring incidents of damage within spatial confines or asset groups. Depreciation rates were also

considered by a small number of Aviation organisations, which allowed for a more detailed appraisal of individual asset condition. Asset level damage metrics measuring damage within spatial confines generally looked at the incidence of failure within a set boundary (e.g. length of road inundated by floodwater at a regional scale). Some metrics that looked at asset groups disregarded spatial confines and focused on impacts on asset types (e.g. number of track buckles). For these metrics to be of most use in relation to climate resilience, the damage would require attribution or collation with weather or climatic impacts.

Quantification of repair costs for specific assets and sub-assets were generally aggregated at an organisational level and were used by organisations as a proxy and description for asset damages. Measures such as flood damage repair costs and annual maintenance costs for asset groups were also compared over time to assess damage and deterioration. Similar to asset condition metrics, the current form of asset level damage metrics means that while they provide useful information on key assets within an organisation, they do not currently facilitate aggregation to provide insight at a transport mode or system level.

Table 4 provides specific insights from interviews with organisations in each transport mode in relation to current and potential metrics related to asset-level outcome metrics.

**Table 4 - Interview key findings - Asset-level outcome metrics**

Road
<p><b>Current metrics:</b> Whilst the condition of assets is monitored both for strategic roads and local roads, especially drainage capacity, structural degradation, and pavement condition, these are typically not weather-attributed. However, this data is used to understand the preparedness of the road network for flooding or high rainfall events. In some cases, weather-related drainage issues are taken out of the Performance Indicator given that this is seen to be outside the organisation's control. Some weather attribution is done post-facto for ARP4 reports. Business cases and cost analysis is typically done based on asset condition, but again this is not attributed to weather or climate resilience. Across the local road network, various local highways authorities capture information on the assets within their domain such as cycleways, footways and carriageways. In addition to specific drainage data, across the road network there is information around asset degradation (for example geotechnical embankments for bridges). While organisations are aware that asset degradation has the potential to be impacted by climate change, climate change impacts are not necessarily being factored into estimates of future asset degradation because the methods for doing so are not well established. For example, long-term degradation correlated to changes in intensity or frequency of causative factors like changing rainfall patterns impacting pothole formation.</p> <p><b>Potential metrics:</b> There is a general ambition to include weather events and climate change into predictive asset management models – e.g. the impact of weather change on geotechnical asset degradation, or wheel condition during periods of low adhesion, because it is recognised that climate change has the potential to influence degradation. It is also recognised that its inclusion may strengthen the case for long-term investment were it to show greater benefits for earlier intervention or higher levels of resilience. However, at the time of the interview there were no definitive plans in place to integrate climate change into the predictive asset management models.</p>
Rail
<p><b>Current metrics:</b> The rail mode has some understanding of the impacts of climate change on its assets, however, the metrics in place largely focus on operations. One rail asset manager measures performance of assets in extreme weather generally, whilst another specifically considers number of weather-related failures related to Overhead Line Equipment systems. One Train Operating Company tracks data on train wheel condition although this data is not specifically linked to climate resilience. This organisation also measures air-conditioning functionality in high temperature conditions.</p> <p><b>Potential metrics:</b> Asset managers tend to track very detailed data on their assets, including points failures, signalling failures, track faults, traction power failures, and non-traction power supply failures, which could potentially be linked to weather events in order to guide investment planning and predictive asset management. At a modal level, there is some spend data on renewals and refurbishment, and on time taken to rectify faults; however, this is not currently weather-attributed.</p>
Maritime
<p><b>Current metrics:</b> Within the maritime transport mode, there is limited focus on the direct impact of climate change on assets. While assets may be susceptible to long term changes, most notably sea level rise and consequent storm impacts, there were no specific asset level metrics associated with this. One port captures some of the asset-level effects of climate change within their Risk Assessment, however there was no specific asset-level data available.</p>

**Potential metrics:** The port organisations expressed that climate change adaptation is often factored into construction or maintenance of ports in the design and planning process, but there are no specific metrics to track how assets are having to be adapted to climate change or weather events.

**Aviation**

**Current Metrics:** The aviation transport mode is primarily focused on operational metrics related to weather events, such as delays and disruptions. ANSPs track incidents where technical assets have failed, but attributing causality to weather events can be challenging. This data provides insights into the performance of assets in different weather conditions. Some airports have been examining historical data to assess the past impact of hazards (e.g. temperature thresholds) on the tarmac, their vehicle fleet, and buildings. They are also using flood model outputs of potential future flood zones to assess potential future building damage.

**Potential Metrics:** The familiarity of the sector with weather data and its impact on performance coupled with the aim of some airports to integrate climate resilience within asset management plans could result in the development of asset level outcome metrics related to damage, costs and degradation. Some efforts are underway at airports due to Taskforce on Climate-related Financial Disclosure (TCFD) requirements to quantify the financial impact of climate risks on assets, although this is a 'journey'.

**Notable DMIs –** Ten notable asset-level DMIs were identified, 6 of which measured weather-attributed damage, and repair costs to assets (e.g. costs incurred due to rainfall-induced landslides, costs of damages to businesses due to delays caused by flooding, *and* flood damage to electrical equipment). These DMIs were identified as notable since they could be tracked over time and facilitate comparison between organisations. Challenges persist however through variance in assets and their capital value, which may impede the utility of comparison of damage cost. The remaining four DMIs measured 'damage' and 'asset performance' with non-discrete, qualitative measures. Reporting on these metrics could be monitored and the underlying data could be tracked over time.

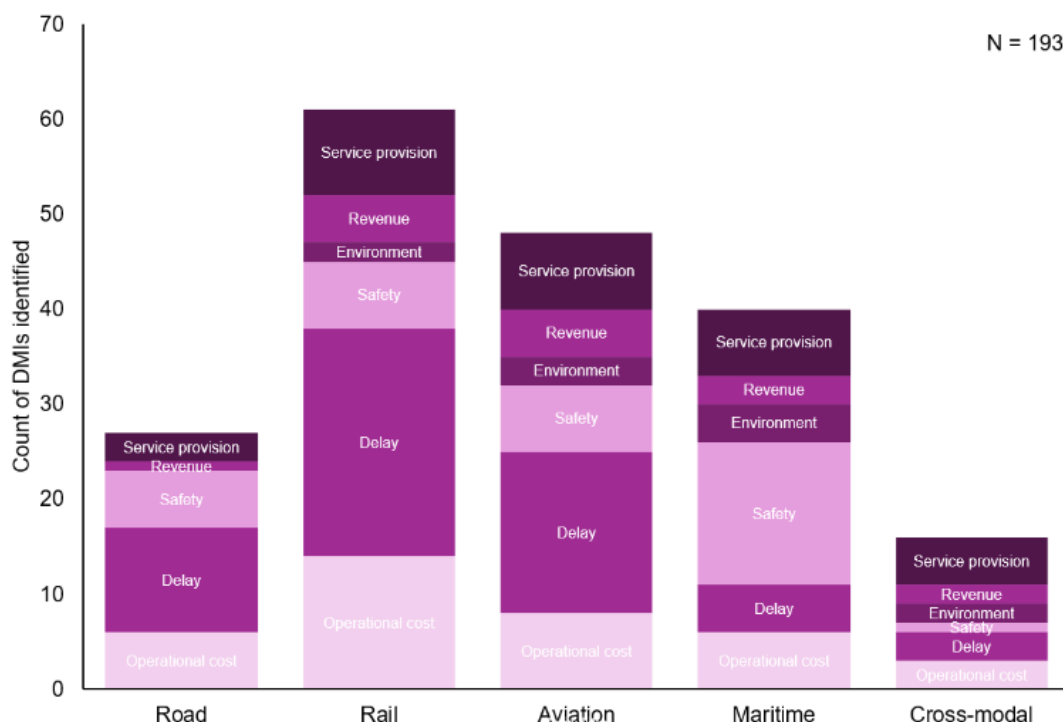
**Table 5 - Summary of notable asset-level DMIs**

Notable DMI type	Commentary
<b>Repair cost</b>	
<p><b>Asset repair cost</b></p> <p><i>Example:</i>                      Cost of flood damage to assets</p>	This lagging metric could be associated with weather data, trended and observed over time to quantify exposure to climate hazards. The underlying data could also be leveraged to inform leading cost metrics when paired with climate projection data.
<p><b>Frequency of hazard-induced damage</b></p> <p><i>Example:</i>                      Incidence of flood damage to electrical equipment</p>	This lagging metric could be trended and observed over time to quantify past exposure to climate hazards. The underlying data could also be leveraged to inform future exposure, which could support the determination of potential future costs.
<b>Other costs</b>	
<p><b>Maintenance costs</b></p> <p><i>Examples:</i>                      Cost of asset surveys and maintenance</p>	This metric can be trended over time and through association with weather-data, could be used to quantify both the impacts of acute weather events and chronic changes over time.
<b>Asset condition</b>	
<p><b>Asset performance in extreme weather</b></p> <p><i>Examples:</i>                      Equipment depreciation rates                      Asset damages due to weather</p>	This lagging indicator could be trended and observed over time to quantify asset performance in extreme weather. The underlying data could also be used with climate change data to inform how the asset may perform in the future.

Damage	
<p><b>Projected damage costs</b></p> <p><i>Examples:</i></p> <p><i>Projected heatwave damage cost</i></p> <p><i>Projected flood damage cost</i></p>	<p>This leading metric could be used to identify the potential damage costs of extreme events in the future. This can be used to provide an indicative budget for adaptive actions to mitigate the risk.</p>

### 3.3.3 Operational outcome metrics

**Figure 3.5: Breakdown of operational outcome metric sub-categories by transport mode**



Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

Operational outcome DMIs (Figure 3.22) were the most widely collected. One hundred and ninety-three operational outcome DMIs were identified from the source material and categorised during analysis under: operational costs; delays; safety; environment; revenue or service provision subcategories (Figure 3.5). However, they are often not attributed to climate or weather causes.

Of these subcategories, organisations presented the most measures for delay (60 DMIs) which measured the additional time added to journeys due to climate hazards. Delays are attributed to weather and climate in some cases by organisations in each of the four modes, and were recorded by measures such as delays due to bad weather, flooding related delay minutes or port downtime due to climate hazards. Modes differed by their subject of measurement, where the aviation mode recorded flight delay, maritime recorded vessel delay etc. Expected durations of delay time also differed between transport modes (e.g. aviation organisations measure minutes, maritime organisations measure hours and days). Since delay standards and scales vary across modes, cross-modal analysis of delay metrics must be informed by the norms and standards of different transport modes, as unprocessed units of time may not facilitate fair

comparison. It is also worth noting that it is not clear in all cases as to whether the delays are within acceptable performance levels.

