MOTT MACDONALD

Measuring Climate Resilience for Transport - Final Report

Report addressed to The Department for Transport

30 January 2026

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Abbreviations

ADEPT	Association of Directors of Environment, Economy, Planning & Transport
ALB	Arms-length body
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
EASA	European Aviation Safety 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
NISTA	National Infrastructure and Service Transformation Authority
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

Asset criticality	Measure of the consequence of asset failure on an organisation
Asset Level Outcome	The impact of a hazard on a (transport) asset
Asset Managers	Organisations responsible for the performance, maintenance and condition of physical assets.
Climate hazard	A climate-related physical event
Climate resilience	Ability of a system to anticipate, prepare for and respond to the impacts of climate change
Data	Information, including facts and statistics collected by transport organisations regarding their operations
Data, metrics and indicators	The various information, measures and observations collected by organisations
Features of a resilient system	Processes, activities or outputs that can be used to indicate climate change resilience
Potential metrics	Range of metrics identified at WS1 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
Interdependence	The dependence of two or more systems, modes or organisations on each other
Lagging metrics	A metric that offers insights into past results or performance
Leading metrics	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	A measure or indicator that is used to measure results or performance
Transport Mode	A subdivision of the transport sector with multiple organisations (e.g. aviation mode, rail mode)
Operational Level Outcome	The impact of a hazard on a (transport) system’s operations
Priority hazards	Hazards identified as priorities for modes at WS1 through literature reviews
Priority impacts	Impacts (asset level and operational) identified as priorities for modes at WS1 through literature reviews
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.)

Executive summary

This report is not government policy.

Context and purpose: what does this report seek to do?

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 Government 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.

Acute weather shocks and chronic climate change can impact the transport system in various ways. The Department for Transport commissioned this study to help understand what information and insight could be drawn from the literature about weather and climate resilience and the UK transport sector (across road, rail, aviation, maritime and cross-modal stakeholders) by considering both the impacts of weather events and climate change on the sector, and the measurement of these impacts.

The findings of this study are organised across three reports. Deliverable 1 from Workstream 1 sets out the impacts of weather events and climate change on the transport sector and how these could be assessed at a sector level. Deliverable 2 from Workstream 2 details the datasets, metrics, and indicators (DMIs) that transport sector organisations across modes are currently using to measure weather and climate resilience based on their published reports and stakeholder discussions. This report, Deliverable 3, consolidates findings from Deliverables 1 and 2 into a **sector-level roadmap, showing what metrics could be developed to measure weather and climate resilience at a sector level; summarising what data, metrics and indicators are currently being used; and outlining potential high-level next steps that could be taken to measure weather and climate resilience at a sector level.**

Contextual notes about the findings of this report:

- The findings should be read in the context of findings from Deliverables 1 and 2. They are based on the literature review and stakeholder discussion with 30+ stakeholders across the road, rail, aviation, and maritime modes, plus some cross-modal organisations. Further engagement will be required with these stakeholders as well as their supply chain to detail and deepen the findings.
- These findings represent a gap analysis of the transport and metrics landscape at the time when this research was undertaken. However, this is a fast-evolving area and both actual practice and good practice will change over time.
- It is worth noting that the focus of the analysis is on metrics and measurement, which is only one aspect of building a weather and climate-resilient transport sector. Other aspects including investment in infrastructure and policy changes and linkages with general safety and asset management strategy are not considered in this study.

Sector-level metrics: what are the potential benefits of sector-level metrics and how could they be built up over time?

Sector-level climate and weather resilience metrics could help the sector as a whole to measure and improve its resilience. As summarised in the table below and detailed in the main report, sector-level metrics (Table 1.1) could serve four objectives which were identified in Deliverables 1 and 2 (including literature reviews and stakeholder insights), and are of four types – hazard metrics, asset-level impact metrics, operational impact metrics, and metrics to understand the system's capacity ("features of resilience").

Table 1.1: Potential metrics to measure sector-level resilience

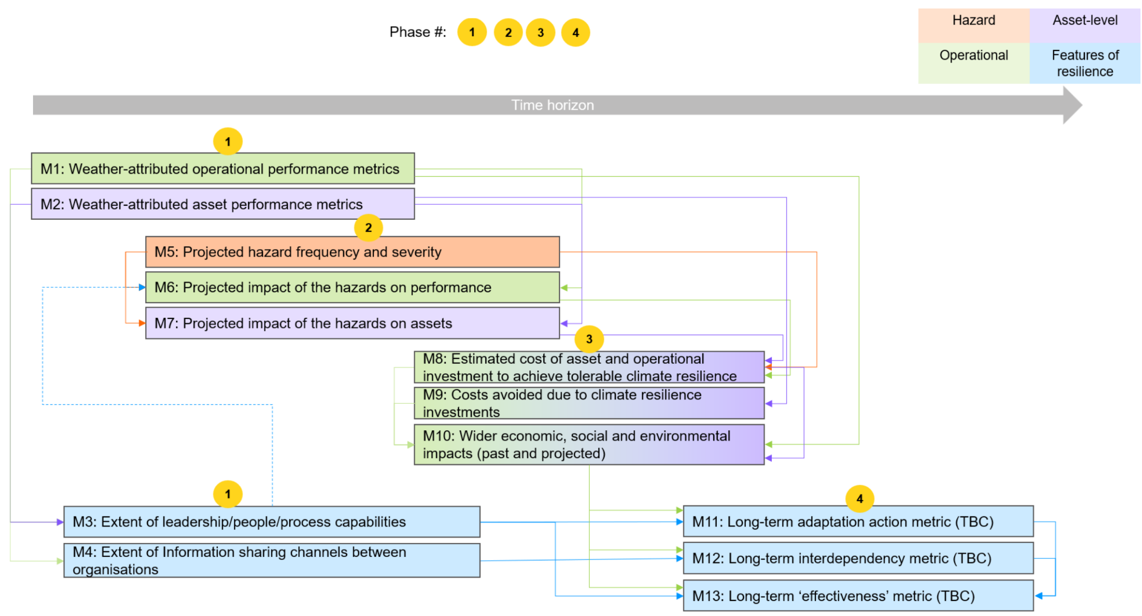
Metric key	Hazards	Asset-level Impacts	Operational Impact	Features of resilience

Sector-level objectives	Types of metrics to consider	How metrics could support objectives
To assess the performance of the sector in response to acute weather events and chronic climate change	M1: Weather-attributed operational performance metrics (e.g. delay)	To help understand how assets are performing against expected asset condition
	M2: Weather-attributed asset performance metrics (e.g. asset damage)	To help understand how the sector is operating against expected service levels
	M3: Extent of leadership/people/process capabilities	To help understand organisations' investment in adaptation capabilities
	M13: Long term effectiveness metric	To help ensure that various actions are effective in the long term
To project what hazards the sector might be faced with, where and when	M5: Projected hazard frequency and severity	
	M6: Projected impact of the hazards on performance	To help understand how hazards might impact the transport network in the future
	M7: Projected impact of the hazards on assets	
To inform investment cases for the sector	M8: Estimated cost of asset and operational investment to achieve tolerable climate resilience	To help understand how much it will cost to be weather/climate resilient
	M9: Total Economic Costs avoided due to climate resilience investments	To help understand whether the investment provides value for money