Safety operational metrics were used by organisations to assess the safety of their systems for staff, stakeholders and passengers. Incidents of “near miss” and “serious incident” events were measured widely by organisations in all modes for staff and passengers, with some attributing a cause such as climate hazards (e.g. near misses due to tidal conditions). Organisations were particularly interested in the impact of safety incidents on staff lost time as a way of measuring the impact of delays and costs from safety incidents. Literature reviewed for the road transport mode provided the most extensive assessments of network safety through their key safety indicators (KSIs), measuring the number of people killed or seriously injured and accident frequency rates. Safety incident data for the Aviation and Maritime sectors is recorded by the Air Accidents Investigation Branch (AAIB) and European Maritime Safety Agency (EMSA), both of which attribute weather conditions to incidents where relevant, although this data is not currently available as a dataset.

Operational metrics for different costs and varying impacts on revenue were measured and have been attributed to climate hazard causes in multiple cases. Measures of damage and disruption were quantified through measures such as annual cost of cold weather impacts, loss of landing fees and lost customer revenue.

Metrics directly measuring service provision were primarily collected by the aviation industry who quantified air-traffic movement utilisation, runway availability and aircraft load factors. Road and maritime modes also measured their service provision through measures such as incident clearance rates and pilotage service reliability. The rail sector measures accountability for shortfalls in service provision with Network Rail’s schedule 8. This mechanism attributes causes to service disruptions, including weather, infrastructure failures, maintenance, staff shortages and other causes to facilitate a cyclical compensation between Network Rail and train companies, where the party at fault reimburses the other.

Service provision metrics can provide information on organisational performance against key performance indicators. Given that performance is generally transport mode specific, this limits comparison between modes. Nevertheless, service provision has the potential to provide direct measures of climate hazard impacts for individual organisations if they have sufficiently reliable processes and data to have confidence in attribution. While some organisations may have confidence in attribution, from the documents reviewed, it is unclear whether this is the case across the transport sector.

Table 6 provides specific insights from interviews with organisations in each transport mode in relation to current and potential metrics related to operational outcome metrics.

**Table 6 - Interview key findings - Operational outcome metrics**

<b>Road</b>
<p><b>Current metrics:</b> Road transport mode stakeholders noted that weather hazards are treated as a 'leading indicator' to inform operational planning – for example, bridges are closed when wind speeds exceed certain thresholds or roads are closed due to snow. However, while hazards are monitored, road closure data is not weather attributed or tracked post facto to facilitate analysis.</p> <p><b>Potential metrics:</b> There is an opportunity to connect the data on road closures and weather causes to identify longer term resilience-planning. However, the level of weather data collected currently constrains the complexity and granularity of any analysis of its connection to closures, closure timings or failures. One cross-modal organisation has access to incident information such as road traffic collisions and road infrastructure failure, but this data is not currently being used in combination with performance data to see how incidents such as climate and weather are affecting performance. These datasets are available for at least three years, with some going back further.</p>
<b>Rail</b>

**Current metrics:** Across the rail transport mode, operational outcome metrics are primarily focused on measuring delays and disruptions caused by weather events. Both infrastructure managers and TOCs capture delay minutes associated with weather-related incidents, but attribution and geolocation can be challenging due to data variability and quality, as well as organisational differences in reporting practices.

Financial metrics tend to be relatively advanced in some organisations, which calculate weather-related compensation costs, financial loss due to severe weather events, and lost customer revenue. However, in relation to material, asset and staff costs, the organisations interviewed reported challenges with being able to attribute a cost to a particular event as the available information does not always disaggregate the underlying reason such as routine maintenance or flood damage.

**Potential metrics:** As stated under 'asset level outcome metrics', some organisations track data on points failures, signalling failures, track faults, traction power failures, and non-traction power supply failures that could potentially be combined with weather data and operational data to inform investment planning and predictive asset/operations management. One cross-modal organisation collects detailed data on journey times, delays on specific routes, travel card demand data capturing movement, and public transport performance – however, this is generally not combined with weather-related data.

## Maritime

**Current metrics:** The maritime transport mode is well accustomed to integrating weather into operational data and functionality. Regular recording of weather effects on critical operational outcomes is standard, with most of this information coming from the Vessel Traffic Service (VTS) but also through desktop research. The VTS data is attributed to weather, and encompasses vessel redirection, pilotage operations cancelled, red or black flags<sup>8</sup>, station closures, and international health and safety incidents. The primary challenge in using this data is that the length and duration of international journeys makes it challenging to pinpoint the impact of weather on delays.

**Potential metrics:** The VTS data, among other data on delays/closures/redirection can be leveraged to illustrate comprehensively and quantitatively the impact of weather events on operations and financial outcomes (including for insurance) within the mode. However, as mentioned, the quality of this data and attribution is a challenge and wider modal approaches to climate resilience are potentially curtailed due to the competitive nature of operations and varying business models, with multiple ports that are less willing to collaborate.

Given the high level of general resilience within the ports system, it was also highlighted that between potential resilience performance metrics of port closures and people, or freight delayed, the latter potentially provides richer insights as it could give more clarity on wider societal impacts.

## Aviation

**Current metrics:** The aviation transport mode is heavily reliant on weather data and forecasting to manage operations and mitigate risks. ANSPs track delay minutes caused by weather events on a daily basis and report this to their customer (airlines) and the regulator (CAA). One airport has been developing plans for passenger cooling and heating, runway de-icing, and staff needs based on weather projections. CAA also collects modal-level data on passenger movements, but this is not attributed to climate or weather events currently.

**Potential metrics:** Stakeholders are working to calculate the cost of weather-related operational delays, but this is difficult due to causality issues. The commercial team within one advanced airport tracks the impact of hazards on their operations on a relatively frequent basis and the climate resilience team is keen to use this data to inform resilience planning. 'Recovery minutes' is being considered as a metric to assess the impact of hazards on operations, but this is still being refined.

In addition to the operational outcome data sources and metrics identified above, non-weather attributed performance data were identified through the desktop study and are provided in Deliverable 2.2. These datasets were recorded as they allow insight into the type and extent of data collection by transport modes and highlight potential opportunities for future weather attribution. Extensive data is recorded for the SRN on delays, speeds and road closures. The UK Combined Aviation Authority (UKCAA) collates performance data from airports on monthly cycles, and ORR and Network Rail report on cancellation data and network and operator performance, assessed against several measures.

**Notable DMIs –** Of the thirty-four notable operational DMIs identified, 18 measured weather-attributed delays and in some cases associated cost (e.g. flooding related delay minutes, weather delay costs per year). These DMIs were identified as notable for their ability to track hazard-operational impacts over time and measure organisational service vulnerability to weather events.

<sup>8</sup> Red and black flags are used by port operators to communicate; small craft; gale; storm or hurricane warnings to vessels.

While potentially useful for comparison within a transport mode, these DMIs may be less useful for comparison between transport modes due to differences in delays (e.g. minutes and hours in rail, and hours or days in maritime). The DMIs that calculate associated cost of delays provide a useful additional indicator yet may not allow comparison between transport modes for these same reason. Ten notable operational DMIs measured revenue loss, due to weather events (e.g. cost of cold weather impacts, costs associated with weather-induced hazards). These DMIs could be useful at a sector level to track weather-attributed financial losses over time, informing business cases, and cost-benefit analyses for investment decisions. The remaining 6 notable DMIs measured recovery rates (e.g. downtime recovery rate following a storm event) and operational safety (e.g. number of weather-related near misses). These DMIs could be useful indicators of climate change resilience at a modal level.

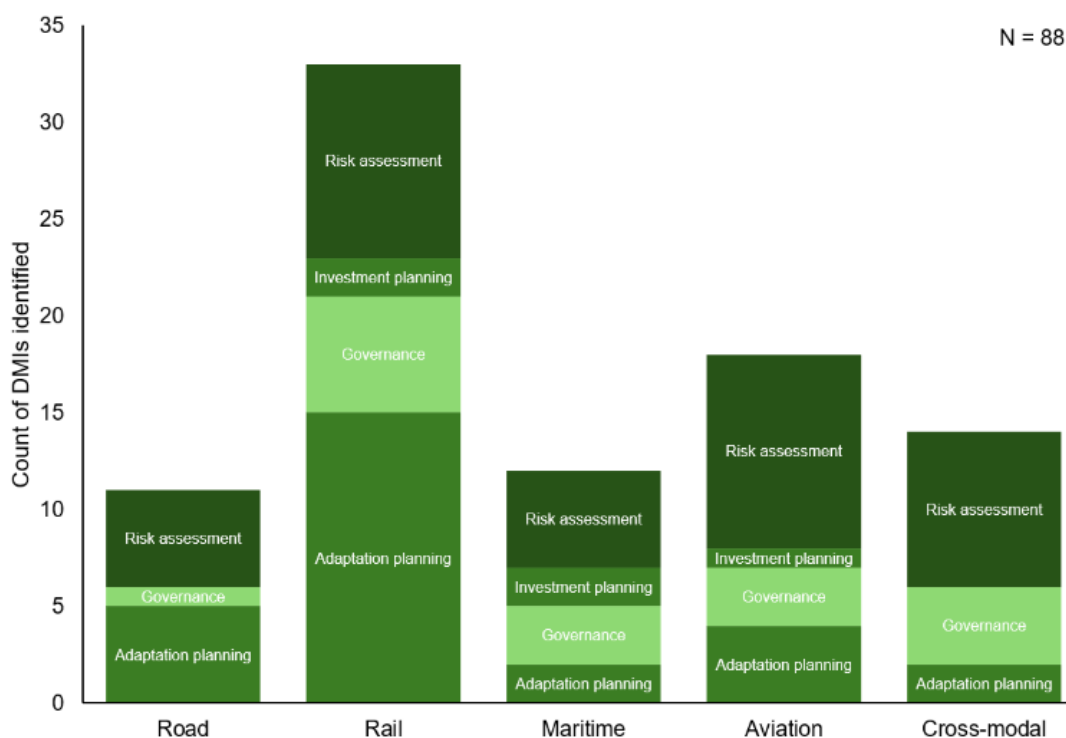
**Table 7 – Summary of notable operational DMIs**