	M11: Long term adaptation metric[1]	To help understand whether the sector is adapting to climate change in the long term
	M4: Extent of information sharing channels between organisations	To help measure organisations network capacity to share information (within and beyond transport)
To enable interdependencies to be effectively managed	M12: Long-term interdependency metric	To help understand whether information is being effectively shared (within and beyond transport)
	M10: Wider economic, social, environmental impacts[2]	To help ensure that other critical objectives are also being considered

These metrics are inherently dependent on each other and could be built up in a phased manner over time. A potential roadmap for metric development is shown in Figure 1.1 below across four 'phases', as discussed in stakeholder workshops. It was noted in workshops that exact timelines would vary by mode or organisation based on their capability and existing practice.

Figure 1.1: Potential sector-level metric development roadmap



Source: Consolidated based on stakeholder workshops and findings from Deliverables 1 and 2

Phase 1: The sector could focus on developing **lagging metrics for weather-attributed operational and asset performance**, which are the essential building blocks for future phases. Whilst the starting point might be weather-related changes or acute shocks (which are easier to measure), over time these lagging metrics would consider slow onset or chronic changes related to climate. The sector could then begin to put in place the **simpler 'features of resilience' metrics – tracking capabilities and information channels** – which would eventually inform the longer-term metrics that have not been developed yet. As detailed in the

[1] This is explored further in Section 3.5.

[2] M10 could also support the Objective 'to inform investment cases for the sector'.

main report, there are existing frameworks and capabilities within some organisations that could be leveraged, particularly where there are links to wider safety, risk, and asset management strategies.

Phase 2: The sector could build on the datasets and capabilities developed in phase 1, using historical trend data to develop forward projections. Established climate projections could then be used to help understand the potential impacts of **future climate hazards on the exposure and vulnerability of assets and operational performance**.

Phase 3: The sector could use both the lagging data developed in phase 1, and the leading data from phase 2, to develop its economic understanding of projected operational and asset damage costs ('the **cost of inaction**'), together with the costs of investments to build resilience and adapt to climate change ('the **cost of action**'). It also collates data from prior phases on the **wider economic, social and environmental impacts** of transport disruption and asset damage and could also be used to help inform other future decisions such as for wider policy and business case appraisal.

Phase 4: The sector could also use a mature and expanding dataset from all the previous phases to assess the **resilience of the transport sector as a whole and establish and monitor long-term metrics**. These are the most complex metrics to develop and will draw from design decisions and attribution methods of previous phases.

Gap assessment: what are the key barriers to developing sector-level metrics?

To help understand the gap between achieving the above sector level roadmap and the status quo across the transport sector, the status quo was considered for each mode across six parameters:

- The need and potential to develop a consistent unit for the metric.
- The extent to which the required data is already collected and/or available.
- The level of capacity required to collect and report on the metric within the organisations.
- Whether or not the metric could be developed at a central level by DfT or regulating bodies without organisational input.
- Whether standards/expected levels of performance have to be defined first for the metric to be useful.
- Whether organisations reporting on the metric can be monitored through existing mechanisms (so as to reduce the risk of duplication and avoid creating an additional burden).

This assessment, which is based on feedback from workshops with organisations, structured interviews with organisations and desk-based research is summarised at a high level below, with details and specific observations for each mode in Chapter 4:

Metrics and data development

1. Several organisations collect relevant data on assets and operations (e.g. delays, cancellations and asset damage), but in most organisations, this is not **currently weather-attributed**. Across the modes considered, operational performance-based weather attribution (particularly where related to safety) was more widespread than asset performance weather attribution. However, the consistency of this data is variable.
2. Consistent and/or aggregable metrics are difficult to develop particularly for asset-level performance given variability in geography, geology, structures, and asset type. While DfT may be placed to identify and guide data collection, **the underlying data for most metrics will have to be collected directly from organisations.**

3. There is some **variability in the extent of projected hazard impacts**, with aviation and strategic roads having the most mature view of projected hazards and impact historically. As a whole, using projections of weather hazards, and understanding the impacts of weather hazards on operations and assets, requires significant historical data which can attribute past weather to operational or asset impacts. This attribution process would be a requirement before the sectors can design Phase 2 forward-looking metrics. In addition, there is currently **no consistent list of hazards for the overall transport sector,** owing to modal variability, and distinct risks and weather hazards to assets in differing locations.
4. Some organisations are investing in building people/process/leadership capabilities (e.g. adapting design standards and improving controls), but not necessarily tracking them. Some advanced organisations publish ARP reports (reports produced under the Adaptation Reporting Power (ARP) of the Climate Change Act 2008, which detail how organisations are taking action to adapt to climate change) where this information can be found.
5. There is limited use of cost and efficacy metrics, though some organisations (e.g. airports) have started collecting this information for TCFD reporting. The cost implications of long-term action (or inaction) are particularly complex, and are not currently being assessed.

Capacity and capability

6. Based on interviews and workshops with transport organisations, many organisations do not generally have the **capacity and, in some cases, capability** needed to collect and report data exhaustively. For example, in many organisations the operational, asset, and weather data sit in different parts of the organisation and there is limited capacity to consolidate this. This challenge is particularly acute for smaller organisations (e.g. local authorities).
7. Conversely, many organisations engaged through this project recognise that the aforementioned **data is needed to make the investment case for, and build resilience capability**, thereby creating a vicious cycle**.**
8. Organisations realise the value of appropriate **information-sharing** between themselves but this is limited to sharing in high-level working groups, including due to the capacity constraints referenced above and commercially sensitive data.

Governance

9. In general, the research and stakeholder engagement showed that **mechanisms to hold organisations to account for their weather or climate resilience** are limited, albeit existing governance and funding settlements could potentially be adapted to hold some public sector organisations to account. For private sector organisations, particularly in the rail, maritime and aviation sectors, there is a challenge around sharing commercially sensitive data.
10. Organisations across modes consistently raised the challenge of **expected levels of asset and operational performance** in different weather conditions having to be defined first as a baseline for reporting and holding-to-account mechanisms to be developed and applied.

Potential steps to close the gap: how could the sector-level roadmap be achieved?

To achieve the sector-level metrics needed for measuring the resilience of the transport sector to climate change and weather events, a range of next steps would be needed across the sector. This long-list of potential next steps is detailed in Chapter 5 against the gaps identified by the literature review and stakeholder engagement, with a high-level assessment of those that are most likely to achieve systemic change (‘high-priority’) and those that are most likely to be implementable within a short time scale (‘quick wins’). These next steps have been developed based on extensive engagement with transport stakeholders.

Potential high-priority next steps at a sector level

1. **Consistent indicators:** DfT could work with modal organisations to develop consistent indicators for each transport mode including the scope of what would be included and excluded – e.g. delay minutes for operational performance, and asset recovery and repair costs for asset performance – including development of associated guidance and/or methodologies. This would be informed by the definition of asset criticality (high-priority next step 4). Existing modal forums and initiatives could be leveraged to develop these – e.g. RSSB's Climate Adaptation Metrics project, EASA (European Aviation Safety Agency), Major Ports Group, and UKRLG/ADEPT. The metrics and indicators could be published and updated iteratively as a 'guiding document' for the sector.
2. **Development and dissemination of weather-attribution methodology:** DfT could support the modes, through engagement with organisations and associations, to develop technical methodologies for (1) correlating performance to weather/climatic factors, and (2) using historic data to project future performance. As a sector-level organisation, the remit of which is cross-modal, DfT is uniquely placed to identify similarities and differences across the modes which could feed into the development of the mode-specific methodologies as well as to disseminate approaches from more advanced organisations to smaller organisations within each mode.
3. **Reporting template for data collection:** As demonstrated in the potential sector-level roadmap (Chapter 3), once consistent indicators have been identified and agreed, DfT could require modal organisations to report on some metrics (e.g. delays attributed to weather hazards, top 5 anticipated hazards for the following year, or estimated cost of asset damage) subject to changes in holding-to-account and governance mechanisms (see high-priority next step 5). DfT could also develop a template for collecting this data that considers Phase 1 data needs, the existing datasets within each organisation, consistency where possible across modes and organisations, and the level of effort required to periodically extract the data from ARP vis-à-vis asking organisations to report it. This template could evolve over time as organisations progress on their data maturity journey and more complex Phase 3/4 metrics are developed. Terms of reference could also eventually be developed for different organisations that are aligned with the governance structure for that organisation and consider commercial/confidentiality challenges.
4. **Asset criticality:** A phased approach to data collection, which takes into account the cost and reporting burden on organisations, would be important to the success of the system. DfT could work with NISTA, sector regulators and modes to define – through a risk-based approach – the most critical assets within the transport network for which leading and lagging metrics are needed in the first instance, which could then be matured over time. It is expected that organisations within the transport sector will already have a high degree of understanding of the assets which are most critical (for example from a safety perspective), based on engagement with asset managers at these transport organisations. DfT would benefit from receiving this information from modal organisations to take sector-level decisions.
5. **Long-term governance:** DfT could develop an operating model, setting out how climate and weather risks could be governed across the sector, given the complexities associated with differing governance structures, regulatory requirements, and funding arrangements. This could consider the organisations involved, their responsibilities and accountabilities, interfaces necessary to support the monitoring and reporting of climate resilience metrics, and potential changes to regulatory/licence conditions and frameworks. To be effective and efficient, this would have to be aligned with the wider transport sector operating model and considered alongside the governance of other priorities like efficiency, safety, decarbonisation, operational performance, and wider resilience.

Potential ‘quick win’ next steps at a sector level

1. **A capability maturity measurement framework:** DfT could set out a capability maturity measurement framework for assessing leadership, people, and processes for adaptive capacity capabilities across the transport sector; and to develop a mechanism for this data to be collected, drawing on existing private or public frameworks such as Adaptation Scotland’s publicly available climate adaptation capability framework[3] that informed the development of NHS England‘s climate adaptation framework[4].
2. **Interdependency risk maps:** Stakeholders identified DfT’s role as an integrator/convenor as critical to developing sector-level approaches. DfT could support organisations across the transport sector to identify and assess interdependent risks by undertaking a project to develop systems thinking-informed interdependency maps for each transport mode that can be used by modes as part of their climate change risk assessments. This could include the clear definition of cross-sector linkages, for example with the energy and water sectors. By carrying out this activity centrally, there would be a consistency in method and interfaces reducing the likelihood of missed connections.

Potential high-priority next steps at a modal level

For sector-level metrics to be developed, action by modal organisations would be required. These are discussed in further detail in this report, with high-priority next steps including:

1. **Internal capability development:** Given the growing impact of weather events and climate change on the business-as-usual operations and financial position of all organisations, climate resilience could be considered at a Board level, and the required capability could be integrated into their asset management, operations, and finance teams along with the consideration of climate change impacts within associated policies, processes and activities. The capabilities of the supply chain of these organisations would also have to be considered.
2. **Expected levels of performance:** Stakeholders identified this as a critical first step to defining metrics. Organisations could work closely with DfT, NISTA, sector regulators, and modal organisations to develop expected levels of service (for operational performance and asset condition) so that performance could be reported against a standard. The degree of leeway and circumstance-based adjustment for performance expectations under extreme weather conditions could also be defined to guide adaptation and preparation for these events. Organisations would have to share some historic weather-attributed data on asset and operational performance to help inform this.

Conclusion

For the sector level metrics shown in the roadmap to be realised, a range of steps may need to be considered by the government, regulators and transport organisations to establish the tools and capabilities to capture, analyse, and share supporting data and information. A selection of the most achievable (quick-win) and most impactful (longer-term, high-priority) steps are summarised in Table 1.2, below.

Table 1.2: Potential ‘quick win’ and ‘high-priority’ steps

	Quick wins	High-priority
DfT	• Develop a capability maturity measurement framework • Develop interdependency risk maps	• Develop consistent indicators • Support the development of weather attribution methodology

[3] Climate Adaptation Capability Framework - Adaptation Scotland

[4] NHS England » A climate adaptation framework for NHS organisations in England

		• Define asset criticality for the sector • Define long-term governance • Develop a reporting template and terms of reference for data collection
Modes	• Improve information through existing channels and forums	• Examine internal capability • Define expected levels of performance

Scoping and delivering the ‘quick win’ steps as packages of work could help to generate early benefits. At the same time, starting the high-priority next steps early would be important because of their criticality to success.

Finally, it is important to remember that the findings of this report are focused on metrics and measurement, which is one critical aspect – alongside culture, funding, governance etc. – of building a weather- and climate-resilient transport sector. These steps would have to be considered in the context of the Government’s wider adaptation strategy.

1 Introduction

1.1 Project and Workstream Background

1.1.1 Overview of Workstreams

To address the requirements described in Section 1.1.2, the overall study was broken down into three workstreams:

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

This report covers the findings of Workstream 3 only. The purpose of Workstream 3 was two-fold:

- To identify and prioritise gaps in the evidence base where further datasets/metrics/indicators are required to measure: (a) the resilience of the transport network at both a modal and sector level and (b) impacts of climate-related damage and disruption over time.
- To outline high-level potential next steps that could be undertaken to address these identified gaps

The analysis in this report builds on the findings of Workstreams 1 and 2 and refers to the evidence base and analysis developed for these workstreams and supplemented by further stakeholder engagement and discussions with DfT. It should be read in conjunction with the Deliverables from Workstreams 1 and 2.