Notable DMI type	Commentary
Operational cost	
<p><b>Weather-related delay / cancellation compensation costs</b></p> <p><b>Examples:</b></p> <p><i>Passenger compensation costs</i></p> <p><i>Schedule 8 cyclical compensation</i></p>	<p>This metric measures the compensation cost issued for delay / cancellations where weather was the cause. These are useful lagging metrics with which to measure the monetary impact of weather on performance. These DMIs could be used to inform business cases.</p>
<p><b>Costs of adaptation</b></p> <p><b>Examples:</b></p> <p><i>Cost of improvements to service provision</i></p>	<p>This metric has high potential utility for informing investment cases for the transport sector. This DMI could inform cost-benefit analyses when compared with the costs of inaction.</p>
Delay	
<p><b>Weather-delay attribution</b></p> <p><b>Examples:</b></p> <p><i>Delay Attribution Service</i></p> <p><i>Flooding related delay minutes</i></p>	<p>Datasets for post-facto weather-attributed delay are valuable repositories of data that could be trended over time to observe trends and vulnerabilities. Data collected for these DMIs could be used to inform leading DMIs.</p>
<p><b>Weather cancellation attribution</b></p> <p><b>Examples:</b></p> <p><i>No. of cancellations due to weather events</i></p>	<p>This metric measures the impact of weather on cancellations. The underlying data could be used with climate projection data to understand potential future cancellations.</p>
<p><b>Downtime due to climate events</b></p> <p><b>Examples:</b></p> <p><i>Downtime recovery rates</i></p>	<p>This is a useful metric to understand recovery, which is an important aspect of resilience. The data could be trended over time and used to understand whether performance is improving or reducing over time.</p>
Safety	
<p><b>Weather-related near misses / incidents</b></p> <p><b>Examples:</b></p> <p><i>No. minor incidents due to fog</i></p> <p><i>No. weather-related incidents on construction sites</i></p>	<p>This metric provides insight into the weather-impacts for safety on the marine mode. It could be applied more generally across the sector to understand the impact of weather on safety. Trending it over time will give an indication of performance over time.</p>
Revenue	

<p><b>Weather-related revenue loss</b></p> <p><i>Examples:</i>                  Revenue loss due to heatwaves</p>	<p>This lagging metric assigns monetary value to performance impacts, facilitating tracking of climate hazard impacts. Financial impacts can be assessed through this DMI. Coupling the underlying data with climate projection data could provide an indication of future potential weather-related revenue losses.</p>
<p>Service provision</p>	
<p><b>Avoided weather-related disruption</b></p> <p><i>Examples:</i>                  Days of avoided weather-related disruption</p>	<p>This metric measures the efficacy of adaptation actions through assumed improvements to performance. The approach has the potential to be applied more widely across the sector to measure the efficacy of adaptation.</p>

### 3.3.4 Features of a resilient system

**Figure 3.6: Breakdown of the features of a resilient system metric sub-categories by transport mode**



Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

The source material provided a variety of current DMIs (88) in relation to features of a resilient system (Figure 3.22). These DMIs were categorised by the literature review process under 4 sub-categories: risk assessments; adaptation planning; governance or investment planning<sup>9</sup> (Figure 3.6).

Risk assessments were used by organisations to assess the potential impacts of climate change on their organisations. The scope of risk assessment varied between sectors due to differing asset-bases, operational considerations and priority hazards. The scope also varied in terms of the climate scenarios and time horizons being considered, depending on the

<sup>9</sup> It is recognised that these sub-categories are not exhaustive. This point is captured within the Section 4 for further consideration in WS3.

requirements of the individual organisations. Both the spatial coverage and quantitative outputs of risk assessments were used by organisations to form metrics to assess exposure (e.g. number of assets sitting within flood risk areas). Risk assessment coverage was used to measure preparedness and awareness of risk (e.g. the use of risk ratings for runways, climate change design impact assessments and risk management software). Reporting on the coverage of risk assessment allowed for the identification of blind spots in resilience building efforts. The outputs of risk assessments were also used by organisations to understand exposures of asset groups or geographical areas. Quantitative measures such as number of high-risk ports with long term flood risk plans, or percentage of UK rail network at risk of landslides provided insight into the magnitude and extent of organisational exposure to climate change. Some organisations also measured changes in the number of risks identified by risk assessments over time as indicators of improved awareness and proactive planning.

Measures of adaptation planning were used by organisations to assess their preparedness to climate and weather hazards and to measure the extent of their adaptive action. While these measures were generally not quantitative nor explicitly metrics, they nonetheless provided measures of system resilience. Some organisations measured adaptation through quantitative metrics such as estimates of adaptation cost and number of resilience elements addressed in their planning documents, yet indirect, non-quantitative measures of adaptation planning were more commonplace in the source material (e.g. level of engineered redundancy, the development of emergency plans and continual monitoring & management systems). Organisations demonstrated their success in adaptation planning through listing their operational practices such as crisis management manuals, severe weather plans and flood management planning. While these were rarely used in quantitative estimations of system resilience, the coverage of strategies and interventions aimed at integrating climate change adaptation within their processes and activities (such as updating design standards to include climate change) can provide insight into organisational resilience.

DMIs relating to governance captured established operating procedures and guidelines set and adhered to by organisations. Again, these measures were generally non-quantitative and measured actions such as risk register maintenance, monitoring practices and system modularity assessments measuring the degree to which components of a system can be separated or integrated without any change to other aspects of the system<sup>10</sup>.

DMIs for investment planning measured the extent or value of investments made on climate resilience. Very few investment planning DMIs were identified, highlighting that this may be a relatively immature area within the transport sector. One organisation quantified their investment in climate change adaptation, and another measured their capital investment in resilience. These DMIs provide valuable points for comparison between organisations and sectors and would be useful for cost-benefit analyses for resilience planning.

Table 8 provides specific insights from interviews with organisations in each transport in relation to current and potential metrics related to features of a resilient system.

**Table 8 - Interview key findings - Features of a resilient system**

Road
<p><b>Current metrics:</b> National Highways has produced several ARPs, hired climate resilience specialists, and incorporated severe weather events as part of its resilience planning, as demonstrated by its ARPs. Local authorities tend to be at different levels of maturity in resilience planning – for example, one has done a detailed review of highway services with regard to weather resilience, and some have submitted ARP reports. However, this cannot be generalised as the focus at the local authority level has been on net zero rather than on climate resilience.</p>

<sup>10</sup> ITF (2024, *Transport System Resilience: Summary and Conclusions*, ITF Roundtable Reports, No. 194, OECD Publishing, Paris.

**Potential metrics:** In general, climate and weather risks are not necessarily currently included as a principal risk within asset level risk registers or asset management strategies, and as discussed under operational metrics, incident response planning does not explicitly include weather and climate considerations. Road organisations could report on the percentage of their risk registers, asset management strategies or incident response plans that consider climate change. Aggregating this data at the modal level could give individual metric showing the percentage of the road sector which has integrated climate change within risk registers, asset management strategies and incident response plans. This could be tracked over time to show progress and identify whether further policy intervention was necessary in this area.

**Interdependencies:** The road transport mode is highly interdependent, both across highways organisations (national and local highways authorities) where closures of one network often result in diversion onto another; or where key routes, for instance for haulage, operate across local authority highway networks. This degree of interdependency is also reflected across modes, where often rail closures will move traffic toward the road network. In extreme weather events, the challenges on local roads may be compounded by additional usage due to rail cancellations. Beyond transport, the road network is important for emergency response services, as well as the provision and distribution of essential health services, for instance, blood banks. As such, cooperation beyond the road network is necessary for holistic adaptation planning for severe weather events and risks.

There is some degree of information-sharing across modes and sectors. For example, there are Local Resilience Forums (LRFs) including representatives from local highways authorities and the SRN which allow for annual strategic planning. There is also the cross-modal Infrastructure Operators Adaptation Forum in which the road transport mode participates.

## Rail

**Current metrics:** The rail transport mode stakeholders who were interviewed are building out climate resilient capabilities to differing degrees. Many organisations conduct regular and periodic adaptation reports (ARPs) to Defra that set the framework for network-wide adaptation plans and risk assessment. The five regions of the network also submit Weather Resilience and Climate Change Adaptation (WRCCA) plans over five-year windows which provide a view of asset risks and weather resilience plans. The ORR has a dedicated team with a focus on sustainability, however resource availability is constrained by 5-year mandates which govern the organisation's focus and resourcing. TOCs may have small teams focused on sustainability that undertake ad-hoc resilience planning. Some infrastructure managers capture resilience KPIs in adaptation reporting.

**Potential metrics:** Despite existing adaptation initiatives, there were still a number of areas where rail stakeholders expressed opportunities for deeper resilience planning. One cross-modal organisation explained that they measure performance in terms of implementation of adaptation plans which is captured within their overall organisational performance scorecard. The organisation reported that they have multiple sources of incident reporting, but the data is not practically usable because of its collection and storage in different systems with no central aggregation of data. They also cited issues with incident reporting quality. The organisation does have a database of ticketing and travel card data from which insights on performance could be inferred. Private rolling stock operators expected to be driven by regulatory requirements and the direction of the infrastructure asset managers on what resilience metrics to consider, and how to integrate this into their strategic planning. However, operators of rolling stock recognise the risk to depot locations, a concern echoed by TOCs. Opportunities to track the risk of specific sites and plan for potential hazards, namely, flood risk, would be applicable to many stakeholders in the industry. Furthermore, TOCs noted that in their role, they act as a liaison between the infrastructure asset manager and the communities they serve.

**Interdependencies:** The rail transport mode is highly interconnected, and the performance of one part of the network can have significant impacts on other parts of the network. Data sharing and collaboration between different rail organisations are crucial to better understand the impact of climate change on the rail network. Currently, TOCs typically report on operational metrics to Network Rail, which serves as a data aggregator. This includes cancellations and delay data, which is a crucial performance and financial indicator of weather impact across the network.

There is some information-sharing across modes (for example, TfL and Network Rail have just signed an MOU). However, most stakeholders interviewed felt that more could be done across modes and other infrastructure sectors if there was more capacity.

## Maritime

**Current metrics:** Port operators have varying approaches to weather and climate resilience – as noted above, ports often integrate resilience into regular operations and do not have specific plans. However, the interviewed organisations do incorporate adaptation planning into their activities. One organisation is compiling an extensive risk register as part of adaptation planning and conducting training to understand the effects of climate change on the organisation's business model and safety.