1.1.2 Structure of the report

The report is structured into the following chapters:

- **Chapter 2: Methodology –** This chapter summarises the main findings of Workstreams 1 and 2, how they inform Workstream 3, and sets out the methodology adopted.
- **Chapter 3:** Potential **sector-level metrics and roadmap –** Based on the literature reviews and stakeholder interviews this chapter sets out the potential metrics that could be adopted at a sector level for the transport sector, and the potential steps (in the form of a high level indicative roadmap) for how the underlying indicators and data could be developed.
- **Chapter 4: Gap analysis –** This chapter considers the feasibility of adopting the potential additional metrics based on the findings from Workstreams 1 and 2.
- **Chapter 5: Potential Steps –** Based on the literature reviews and stakeholder interviews, this chapter sets out potential steps that could be taken at a sector and modal level to close the identified gaps.

2 Methodology

2.1 Overview

This chapter summarises the methodology adopted to undertake the gap assessment and develop the roadmap and potential next steps in this report. It also sets out how these findings and conclusions link to the first two workstreams.

2.2 Structure and logic of Deliverable 3

The research and analysis conducted in Workstreams 1 and 2 provided a set of principles for designing the sector-level metrics and roadmap and the evidence base for the gap assessment against this roadmap.

2.3 Potential sector-level metrics and roadmap

Chapter 3 presents a set of **sector-level** metric types whose measurement could enable the transport sector to monitor its resilience to weather events and climate change over time. These metrics are then presented in a **sector-level roadmap**, which shows a potential logical sequence for developing the metrics over time.

The sector-level roadmap considers what metrics could support the assessment of the sector's resilience to climate change and adverse weather events.

The nature and sequencing of the metrics draw on insights derived from stakeholder engagement, primarily the following design principles:

1. Sector-level metrics are needed to serve the resilience objectives of the sector as a whole, and not individual modes and organisations.
2. Not all metrics or indicators collected at an organisational or modal level will be relevant at a sector level given challenges of developing consistent and aggregable metrics.
3. A phased approach is needed to metrics and data development which factors in organisational capability whilst recognising the criticality of sector-level measurement.

The metrics are categorised into four types based on the framework developed in Workstream 1:

- **Hazard metrics:** Measures the extent (temporal/spatial) of climate hazards.
- **Asset-level outcome metrics:** Measures the impact on transport assets of a hazard occurring.
- **Operational outcome metrics:** Measures the operational impact of the hazard occurring.
- **Features of a resilient system:** Measures that quantify attributes of a resilient system.

2.4 Gap assessment

Chapter 4 presents a **detailed gap assessment** of the feasibility of achieving the sector-level metrics for each mode.

It relies on the findings of Workstream 2 which provided a status quo for current data collection within organisations to assess the gap between the status quo and the sector level metrics roadmap across six parameters. The criteria and findings were discussed at stakeholder workshops:

- The need and potential to develop a consistent unit for the metric.
- The extent to which the required data is already collected and/or available.
- The level of capacity required to collect and report on the metric within the organisations.
- Whether or not the metric could be developed at a central level by DfT or regulating bodies without organisational input.
- Whether standards/expected levels of performance have to be defined first for the metric to be useful.
- Whether organisations reporting on the metric can be monitored through existing mechanisms.

The gaps are then described for each mode at both an organisational level and sector level.

2.5 Potential next steps

Based on the priorities of the sector (as set out in Chapter 3) and the gap assessment (as set out in Chapter 4), **Chapter 5** sets out **potential next steps** that governing and regulatory bodies and modal organisations could consider to close the gaps. Each next step is described, accountabilities are defined, and the potential level of effort required to undertake the action is assessed. The next steps are also shortlisted based on importance and urgency. The 'high-priority' and 'quick win' actions are then explained in more detail.

2.6 Stakeholder engagement

Stakeholder engagement within this workstream was delivered in two online workshops. These workshops gave the project team an opportunity to present the sector roadmap to stakeholders across the various modes and aimed to:

- Test the sector-level roadmap and metrics, including the relative importance and sequencing of the metric roadmap.
- Gather views on the feasibility of reporting against these metrics at a modal and organisational level.

The first workshop was focused on the rail sector, whilst the second covered the roads, aviation, and maritime sectors, to ensure an even split of participants across both (although all participants were invited to both workshops to enable a discussion of interdependencies and commonalities).

3 Sector level Metrics and Roadmap

3.1 Overview

This chapter sets out the sector level metrics that could be developed to support the measurement of climate resilience of the transport network and impacts of climate-related damage and disruption over time. The sector-level metrics have been developed by building on the outputs of WS1 and WS2, while also considering the requirements of DfT's draft Transport Adaptation Strategy[5], the National Infrastructure and Service Transformation Authority's[6] (NISTA) resilience framework[7], and British Standard (BS) 65000 – Organisational Resilience[8].

These metrics have then been sequenced within a potential 'sector-level roadmap', considering the dependencies between them, and in stakeholder workshops across the three workstreams. The feasibility of collecting the underlying data is examined in Chapter 4.

3.2 Rationale for sector-level metrics

3.2.1 Determination of sector-level objectives for developing climate resilience metrics

To determine the purpose of climate and weather resilience metrics at a sector level, analysis was conducted of what metrics would be needed to achieve the objectives of DfT's draft Transport Adaptation Strategy. The objectives of NIC (now NISTA) resilience framework and BS (British Standard) 65000 frameworks were also considered to motivate the metrics because they provide useful insight into what organisations should consider improving their general resilience (agnostic to the type of shocks).

Based on this analysis, **the four objectives of developing and maintaining metrics at a sector level** were identified and agreed with DfT:

- To assess the performance of the sector during acute weather events and over time in response to the gradual increase of exposure to chronic hazards.
- To project what hazards the sector might be faced with, where and when.
- To inform investment cases for the sector to develop its resilience.
- To enable interdependent risks across modes to be effectively managed.

Details of how these metrics were derived from other frameworks are shown in the box below.

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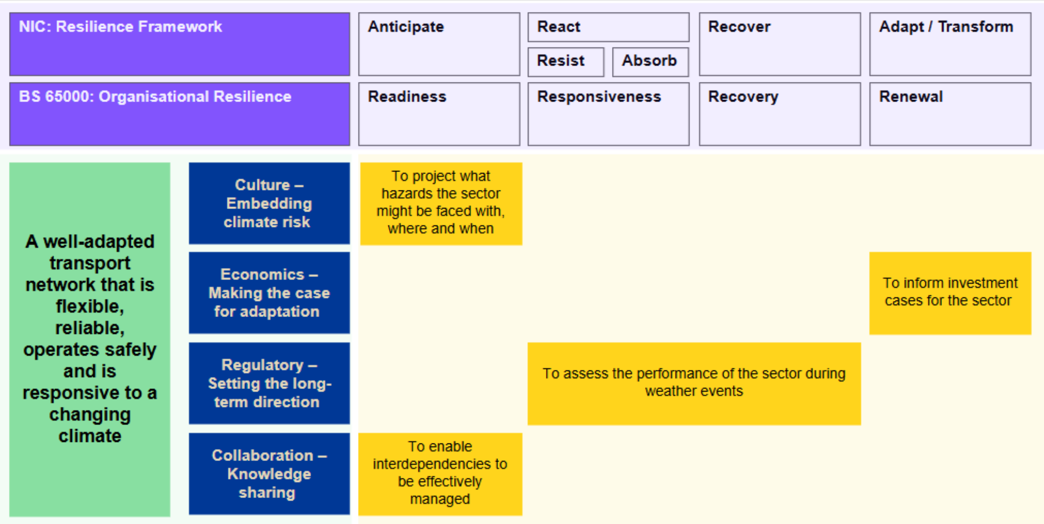
[5] https://assets.publishing.service.gov.uk/media/66152059c4c84de468346aea/dft-transport-adaptation-strategy-consultation.pdf

[6] Previously named the National Infrastructure Commission

[7] Resilience-Anticipate-React-Recover-28-May-2020.pdf (Note – The original report is no longer available on the NIC's website as the commission has been replaced by NISTA and not all of the NIC's reports are available on NISTA's website)

[8] BS 65000:2022 - TC | 31 Aug 2022 | BSI Knowledge

Figure 3.1: Mapping objectives for sector-level metrics



Source: DfT, NISTA

It should be noted that there are links between the objectives. For example, the investment case for the sector is linked to understanding the hazards that may affect the sector in the future. These links are developed further in the roadmap in later sections.

3.2.2 Defining requirements of the sector-level metrics

In addition to the four sector-level objectives, each was also supported by the rationale for them being needed. These reasons are shown below in Table 3.1. These reasons were also informed by the findings and outputs of previous workstreams.

Table 3.1: The requirements of sector-level metrics

Sector-level objectives	How metrics could support objectives
To assess the performance of the sector in response to acute weather events and chronic climate change	• To understand how assets are performing now, and are projected to perform under a changed future climate against expected asset condition • To understand how the sector is operating against expected service levels • To understand whether organisations have invested in the capabilities they need
To project what hazards the sector might be faced with, where and when	• To understand how hazards might impact the transport network in the future
To inform investment cases to develop the sector's resilience	• To understand how much it will cost to mitigate the effects of weather events/climate change • To understand whether the investment provides value for money • To understand whether the sector is adapting to climate change in the long term
To enable interdependencies to be effectively managed	• To understand whether modes are effectively sharing information with each other/other sectors • To ensure that other critical objectives like safety, community impact, environment and accessibility are also being considered • To understand which investments are resulting in better climate action

3.3 Metrics needed to achieve sector-level objectives

A set of high-level metrics was developed to support these objectives and rationale. These metric types follow from the metric types developed in Workstream 1 to characterise the impacts of weather events and climate change on the transport system.

Table 3.2: Metrics required at a sector level

Metric key	Hazards	Asset-level Impacts	Operational Impact	Features of resilience

Sector-level objectives	Required metrics	How metrics could support objectives
To assess the performance of the sector in response to acute weather events and chronic climate change	M1: Weather-attributed operational performance metrics	To understand how assets are performing against expected asset condition
	M2: Weather-attributed asset performance metrics	To understand how the sector is operating against expected service levels
	M3: Extent of leadership/people/process capabilities	To understand organisations' investment in adaptation capabilities
	M13: Long term effectiveness metric	To ensure that various actions are effective in the long term
To project what hazards the sector might be faced with, where and when	M5: Projected hazard frequency and severity	
	M6: Projected impact of the hazards on performance	To understand how hazards might impact the transport network in the future
	M7: Projected impact of the hazards on assets	
To inform investment cases for the sector	M8: Estimated cost of asset and operational investment to achieve tolerable climate resilience	To understand how much it will cost to be weather/climate resilient
	M9: Total Economic Costs avoided due to climate resilience investments	To understand whether the investment provides value for money
	M11: Long term adaptation metric[9]	To understand whether the sector is adapting to climate change in the long term
To enable interdependencies to be effectively managed to enable interdependencies to be effectively managed	M4: Extent of information sharing channels between organisations	To measure organisations network capacity to share information (within and beyond transport)
	M12: Long-term interdependency metric	To understand whether information is being effectively shared (within and beyond transport)
	M10: Wider economic, social, environmental impacts[10]	To ensure that other critical objectives are also being considered

[9] This is explored further in Section 3.5.

[10] M10 also supports the Objective 'to inform investment cases for the sector'.

3.4 Sector-level metric roadmap

The pathway to establishing the high-level metrics defined above has been structured into a potential sector-level roadmap (Figure 3.2). The roadmap aims to chart a logical path to developing an effective overarching approach to measuring the resilience of the transport sector. It has been developed by considering two factors:

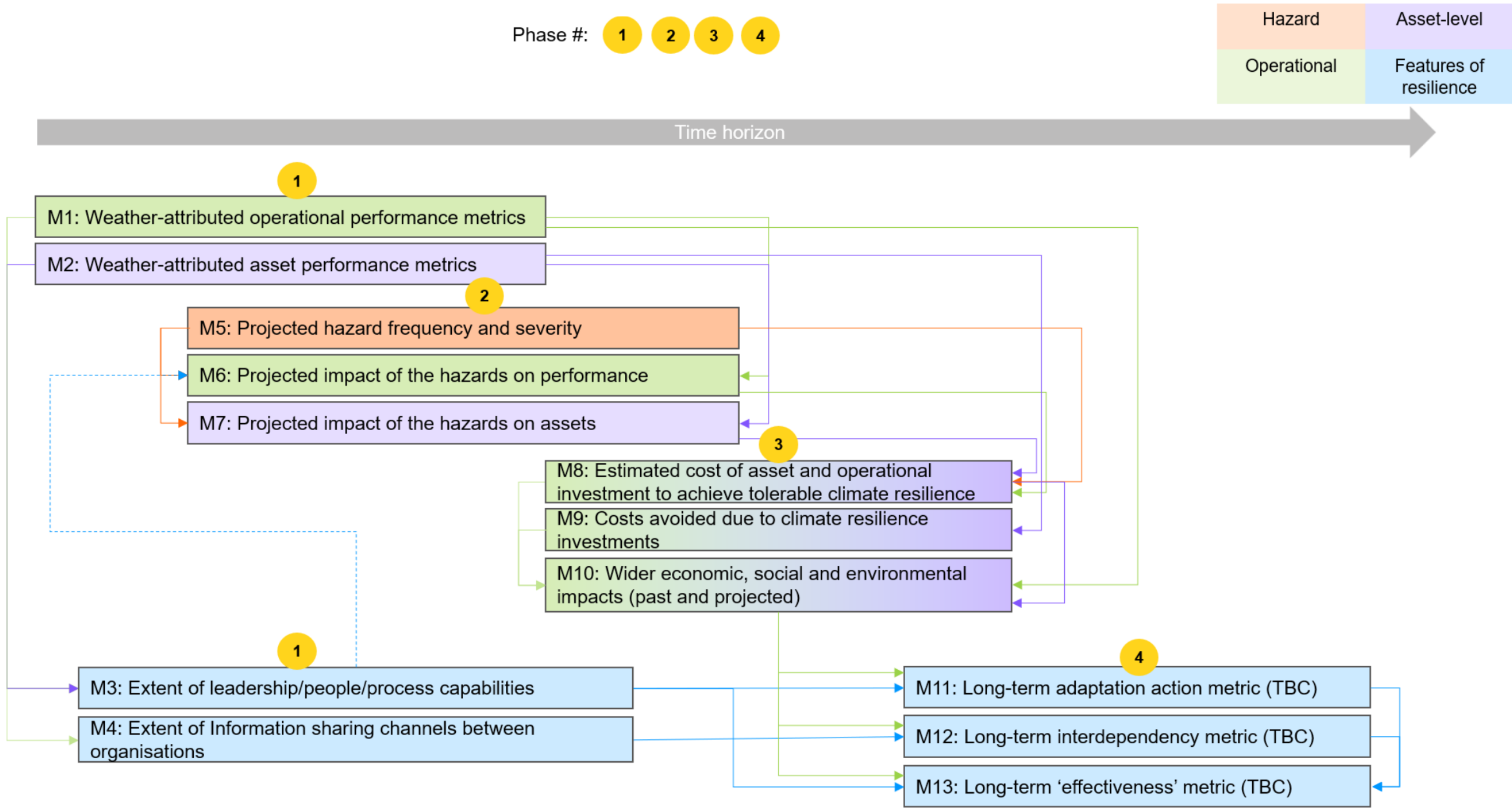
- How the different metrics described above would have to logically feed into each other based on the underlying data required.
- The theoretical challenge of developing some of the long-term metrics described above and therefore the short-term 'proxies' that could be used.

The following assumptions have been made in designing this roadmap:

- There is a high level of ambition from DfT and other 'sectoral' organisations to achieve all the objectives set out in the strategies in Section 3.2.
- At this stage, the feasibility of collecting data based on the differing states of maturity across different organisations, and availability of datasets have not been considered. This is detailed in Chapter 4.
- The 'phases' are meant to indicate sequencing rather than specific time periods, as the latter would have to be developed based on the considerations of the feasibility assessment in Chapter 4 such as level of maturity of different organisations or enabling governance. The 'phases' may also overlap.
- Which assets, operational processes, and hazards require weather or climate-change attribution would need to be determined by individual modes and organisations based on a risk assessment of asset criticality. This will also mature over time but follow the same journey outlined below – i.e. the most critical assets will go through the phases shown below earlier than the less critical assets.
- Some of the underlying data and insights needed to inform latter-phase metrics would have to be collected and developed in earlier phases – for example, whilst a quantitative measurement of the wider economic, social, and environmental impacts of climate change on the transport system may only be possible in Phase 3, the qualitative insights or 'stories' needed to inform this would have to be collected earlier. These insights may include illustrative cases of the impact of extreme weather events or changing climatic conditions on regular functions.

The roadmap below also notes where the metrics need to be consistent across the modes and organisations within the mode (i.e. have a consistent unit to enable ease of data collection and analysis), and where it needs to be aggregable (i.e. aggregated across the sector to achieve a specific strategic objective discussed in Section 3.3).

Figure 3.2: Sector level roadmap



Source: Stakeholder workshops and preceding analysis

The section below describes the potential phases for establishing the metrics. Examples of specific metrics and indicators are provided in Section 3.5.

First phase

- The sector focuses on developing **lagging metrics for weather-attributed operational and asset performance**, which are the essential building blocks for future phases. Whilst the starting point for this analysis might be weather-related changes or acute shocks (which are easier to measure), over time these lagging metrics would consider slow onset or chronic changes related to climate.
- These metrics would **not necessarily need to be aggregable at a sector level** given variations in asset types, operational processes, and relevant hazards. However, some level of consistency in the units of these metrics would enable ease of analysis and data collection at a sector level.
- The sector begins to put in place the **simpler 'features of resilience' metrics – tracking capabilities and information channels** – which would eventually inform the longer-term metrics that have not been developed yet. It would be beneficial and potentially simpler to develop a common framework using a common set of indicators that can be used to measure these features across the whole sector rather than developing mode-dependent frameworks (detailed in Section 3.5).

Second phase

- The sector builds on the datasets and capabilities developed in phase 1, using historical trend data to develop forward projections. It uses established climate projections to understand the impacts of **future climate hazards on the exposure and vulnerability of assets and operational performance**.
- Similar to phase 1, these metrics **would not have to be aggregable** at a sector level. However, for ease of data collection and analysis, **consistent units** would be helpful for M6 and M7 around projected impacts. Projected hazard frequency and severity (M5) would have to vary across modes (and potentially even organisations within a mode), based on the variations in relevant hazards and their thresholds across organisations. However, at a consistent sector-level framework, for example, measuring 'top 5' hazards could be developed.

Third phase

- The sector uses both the lagging data developed in phase 1, and the leading data from phase 2, to develop its economic understanding of projected operational and asset damage costs ('the **cost of inaction**'), together with the costs of investments to build resilience and adapt to climate change ('the **cost of action**'). This enables more effective forward-looking economic appraisal, capturing the benefit-cost ratios of investments – a key input into business planning. Given the role of the metrics in this phase to support investment planning, **the metrics need to be consistent and aggregable** across the sector to ensure that comparisons between transport modes are based on common inputs.
- This phase collates data from prior phases on the **wider economic, social and environmental impacts** of transport disruption and asset damage and projects this into the future for wider policy and business case appraisal. It is worth noting that some of the underlying inputs for wider impacts (e.g. community-level impacts of weather events) might have to be developed earlier.

Fourth and final phase

- The sector uses a mature and expanding dataset from all the previous phases to assess the **resilience of the transport sector as a whole and establish and monitor long-term metrics**. As such, metrics at this phase would pull in attributed historical data, projected hazards and cost implications to illustrate a broader view of resilience at the sectoral level. These are the most complex metrics to develop and will draw from design decisions and attribution methods of previous phases – for example, the long-term effectiveness metric may have to develop a causal relationship between the adaptation actions that the sector takes to improvements in metrics related to weather-attributed operational or asset performance. Similarly, the long-term interdependency metric may have to develop a causal relationship between short-term improvements in 'information-sharing' metrics and improvements in metrics related to weather-attributed operational or asset performance.