One stakeholder also noted that within the maritime transport mode, there is generally a high level of resilience through redundancy. For example, if a single port closes for a short period of time, cargo ships can be rerouted to other ports. However, some ports are more significant in terms of the impacts if they close so they may require higher levels of resilience to ensure those impacts do not materialise

**Potential metrics:** Interviews highlighted significant variation across the maritime transport mode in terms of the organisational structures that have oversight and governance of a port. In many locations, the historic and complex nature of these organisational arrangements limit the data that is and can be collected, compiled and analysed to support reporting on climate adaptation and resilience. This must be factored into the development of resilience metrics for the transport mode as the impacted organisations may need time to develop and set up the arrangements that will support the collection of the required data necessary to report resilience metrics.

**Interdependencies:** The ports within specific regions (for instance along the Thames) may be in competition for customers, but at the same time face common challenges that incentivise collaboration, and therefore they share some operational data between them. There is also some data-sharing between port authorities and highway authorities (e.g. Operation Brock) which could be extended to weather events.

The mode at large is a critical entry point for goods and constitutes a significant part of regional and national economies, however, to date there has been little examination of interdependencies both within the mode, as well as with other modes, through a climate resilience lens.

## Aviation

**Current metrics:** One organisation with relatively advanced climate resilience strategies captures climate risk in both enterprise and asset-level registers and has a flood tool that supports mitigation of flood risks. It also uses a composite score to assess the relevant environmental 'efficiency' of flights by comparing each flight path to the 'ideal' flight path. This captures weather-related information to some extent but has the potential to be expanded. In another organisation, their relatively advanced capabilities evolved as a result of having experienced significant consequences from a past severe weather event rather than a coordinated effort to measure and improve the integration of resilience within their normal business practices. They are in the process of incorporating climate change considerations within their technical standards and asset management plans. Some advanced airports have been focusing on climate risk, ensuring that this is factored into the strategic risk register with an accountable owner. One airport has also been reviewing different policies (e.g. health & safety) to consider how climate change may impact them. From a capability perspective, international initiatives like EACA or knowledge-sharing with European airports tends to be very useful.

**Potential metrics:** In general, climate resilience capabilities tend to vary widely across organisations. Whilst some advanced airports have discrete teams, they are keen to embed climate resilience into wider policy and strategy. Less mature organisations are keen to expand their capability.

**Interdependencies:** Within the mode, there is a good level of information-sharing. ANSPs share delay data with airlines and CAA, and also meet with Eurocontrol and other ANSPs to discuss climate risk and sustainability. Airports share their high-level adaptation plans with ANSPs although there are commercial sensitivities at play. Airports tend to have strong resilience networks where they consider operational plans during extreme weather events

Highway authorities, local authorities and airports also share operational data about incidents with each other although these are not weather-specific or weather-attributed. One airport mentioned that whilst they had received some data on delays from rail authorities, this was not sufficient for drawing conclusions. There is a desire to have more data sharing with utility companies, but this is not in place yet and formats have to be agreed.

**Notable DMIs –** Nineteen notable DMIs measuring features of resilience were identified, the majority of which measured aspects of people capabilities (e.g. number of teams briefed on climate resilience, *and* presence of dedicated team for climate resilience) and processes (e.g. ARP reporting and CCRAs). These indicators were identified as notable for their utility as mechanisms for measuring organisational ability to adapt to climate change and investment in resilience. Both measures of people and processes could be aggregated at a sector level to indicate modal or sector-level resilience. Some organisations also provided measures of absorptive and restorative capacity, measuring the ability of their systems to recover to original levels of service following a climate shock. These DMIs could provide valuable metrics for resilience if consistent methodologies of assessment were used across the sector. Some forward-looking cost DMIs were also identified as notable (e.g. adaptation costs), for their utility in cost-benefit analyses through climate and adaptation scenario comparisons.

**Table 9 - Summary of notable features of a resilient system DMIs**

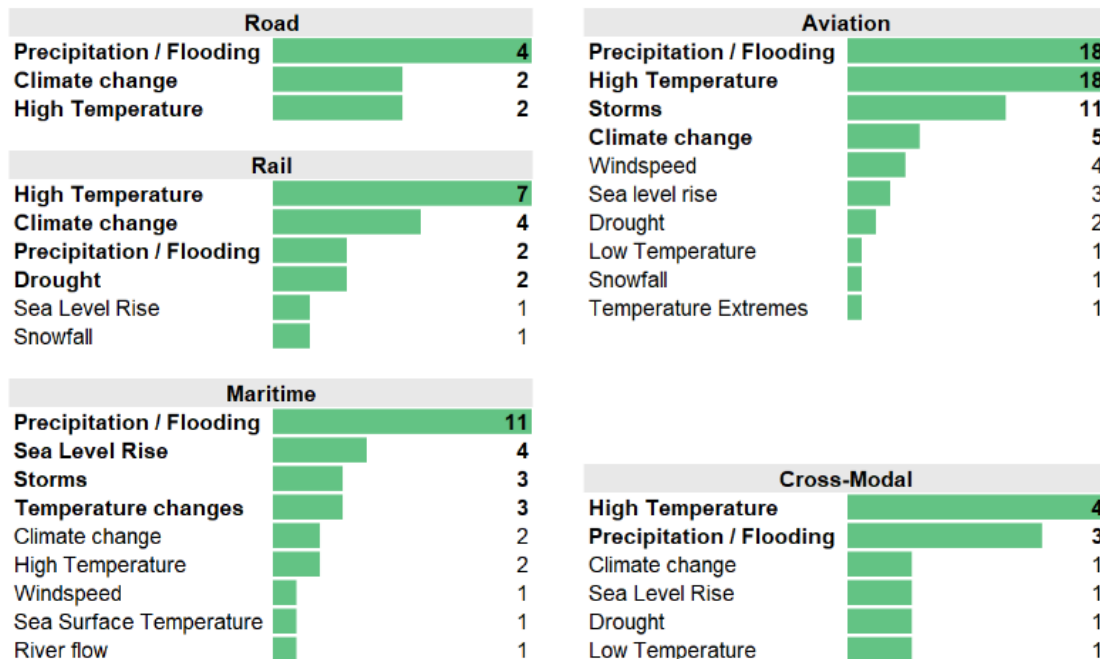
Notable DMI type	Commentary
Risk assessment	
<b>Climate change risk assessment</b> <i>Examples:</i> <i>CCRA: Infrastructure and operations</i>	CCRAs demonstrate organisational considering climate impacts and resilience. The total number or percentage of organisations conducting CCRA's could form part of an aggregated sector-level dataset for resilience.
Adaptation planning	
<b>ARP reporting</b> <i>Examples:</i> <i>Number of organisations reporting through ARP</i>	ARPs demonstrate which organisations are developing adaptation plans and actions using their climate change risk assessments. It is also useful indicator showing engagement in climate resilience and adaptation. The number or percentage of organisations reporting through ARP could be monitored and reported on over time.
Governance	
<b>Adaptive capacity assessment</b> <i>Examples: Adaptive capacity maturity score</i>	This indicator demonstrates an organisations ability to adjust to climate change. If consistent methodologies are used, results could be aggregated to assess adaptive capacity at a sector-level.
<b>Organisational capacity</b> <i>Examples:</i> <i>No. teams briefed on climate resilience</i> <i>Dedicated team for climate resilience</i>	This indicator provides a proxy with which to measure organisations' investment in adaptation capability.
Investment planning	
<b>Investment in climate adaptation</b> <i>Examples:</i> <i>Capital investment in climate adaptation</i>	This metric could be tracked over time to assess the capital value of adaptation action taken by organisations. Retrospective comparison of this metric with cost metrics could be used to assess the efficacy of climate adaptation investment for business cases.

### 3.3.5 Summary of literature review and stakeholder interview findings

The literature review and interviews present an overview of DMIs currently used and reported by transport organisations and shed light on metrics used for other purposes that could potentially be used in the measurement of weather and climate resilience. DMIs were categorised as measures of climate hazards, asset-level outcomes, operational outcomes and features of a resilient system. DMI focus areas were identified as those most measured by modes, and most critical to their operations in the context of identified priority hazards and outcomes.

- **Road:** DMI focus areas measure flooding, extreme temperatures, and heavy precipitation, reflecting vulnerability to ground-level weather impacts. Road organisations prioritise winter planning.
- **Rail:** DMI focus areas measure flooding, extreme temperatures, and heavy precipitation, reflecting vulnerability to ground-level weather impacts and geotechnical conditions.
- **Maritime:** DMI focus areas measure sea-level rise, coastal storms, and wave heights, addressing the specific risks to coastal infrastructure and operations.
- **Aviation:** DMI focus areas measure thunderstorms, high winds, and icing conditions, which directly affect flight safety and airport operations.

**Figure 3.7: Hazards measured by Hazard DMIs by sector**



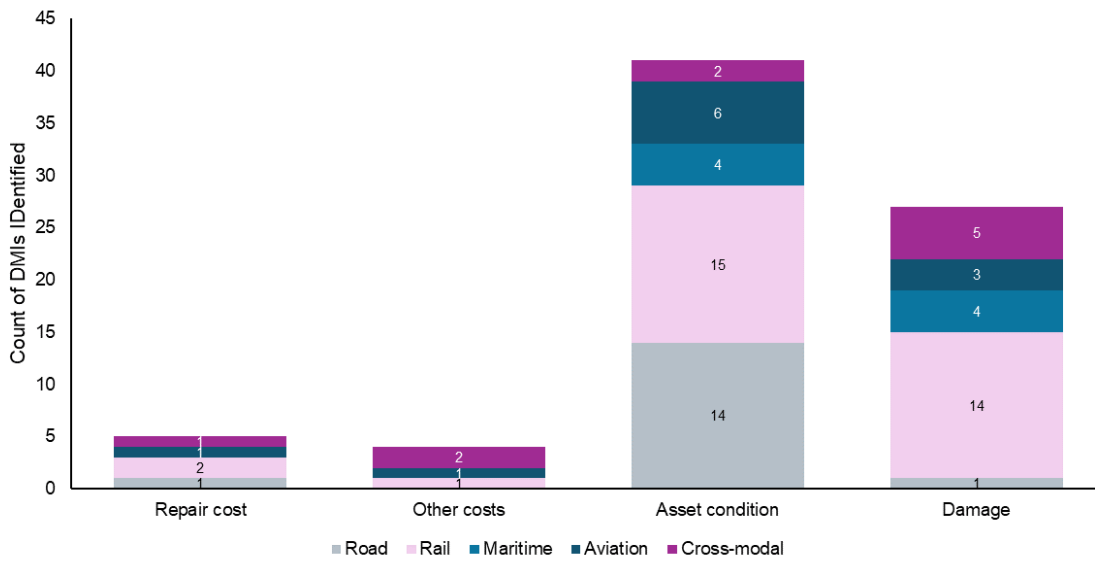
Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

Organisations choose to measure hazards according to their own specific vulnerabilities (Figure 3.7). Organisations and modes vary in terms of what, how and why they measure hazard data, making it difficult to compile and aggregate existing data at a transport mode or system level. Organisations also measure hazards for different reasons – for example, backward-looking to attribute the cause of a delay, current and near-future to plan and respond operationally to weather events, and longer-term to plan for future system adaptation and resilience. Met office data was used extensively across all modes as a source of historic data, short-term weather forecasts and climate projections (UKCP18).

**Asset Level Outcome Metrics (typically not weather-attributed)**

- **Road:** DMI focus areas measure pavement condition, drainage capacity, bridge scour, and culvert failures.
- **Rail:** DMI focus areas measure aspects of track geometry, bridge condition ratings, and signal system failures.
- **Maritime:** DMI focus areas measure the condition of port structures, navigation channel depth, and the integrity of coastal protection measures.
- **Aviation:** DMI focus areas include the condition of airport runways and taxiways, the structural integrity of airport buildings, and the performance of drainage systems.

**Figure 3.8: Asset DMIs by sector and mode**



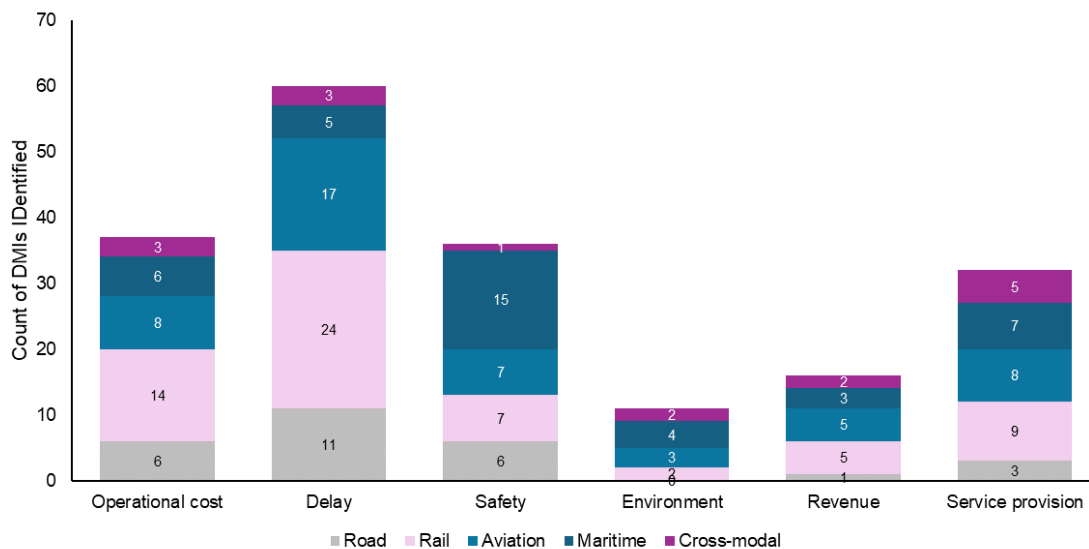
Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

Organisations do record asset-level metrics and link these to costs, though how this is done varies considerably between modes and across the transport system (Figure 3.8). For asset performance, roads primarily track exceedance of drainage capacity, and rail primarily tracks asset failures. However, these are not attributed to weather or climate change. The maritime and aviation modes have limited, or no asset-level data associated with climate and weather. These differences limit the comparability of data, and potential for aggregation beyond an individual organisational level. Across the modes, organisations said they wanted to link information on asset degradation to weather and climate change data, to inform investment planning and predictive management.

### Operational Outcome Metrics

- **Road:** DMI focus areas measure traffic delay times, road closures, and accident frequency during adverse weather.
- **Rail:** DMI focus areas measure train delays and cancellations, service disruptions, and on-time performance.
- **Maritime:** DMI focus areas measure port congestion, shipping delays, and the availability of navigation channels.
- **Aviation:** DMI focus areas measure flight delays and cancellations, diversions, and air traffic management efficiency.

**Figure 3.9: Operational DMIs by sub-sector and mode**



Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

Each mode uses operational level metrics extensively to track operational performance (Figure 3.9). Service level issues such as delays and cancellations can have major financial and regulatory impacts on transport operators. We found that most organisations tracked delay metrics, but beyond that we found significant differences between the metrics used by different transport modes, and how they are attributed to weather or climate impacts. The granularity of operational metrics was also varied, and variance in expected levels of service across organisations and modes challenges the utility of existing metrics for comparison. Some notable DMIs measuring recovery rates and operational safety were identified which may be useful for measuring performance at a modal level.

**Features of a Resilient System**

- **Road:** Considers the availability of alternative routes, the capacity of emergency response services, and public awareness.
- **Rail:** Considers the redundancy of rail lines and signalling systems, back-up power sources, and coordination among operators and responders.
- **Maritime:** Considers port capacity to handle storm surge, the availability of alternative berthing locations, and emergency response plans.
- **Aviation:** Considers back-up power systems at airports, air traffic control capacity, and coordination among stakeholders.

Features of a resilient system are examples of where the presence of an assessment, a well-implemented governance and decision-making system, or a process, has been demonstrably implemented, and provides a positive indication of an organisation's resilience to climate change impacts. These are measured by organisations largely through non-quantitative means. Risk assessments provided some quantitative estimates of exposure, both at a systems and asset-group or spatial level. Due to their largely qualitative nature, and specificity to organisations and modes, empirical comparison and analysis of interdependency would be challenging using resilience metrics alone. However, some modes have undertaken adaptive capacity assessments to track the maturity of various modal participants, which offers an example of consistent measurement and the opportunity for benchmarking. Some notable DMIs

measuring people and process capabilities were also identified, which could be used as proxies to measure investment in resilience and ability to adapt to climate change at a sector level.

**Notable DMIs**

The workstream has found that there are many DMIs collected in relation to climate resilience. The notable DMIs identified at WS2 were identified for their potential to be deployed and be effective at a sector level. A summary of these is found below:

**Table 10 - Summary of notable DMIs**

Notable DMIs	Characterisation
<b>Notable Hazard DMIs</b>	Notable hazard DMIs measured historic and projected climate data. These datasets are crucial for organisations in all modes as part of weather attribution and to improve understanding of potential future weather and climate impacts.
<b>Notable Asset-level DMIs</b>	Notable asset-level DMIs tracked asset condition, damage and associated costs over time, and were not specific to certain assets, meaning they could feasibly be aggregated at a sector-level. However, challenges at the sector level remain due to differences in asset types and attributing impacts to weather or climate events.
<b>Notable Operational DMIs</b>	Notable operational DMIs tracked operational performance, costs, delays and cancellations and revenue. These DMIs were identified as notable for their ability to track hazard-operational impacts over time, and their utility for assessment of hazard impacts on operations for all modes. These DMIs could facilitate the tracking of cost and service climate impacts on the transport sector if aggregated. It should be noted that they also rely on the ability to attribute impacts to weather or climatic causes.
<b>Notable Resilience DMIs</b>	The majority of notable resilience DMIs measured aspects of people and process capabilities. These were largely indicators that could be aggregated at a sector level as proxies for organisational capacity to adapt to climate change or investment in resilience.

## 3.4 Discussion

Based on the information and insights collected from the literature review and interviews, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis has been conducted. The strengths and weaknesses have been informed by the compiled findings that have come from individual transport sector organisations, while the resulting opportunities and threats focus on the ability of the transport sector to develop appropriate metrics and collect relevant data to assess the impact of climate change and weather events on the sector as a whole.

### Strengths (organisation-level):

These are the strengths of the organisations that have been found in relation to their assessment of the resilience of their assets and operations to weather events and climate change:

- **Hazard data:** Organisations across modes are already collecting a range of data to assess the hazards that are most relevant to their operations. Most organisations collect these from the Met Office (Appendix 4: Supporting graphics, Figure 5.3) so the data is likely to be relatively uniform, although thresholds vary by mode, geolocation, and asset type.
- **Some relevant operational data:** Many organisations are already collecting operational data at a granular level because they are held to account for operational failures (e.g. delay minutes) (Appendix 4: Supporting graphics Table 11). This data could be used with past weather or future climate (hazard) data to understand their impact on operations. Some organisations also analyse the financial impact of this operational data (e.g. revenue loss due to delays).
- **Some investment in features of resilience:** Organisations across the transport system are investing in measures that could help them become more weather and climate resilient, including procuring and developing climate resilience capability, and conducting climate risk and adaptation assessments. A high-level indicator of this is the increase in number of organisations reporting through ARP from round 3 to round 4 (Appendix 4: Supporting graphics, Figure 5.4).

### Weaknesses (organisation-level):

These are some of the challenges that organisations are facing in collecting DMIs to assess the weather and climate resilience of their assets and operations:

- **Lack of capacity:** Organisations indicated that there is a wealth of data that is collected by and stored in different parts of their organisations (e.g. asset management, operations, environment sustainability) or by their stakeholders or value chain. However, they do not always have the contractual arrangements or systems in place to access this data, or the capacity and resources to collate it effectively or even form a consolidated view of how best to use it.
- **Lack of 'leading metrics':** Most organisations collect a wealth of asset and operational data – however this is not always linked to weather data to create leading metrics. This impedes the organisations from analysing data and developing forward-looking operational responses or asset management strategies in response to specific weather events.
- **Variation in climate resilience maturity:** Across the transport sector there is large variation in climate resilience maturity. With their advanced maturity, some organisations may be better positioned to support the measurement of climate resilience while less mature organisations may require more time, resources and support to reach the same point.
- **Asset data:** There are large variations in the type and availability of asset level data across the transport organisations, which is influenced by their level of asset management maturity. Furthermore, asset performance metrics often rely on inspection data or qualitative data

which, when available, is challenging to link to weather or climate impacts (e.g. degradation over time). Additionally, differences between asset types between transport modes increases the challenge of meaningfully aggregating and comparing data between modes and across the sector.