- This could include a measure of long-term adaptation action, and adaptation effectiveness. It could also include an assessment of interdependency between the resilience of different parts of the transport system as well as adjacent sectors such as flood prevention infrastructure, agriculture, housing and the power network. The metrics in this phase need to be based on a **consistent approach** that can be applied across all transport modes.

A note on lagging and leading indicators and how they can be used

It is worth noting that the roadmap metrics could be underpinned by either lagging indicators that measure past performance or leading indicators that predict the future, as shown in Table 3.3 below. The same supporting data could inform both the lagging and leading indicators – for example, weather-attributed operational performance data could be used to inform a lagging indicator around past asset performance or be used to inform a leading indicator around how projected hazards may impact asset performance in the future. This thinking is factored into the potential sequencing of the metrics in the sector-level roadmap in Section 3.4.

Table 3.3: Summary of lagging and leading indicators

Lagging indicators to measure past performance	Leading indicators that project potential future performance
• Weather attributed operational performance • Weather-attributed asset performance • Costs avoided due to climate resilience investments • Wider economic, social, environmental impacts (past) • Long-term adaptation metric • Long-term interdependency metric • Long-term effectiveness metric	• Projected hazard frequency and severity • Projected impact of hazards on operational performance • Projected impact of hazards on asset performance • Estimated cost of asset and operational investment • Wider economic, social, environmental impacts (projected) • Features of a resilient system[11]

3.5 Potential Example Indicators

The potential metrics presented in Section 3.3 and Section 3.4 are at a strategic level. In some cases, this is because they would need to be supported by multiple individual indicators, some of which would be different between modes, and in other cases, it is because the best mechanism for measuring performance is not currently clear. Nevertheless, the work undertaken throughout this project has allowed the identification of potential indicators that could meet the need and objective of each required metric defined above and included in the roadmap. Appendix A.2 compiles the notable datasets, metrics and indicators (DMIs) from Workstream 2 that were highlighted for their potential to be useful at a sector level for

[11] While Features of a Resilient System measure the current state of an organisation, higher scores show greater organisational capability and expertise which is a proxy for future performance because it indicates the organisation is undertaking activities now to prepare for the future.

measuring climate resilience. These have been considered when developing the potential example indicators in Table 3.4.

It should be noted that, as emphasised by transport organisations throughout the project, additional work is needed to develop indicators that are applicable to, or consistent and aggregable across, modes. Therefore, while this section provides examples, more work is required to refine and develop them. Some of the key challenges are as follows:

- **Applicability and importance:** Whilst ‘delay minutes’ is an indicator against which several organisations in the rail and aviation sectors collect data, ports have pointed out that ‘recovery minutes’ may be a more useful indicator for maritime freight given that they can reroute and use other facilities. The most appropriate transport mode specific indicators are still to be determined along with the critical assets for which they need to be collected.
- **Consistency and aggregability:** While certain data, particularly asset-specific data on granular asset types (for example the condition of walkways at a regional airport), is important for individual transport organisations, it is not likely to be valuable at a sector level and is challenging to aggregate at a transport mode or sector level.
- **Monetisation:** Monetising data was generally agreed in workshops to make the data more consistent and comparable at a sector level. This will require agreed methods or standards to be developed such that there are common approaches for estimating direct costs and indirect (e.g. socio-economic) costs of the impacts of climate change on assets and operational performance.
- **Attribution:** Determining causation and even correlation between weather or climatic events and impacts to an organisation is challenging. As discussed in interviews and workshops, organisations do not necessarily have the data to allow causation or correlation to be determined, and where they do have the data, they may not have the systems or processes, the necessary resources, or the internal capabilities to draw causal relations between weather and other factors.

Given the considerations above, and that the detailed design of these indicators is beyond the scope of this study and would require further consultation with stakeholders, potential example indicators for the sector-level metrics and roadmap have been provided in Table 3.4. The example potential indicators include units of measurement and means of aggregation / consistency. Accompanying commentary on these factors, their feasibility and potential efficacy, and the mapping of the DMIs to the potential next steps detailed in Chapter 5 are contained in Appendix A.5. These have been developed based on desktop research in Workstreams 1 and 2 and discussed with stakeholders in interviews and workshops.

Table 3.4: Potential metrics and associated example indicators

Potential metrics		Example indicators currently used by transport organisations
	M1: Weather-attributed operational performance metrics	Total annual delays where 'beyond-threshold' adverse weather was a contributing factor
		Share of service cancellations where 'beyond-threshold' adverse weather was a contributing factor
	M2: Weather-attributed asset performance metrics	Total annual asset recovery costs (labour, materials, etc.) following 'beyond-threshold' weather-related events
		Maintainability – Average time to return to service following a 'beyond-threshold' weather-related event
		Condition Index or Health Score – A composite metric (made up of quantitative and/or qualitative data) that quantifies the overall physical state or performance of an asset
	M3: Extent of leadership/people/process capabilities	(Leadership) Percentage of transport sector Executive Leadership Teams that have an individual responsible for climate change risk
		(Leadership) Percentage of transport sector organisations where internal decision making processes require the consideration of climate change
		(People) Percentage of transport sector organisations with an individual or team managing climate change risk
		(People) Percentage of transport sector organisations with internal climate change risk training
		(Process) Total coverage of the transport sector by a climate change risk assessment
		(Process) Percentage of transport organisations using internal design standards where climate change has been fully integrated
	M4: Extent of information sharing channels between organisations	Percentage of transport sector organisations participating in recognised climate change risk information sharing channels such as forums, networks or working groups
		Percentage of transport sector organisations assessing and sharing information on interdependent climate change risks in line with best practice guidance/techniques
	M5: Projected hazard frequency and severity	Top 10 most significant climate change risks for each organisation, mode and sector
		Projected increase in priority risks at given future time-horizons
		Projected increase in priority hazard key performance thresholds (e.g. projected number of days above X°C)
	M6: Projected impact of the hazards on performance	Projected annual delays (based on projected changes in weather/climate)
	M7: Projected impact of the hazards on assets	Projected total annual event recovery costs as a portion of overall asset maintenance costs
	M8: Estimated cost of asset and operational investment to achieve tolerable climate resilience	Estimated cost of asset and operational investment required within the next investment period to achieve tolerable climate/weather resilience

	M9: Costs avoided due to climate resilience investments	Estimated avoided direct[12] costs due to resilience investments
		Socio-economic benefits accrued due to resilience investments
	M10: Wider economic, social, environmental impacts	Socio-economic costs of climate risk being realised
	M11: Long term adaptation metric (TBC)	Completion of organisational adaptation actions
	M12: Long-term interdependency metric (TBC)	% of organisations in the mode with arrangements in place that enable or support a shared response to an interdependent climate risk
		Percentage of critical infrastructure operators with arrangements in place that enable or support a shared response to an interdependent climate risk
	M13: Long term effectiveness metric (TBC)	Change in system performance compared to the change in climate (compared to a baseline year)

While the metrics in the table above are potential examples, for the purposes of this report they have been used to inform potential actions for the DfT to develop the final sector-level metrics. The gap analysis in the following section provides additional insight as to what is required from, and what support is needed by, each transport mode. Further detail on example indicators and commentary on metrics is provided in **AppendixA.6.**

[12] Direct costs in this case refers to the avoided costs to the transport sector organisation. This would be aggregated up across transport modes and the sector as a whole.