### Opportunities (sector-level):

At a system or sector level, these are opportunities for organisations within the transport sector to leverage, as demonstrated by the interviews and literature review. Opportunities are defined here as areas where action can have a large impact. This will be the focus of Workstream 3, but initial hypotheses are summarised here:

- **Defining the metric purpose:** Before setting a metric, organisations stressed that it is important that its purpose or objective is clearly defined along with how it is intended to be used. This helps to ensure that the chosen metric will measure what is required. The challenge associated with this is increased by the complex stakeholder landscape and the different potential use cases for climate resilience metrics at the system level compared to the organisational level. Nevertheless, for climate resilience metrics to provide benefits, it is important that this is appropriately considered.
- **Defining expected levels of service:** Organisations highlighted that for weather attribution for operational metrics to be relevant and useful, it is necessary to define an 'expected level of service' under different weather conditions. Currently some organisations remove weather-attributed delays or damage from the data (for example, operational delays in the aviation transport mode or drainage/pavement condition indicators for the roads transport mode) because the weather is treated as outside their control. Defining expected levels of service or supporting the definition of expected levels of service for different modes, asset types, and weather conditions, is challenging, but a critical step in measuring resilience.
- **Metric progression:** Given the range of climate resilience maturity across the transport sector, there is the potential to progressively develop and implement metrics over time, starting with simple metrics that require less data and resources to report. As maturity develops, additional metrics could be developed and implemented alongside stakeholder engagement.
- **Asset criticality:** When considered at a systems level, individual assets have different levels of importance depending on the socio-economic services they support and whether or not there are alternatives in the system. Some transport system assets may require higher levels of resilience due to their failure having greater consequences than other parts of the system. There is an opportunity according to organisations to focus efforts on the most important parts of the system.
- **Measuring the features of system resilience:** Whilst organisations are investing in specific measures to improve their weather and climate resilience, there is an opportunity to determine the different ways this is being undertaken, to track them over time and link them to the outcomes to be achieved.
- **Assessing and measuring interdependencies:** The interviews revealed that whilst there is some data-sharing within modes (e.g. between the SRN and local highway authorities or ANSPs and airlines), organisations do not tend to share and track data across modes, and even less so, between sectors (e.g. energy and water). Information sharing between modes is most often done by climate adaptation or resilience practitioners. This shortfall is beginning to be tackled through organisational CCRA's but is still a relatively immature practice in most organisations. This topic was identified as a significant opportunity within the transport modes, between transport modes, and between sectors.

### Threats (sector-level):

These are some sector or system-wide challenges that might be barriers for the sector in developing appropriate metrics and collecting relevant data. Again, this will be the focus of Workstream 3 but initial hypotheses are summarised here:

- **Challenge of attributing causality:** It is challenging to attribute causality to specific weather events or long-term climate change when assessing asset damage or operational challenges. Similarly, it is difficult to causally link improvements in outcomes to the completion of adaptation actions.
- **Variations in data collection and reporting:** There is a wide variation among organisations in the type and format of data collected because of the variations in how weather events and hazards impact assets and operations across different modes, assets, geographies, and geotechnical features. This makes it challenging to aggregate, compile and compare data at a sectoral level. Variations in temporal and spatial aspects of collated DMIs are presented in Appendix 4: Supporting graphics (Figure 5.5).

## 4 Conclusion and Next Steps

WS2 presents its findings from a desktop-based literature review and stakeholder interviews to provide an overview of the transport sector's current use of DMIs for measuring climate change resilience.

The workstream has found that there are many DMIs collected in relation to climate resilience. Furthermore, several organisations also have existing performance data sources that could be used to inform or measure climate resilience if they were used in conjunction with past weather data or future climate data.

Analysis of the DMIs has allowed notable DMIs to be identified for their potential to be deployed at a sector level as a means of measuring resilience. Notable DMIs have been identified across all four categories of: hazards; asset-level outcomes; operational outcomes; and features of a resilient system. These notable DMIs will be considered further within WS3 for their potential to support recommendations or the closure of gaps identified within that workstream.

The information collected within WS2 has also been used to develop a SWOT analysis as a means of highlighting important themes that have emerged from the data and stakeholder engagement. The key findings from this assessment were:

**Strengths** – *Organisations across modes already collect hazard data relevant to their operations. Many also collect operational data that could be combined with hazard data to understand the impacts of hazards on operations. Across the sector organisations are investing in features of resilience by improving their climate resilience capability.*

**Weaknesses** – *While organisations have data available to them, they are often limited by their capacity to compile and assess it. This is particularly the case for asset data where the challenge is compounded by differences in asset management maturity across the sector and the challenge in attributing the impact of weather on asset conditions and outcomes. Few organisations use forward-looking metrics, which have the potential to inform adaptation strategies and plans. There is also varied climate resilience maturity within the sector, meaning different modes and organisations would benefit from different levels and types of support to enable them to measure and report on their climate resilience.*

**Opportunities** – *There are several opportunities that can be leveraged to improve the measurement of climate resilience across the sector including by clearly defining the purpose of climate resilience metrics at the sector level and by defining expected levels of service within the sector. Understanding the criticality of assets across the sector would also help to focus efforts on the most important parts of the transport system. There is an opportunity to develop the measurement of climate resilience over time by first using simple metrics that can be progressively improved. Finally, stakeholders across the sector identified that interdependencies between organisations, modes and sectors was an area where significant impactful progress could be made by improving communication channels and the mechanisms for understanding interdependent risks.*

**Threats** – *The sectors' primary threats are associated with challenges attributing weather- and climate-impacts to outcomes as well as variations in data collection and reporting between organisations across the sector. These threats increase the challenge of effectively measuring climate resilience across the transport sector.*

The findings and insights collected through this workstream will be considered further within WS3. They will be used to characterise the gaps to improve the measurement of climate change

impacts on the transport system. WS3 will use the combined evidence base of WS1 and WS2 as a set of design principles with which to define required sector-level metrics and a roadmap to achieve them. The findings and insights from WS2 SWOT analysis and notable DMIs will then also be used in the development of high-level recommendations to support the implementation of the roadmap.

# 5 Appendices

## 5.1 Appendix 1: List of Interviewed Organisations

<b>Organisation</b>
Network Rail TA
Rail Safety and Standards Board (RSSB)
Office of Rail and Road (ORR) - Rail
East West Rail
High Speed 2 (HS2)
Southeastern/Govia Thameslink Railway (GTR)
Rockrail
National Highways
UK Roads Leadership group (UKRLG)
Office of Rail and Road (ORR) - Road
British Ports Association (BPA)
Port of London
Civil Aviation Authority (CAA)
National Air Traffic Services (NATS)
Transport for London (TfL)
West Midlands Combined Authority (WMCA)
Transport for West Midlands (TfWM)
Active Travel England
Decarbonised, adaptable, climate resilient transport (DARE)
Climate Sense

## 5.2 Appendix 2: List of additional sources of data, metrics and indicators

Appendix 2 lists the 27 publications reviewed in addition to sources reviewed at WS1 for the literature review conducted at WS2, the relevant mode or sector, their type and source.

Document Name	Mode / Sector	Type	Source
<b>Forth Ports (Tilbury) Tilbury Flood Risk Summary</b>	Maritime	ARP4	Provided by DfT
<b>Gatwick Airport ARP4</b>	Air	ARP4	Provided by DfT
<b>Office of Rail and Road ARP4</b>	Rail / Road	ARP4	Provided by DfT
<b>Highlands and Islands Airports Limited ARP4</b>	Air	ARP4	Provided by DfT
<b>Climate Change Committee: CCRA4 Template 17</b>	Air / Maritime	CCRA4	Provided by DfT (from CCC)
<b>Climate Change Committee: CCRA4 Template 15</b>	Road	CCRA4	Provided by DfT (from CCC)
<b>Climate Change Committee: CCRA4 Template 16</b>	Rail	CCRA4	Provided by DfT (from CCC)
<b>National Highways ARP4: Climate Change and the strategic Road Network</b>	Road	ARP4	Provided by DfT
<b>National Highways Appendix A ARP4</b>	Road	ARP4	Provided by DfT
<b>Birmingham Airport ARP4</b>	Air	ARP4	Provided by DfT
<b>Civil Aviation Authority ARP4</b>	Air	ARP4	Provided by DfT
<b>Edinburgh Airport ARP4</b>	Air	ARP4	Provided by DfT
<b>London Luton Airport CCAR</b>	Air	CCAR	Provided by DfT
<b>NATS ARP4: Climate risk and adaptation progress report</b>	Air	ARP4	Provided by DfT
<b>NATS ARP4 Risk assessment &amp; action plan</b>	Air	ARP4	Provided by DfT
<b>Newcastle Airport ARP4</b>	Maritime	ARP4	Provided by DfT
<b>Groveport ARP4</b>	Maritime	ARP4	Provided by DfT
<b>Teesport &amp; Hartlepool ARP4</b>	Maritime	ARP4	Provided by DfT
<b>Peel Ports Group ARP4</b>	Maritime	ARP4	Provided by DfT
<b>Port of Dover ARP4</b>	Maritime	ARP4	Provided by DfT
<b>Port of London Authority ARP4</b>	Maritime	ARP4	Provided by DfT
<b>Arriva Rail London Climate Risk Assessment ARP4</b>	Rail	ARP4	Provided by DfT
<b>HS2 ARP4</b>	Rail	ARP4	Provided by DfT
<b>Network Rail ARP4</b>	Rail	ARP4	Provided by DfT
<b>South Eastern Railway ARP4</b>	Rail	ARP4	Provided by DfT
<b>TFL ARP4 (full report)</b>	Rail	ARP4	Provided by DfT
<b>TFL ARP4 (non-technical summary)</b>	Rail	ARP4	Provided by DfT

## 5.3 Appendix 3: Interview questions

### A. Indicators, Metrics and Data that are currently used to assess climate resilience

#### Simple definitions for the purpose of this study:

- **Indicator:** Calculated measure of a strategic objective that can combine different metrics
- **Metric:** Specific measures of value or quantity
- **Data:** Statistics beneath the metric

1. What indicators and metrics does your organisation currently use to specifically assess the impact of climate change and weather hazards on the resilience of your organisation/transport mode?
2. Why does your organisation use these indicators and metrics?

*Please note that these can be metrics that measure the hazard itself, the impact on assets, or the impact on operations, as shown in the example below.*

1. What data does your organisation collect to support the assessment of these indicators metrics?
2. Why does your organisation use these data?

#### Example:

Indicators	Metrics	Data points
Hazard risk	High temperatures	Number of hot days >35C over a certain period
Impact of a weather event on physical assets	Changes to physical assets Asset repair & replacement	Number of rail faults attributed to high temperatures Opex cost of repairing assets 'x' days after recorded high temperatures
Operational impact of a weather event	Delay minutes Delay costs	Number of people affected by delays on hot days Operational cost of delay (delay repay schemes, additional staff, etc.)

#### For the identified data (metadata):

1. Who is accountable/responsible for the metric, and for collecting the underlying data?
2. How is the data collected? (e.g. public online portal, subscription with a public organisation, subscription with a private organisation, another internal department, supply chain, etc.)
3. How sensitive is the data? (e.g. public, commercially sensitive)
4. Can you share any information about the cost of the data?
5. What is the spatial coverage of the data? (e.g. site-specific, asset-specific, regional, national, etc.)
6. How often is the data available? (e.g. daily, monthly, annually, etc.)
7. What date range does the data cover? (e.g. 2000-2025, etc.)
8. Are there any issues with the metrics and underlying data? (e.g. incomplete datasets, late reporting, poor geolocation, changes in definitions and boundaries, multiple disparate systems etc.)

### B. Indicators, Metrics and Data that are not currently collected or used specifically to assess climate resilience

1. What metrics would you like to use to assess the impact of climate change/weather hazards on your organisation and transport mode but are not currently?
2. What are the barriers to using these metrics?
3. What data that your organisation is currently collecting or using for other purposes could also be used to assess these potential metrics?

**C. Cross-Modal and Cross-Sector Metrics and Data**

1. What metrics and data are your organisation currently receiving from other modes to help with your response to weather events and climate change?
2. What metrics and data are your organisation currently receiving from other sectors (e.g. power, water, telecoms) to help with your response to weather events and climate change?
3. How does your organisation receive these data? (e.g. shared portal, automatic feed, ad hoc information requests, etc.)
4. What metrics and data are your organisation currently collecting and reporting to other modes to help with their response to weather events and climate change?
5. What metrics and data are your organisation currently collecting and reporting to other sectors (e.g. power, water, telecoms) to help with their response to weather events and climate change?
6. How does your organisation provide this data? (e.g. shared portal, automatic feed, ad hoc information requests, etc.)
7. What would you like to receive and report in the future?
8. What metrics and data do you think should be collected at a sector level vs. specific organisational level?

**D. Attributes of a Resilient System**

1. What adaptation and resilience measures and capabilities does your organisation have?

<b>Examples:</b>
Asset-level risk register
Regular risk assessments
Climate change risks on enterprise risk register
Climate change risks factored into business cases
Adaptation plans
Climate resilience specialists
Climate resilience training

1. Does your organisation currently assess progress of these measures and capabilities? If yes, how?
2. Does your organisation currently assess the impact of these measures and capabilities on the organisation’s response to climate change/weather events? If yes, how?

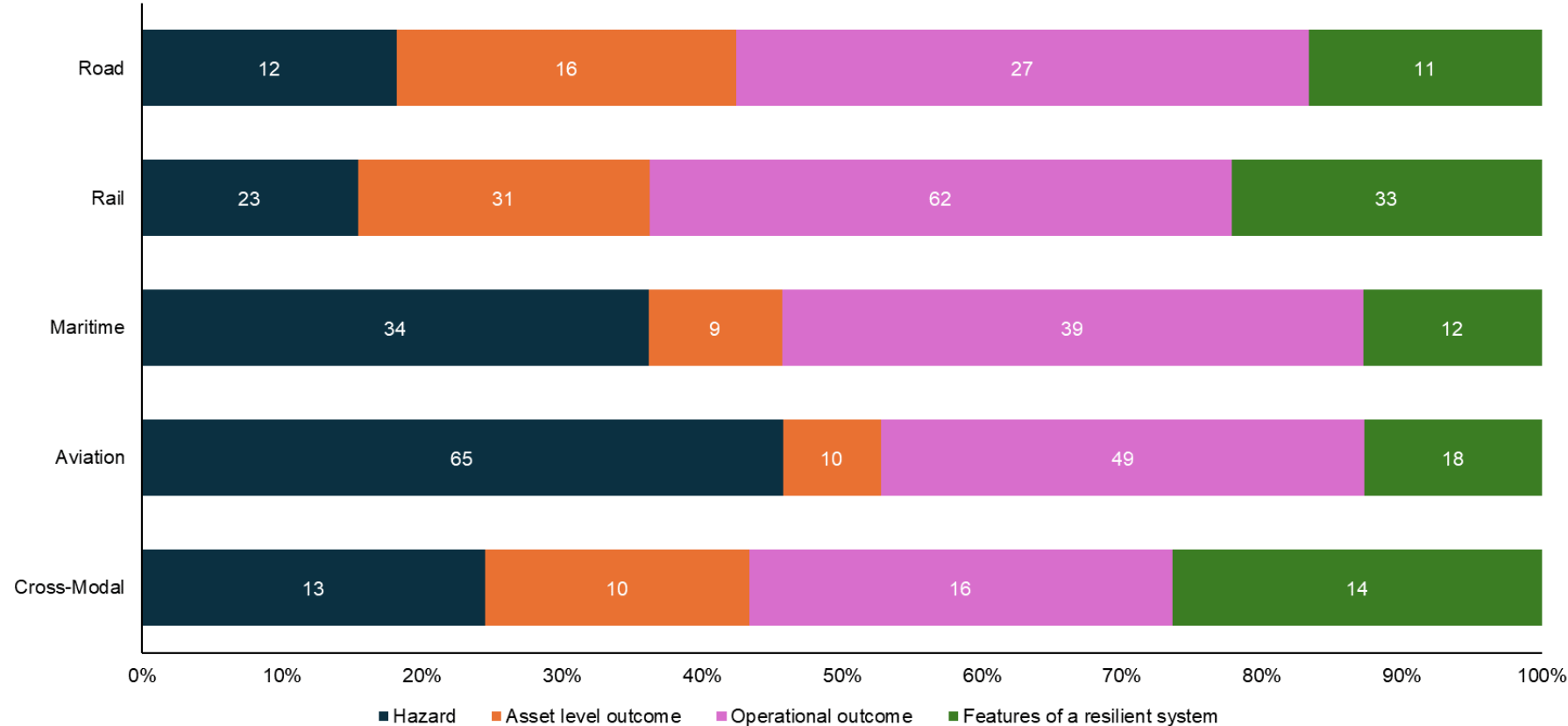
**E. Other**

1. Is there anything else you would like to share with us?

*Please feel free to email the project team for any further conversations or questions following the interview*

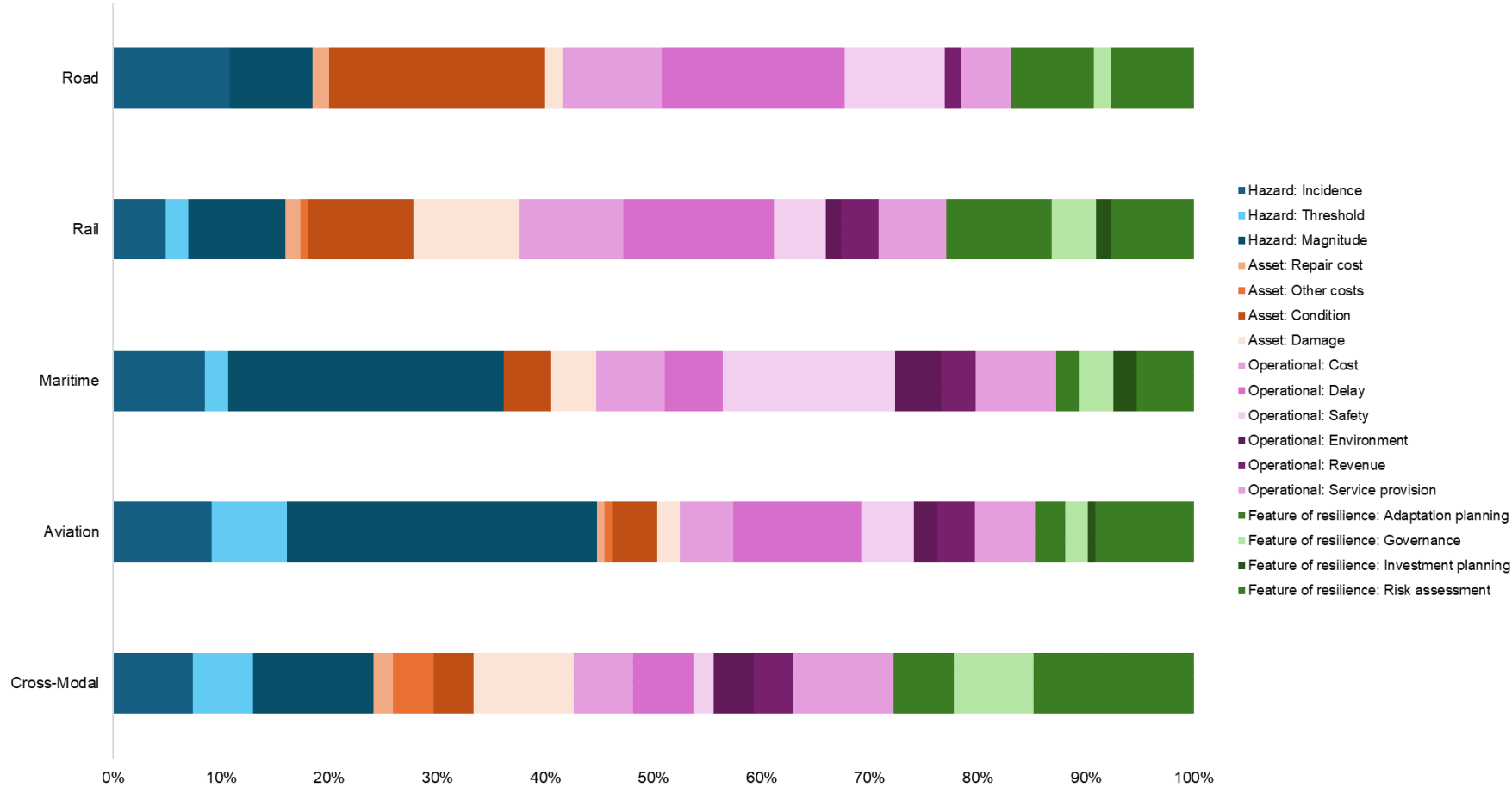
## 5.4 Appendix 4: Supporting graphics

Figure 5.1: Breakdown of metrics by category



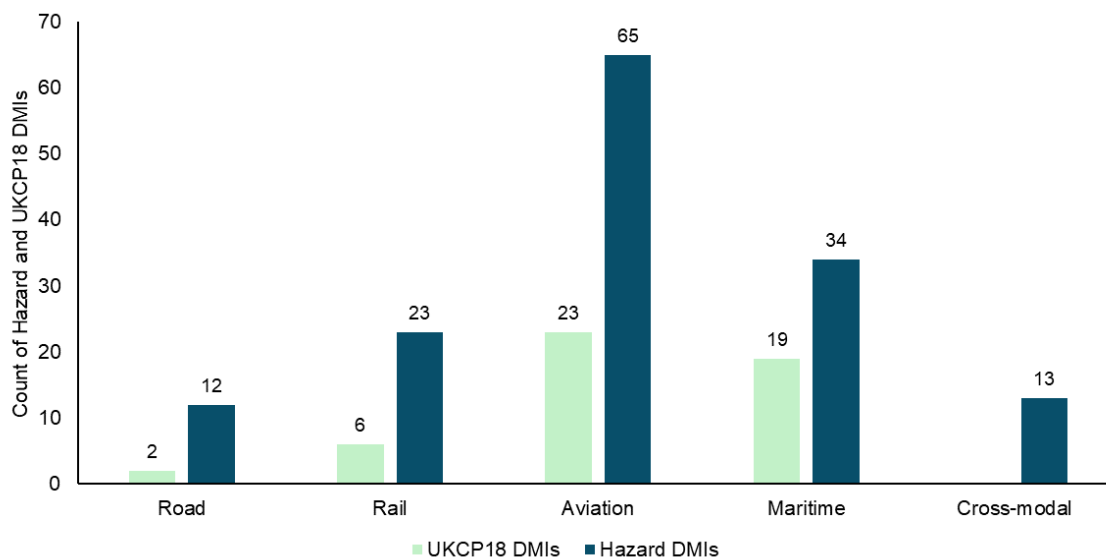
Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

Figure 5.2: Breakdown of metrics and sub-metrics by sector



Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

**Figure 5.3: Use of hazard and UKCP18 DMIs by mode**



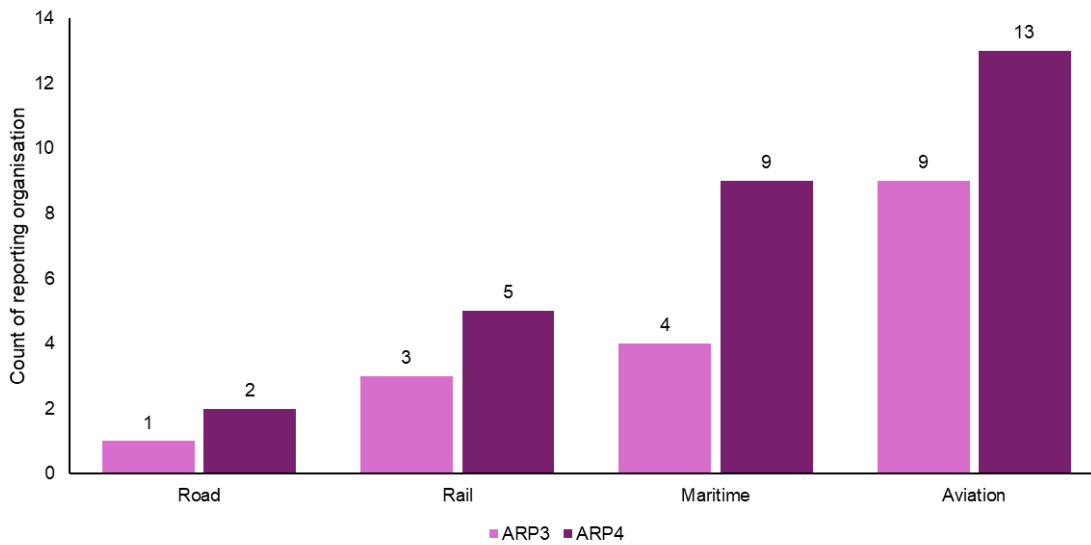
Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

**Table 11 - Performance Datasets**

Organisation	Mode	Dataset	Description
UK Civil Aviation Authority	Aviation	UK Airport Data (Monthly)	UKCAA collates data collected and reported by Airports at a monthly resolution on; passenger and freight movements; cancellations; and other performance data.
Air Accidents Investigation Branch	Aviation	Accident Reports	AAIB holds data on ongoing accidents and incidents. Where relevant, data is weather attributed, but it is unclear if this is aggregated in any way
Marine Accident Investigation Branch	Maritime	UK Shipping Accident Data	MAIB holds dataset of investigation reports into maritime incidents. Where relevant, data is weather-attributed, but it is unclear if this is aggregated in any way.
European Maritime Safety Agency	Maritime	Serious marine casualties & incidents	EMSA holds dataset of serious maritime casualties and incidents in European waters. Where relevant, data is weather-attributed and annual overviews provide totals by country and cause.
Network Rail	Rail	Schedule 8 performance data	NR collect monthly weather-attributed performance data to determine cause and responsibility for delays to manage the cyclical compensation mechanism between TOCs and NR.
Office of Rail and Road	Rail	Rail performance data	ORR collects rail data on health and safety, passenger rail performance, performance at stations, P-coded cancellation data (i.e. pre-cancellation) and data on delay compensation claims.
Network Rail	Rail	Infrastructure scorecards	NR collect data on infrastructure through bespoke 'infrastructure scorecard' system, ranking assets against 6 criteria.

Delay Attribution Board	Rail	Principles and Rules	DAB standards are used by NR in attributing responsibility for delays.
National Highways	Road	Travel time reporting tool	NH travel time reporting tool collates data at a granular level for 'average delay', 'total delay', 'reliability' 'average speed' and 'average travel time'. Data can be filtered by carriageway, road class, area code, road number and direction and is not weather attributed.
National Highways	Roads	Roadwork status	NH maintain a live dataset showing up to date and short-term forecasted status for the SRN. Dataset records closures due to roadworks. Data is not weather attributed.

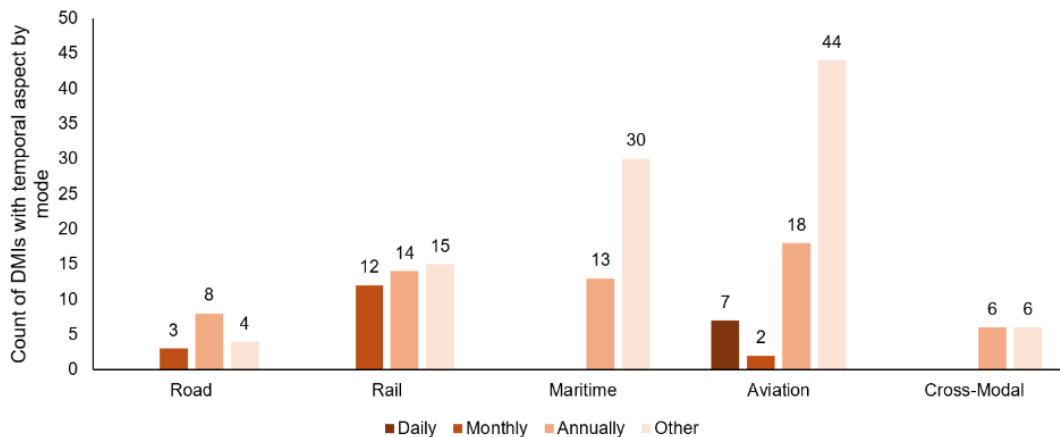
**Figure 5.4: Change in number of organisations reporting through ARP by mode**



Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

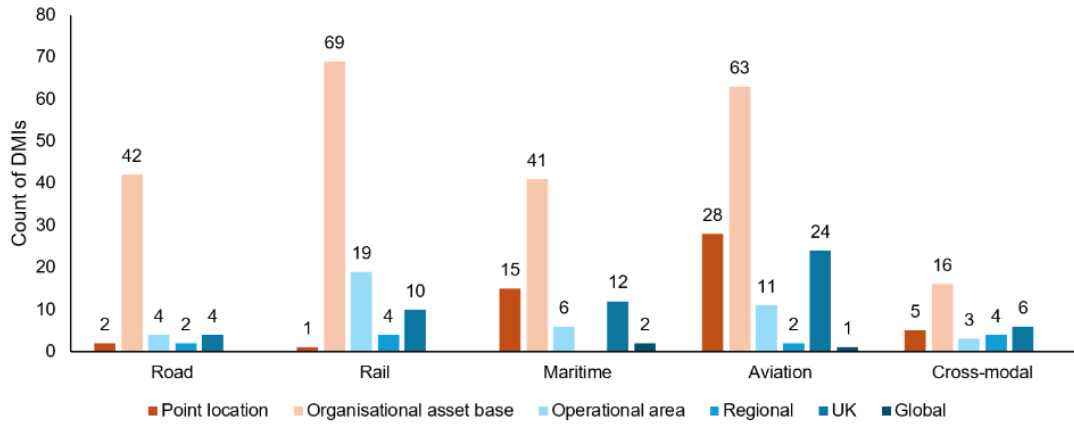
**Figure 5.5: Identified DMIs with temporal aspects by mode**

Temporal coverage of DMIs



**Summary:** Aviation and cross-modal organisations measure and aggregate some DMIs daily. The most temporally granular DMIs identified for road and rail organisations were reported at a monthly level. Of the three distinct temporal ranges, organisations across all sectors collected and reported DMIs on an annual basis the most. 'Other' temporal ranges (i.e. reporting period of >1 year) were also used extensively by organisations. Aviation organisations reported the most DMIs with temporal aspects, while road organisations reported and collected the least.

**Spatial coverage of DMIs**



**Summary:** Organisations measure and report DMIs for their organisational asset bases the most across all sectors. This is especially true for road and rail organisations, who’s asset bases are dispersed. Maritime and aviation organisations report a significant amount of DMIs at point locations due to their nucleated asset bases. Maritime and aviation organisations also collect and report some global DMIs due to the international reach of their services. Some DMIs are collected at a national level (UK), primarily by maritime and aviation organisations.

Source: Mott MacDonald analysis based on information collected through reviews of publicly available information and stakeholder engagement, 2025