4 Gap assessment

4.1 Overview

This chapter assesses the feasibility of collecting and reporting the sector-level metrics described in Chapter 3 across different transport modes. Whilst Chapter 3 sets out the target roadmap at a sector level (in Figure 3.2), the gap between the status quo and target state has to be assessed in order to develop a realistic potential plan for achieving sector-level resilience.

This analysis provides a view of the difference between the status quo and the target state, and the gaps in metric development, data collection, and capability planning that would need to be addressed for informed decision making and effective climate resilience planning across the transport sector.

4.2 Gap assessment

For each mode, the gap between the status quo and the target state is assessed against six parameters that were agreed with the DfT and validated with stakeholders:

- P1: The need and potential to develop a consistent unit for the metric.
- P2: The extent to which the required data is already collected and/or available.
- P3: The level of capacity required to collect and report on the metric within the organisations.
- P4: Whether or not the metric could be developed at a central level by DfT or regulating bodies without organisational input.
- P5: Whether standards/expected levels of performance have to be defined first for the metric to be useful.
- P6: Whether organisations reporting on the metric can be monitored through existing mechanisms.

A Red-Amber-Green (RAG) rating and point system is used to assess these parameters for each mode. These RAG assessments are detailed in Appendix **Error! Reference source not found.**5 along with a detailed explanation of the logic of the RAG ratings.

The **key findings of the gap assessment are summarised in the tables below at the level of the modal organisations and the sector**:

- Phase 1: Weather attributed lagging metrics;
- Phase 2: Weather attributed leading metrics;
- Phase 3: Cost and efficacy metrics; and,
- Phase 4: Long-term adaptation, interdependency, and effectiveness metrics.

The assessment **examines the relative feasibility of using the sector-level metrics for the different modes**. It should not be treated as an objective assessment because each mode consists of a diverse range of organisations within each transport mode, which have different governance, funding and operational structures, roles and responsibilities, and capacities and capabilities. Some of the variations and nuances between different organisations are brought out in the narrative below, however the assessment should be treated as a high-level representative view of the mode, with significant variation among individual organisations.

4.2.1 Summary of assessments

The following section discusses the results of the rated feasibility assessment scorecards for each mode (provided in Appendix **Error! Reference source not found.**5). A total of 35 organisations were engaged across the four modes (10 rail organisations, 4 road transport organisations, 4 maritime organisations, 6 aviation organisations and 8 cross-modal organisations).

4.2.2 Road assessment

Table 4.2: Metric feasibility assessment for the Strategic Road Network

	Modal perspective	Sector perspective
Phase 1: Weather-attributed lagging metrics	• Some **asset data** (particularly related to pavement condition and drainage) is linked to weather hazards. However, this does not extend to all asset types and is limited to precipitation and high temperatures. Sensitivity and exposure of assets to climate change is also assessed as part of ARP reporting; however, this is a qualitative assessment. • There is limited linkage of **operational impact data** such as delays or accidents (which are collected to measure general performance) to hazards. The emphasis is more on operational resilience during a weather event, for example tracking of wind speeds to determine bridge closures. • **Leadership/people/process capabilities** are tracked through ARP reporting and climate risk assessments. The general approach is for weather and climate resilience to be considered within the overarching asset management strategy and not separately. • **Information-sharing** largely occurs during weather events through local resilience forums, highways alliances, and data exchanges via mayoral authorities. Information sharing across modes and other sectors is limited. This is not systematically tracked.	• There is a significant challenge around developing consistent sector-level metrics particularly for **asset performance**, given the variations in asset types (although recovery or availability of the SRN could be an aggregate metric). • In general, weather-attributed data cannot be estimated centrally by DfT or regulatory bodies without organisational input. Regional variation in weather hazards precludes generalisation of the mode. • There is a circular challenge because organisations expect standards or expected levels of performance and asset condition to be specified in order to start reporting their weather-specific asset and operational data, but some trend data is needed to set the appropriate standards. • Whilst the ORR regulates SRN **operational performance**, this does not currently extend to climate/weather. • Some information on **capability** can be drawn from ARP reports, but a consistent sector-level framework would have to be developed for the organisation to report on this. • This information would have to come directly from the organisation; however, to enable this an **information-sharing** framework needs to be developed first.
Phase 2: Weather-attributed leading metrics	• **Weather hazard data** is collected from the Met Office and UKCP18 data is used for projections. • **Projected asset and operational impacts** of weather hazards and climate change are not currently assessed – there is a view that this should be done for all future risks and not specifically for climate and weather.	• There are challenges with developing consistent and relevant sector-level metrics, particularly around **asset performance** (as above) • As above, there are limited mechanisms through which **future projections** can be reported on, although could potentially be tied into resilience-specific funding settlements.

Phase 3: Cost and efficacy metrics	• **Adaptation costs** are calculated as part of reporting though the underlying data is not published. • There is currently **no estimation of avoided costs** from climate or weather resilience action. Whilst there is recognition that avoided costs have to be estimated to unlock funding for business cases, stakeholders believe that this should consider risk and resilience broadly (without necessarily being weather or climate specific). • **Wider economic, social and environmental impacts** are not currently assessed though a qualitative measure of reputational damage has been developed.	• From a sector perspective, for **cost projections and wider impacts**, it may be possible to analyse the underlying data to develop the overall sector-level metric without directly gathering organisational input. • As with the above categories, there are currently no holding-to-account mechanisms for these types of metrics but could be included in funding settlements.
Phase 4: Longer-term systems metrics	• **Long-term metrics** around climate action are yet to be developed. However, some efforts to assess the effectiveness of actions are being made, for example, around flood mitigation action (number of assets protected from flooding due to resilience action).	• These metrics will have to be developed over time using the data collected in previous phases. • All challenges described in previous phases like holding-to-account mechanisms, and capability would have to be unblocked. • From a sector perspective, it may be possible to analyse the underlying data to develop the overall sector-level metric without directly gathering organisational input.

Table 4.3: Metric feasibility assessment for local roads

	Modal perspective	Sector perspective
Phase 1: Weather-attributed lagging metrics	• A few advanced local authorities track **weather-attributed asset data**, for example the impact of flooding on pavements and properties, or the impact of heatwaves on material degradation on highways. However, there is no consistent tracking of weather impacts on the assets of local road networks across the country. • A few advanced local authorities track the **impact of weather on their operations** (e.g. reduction in the number of journeys.) However, the emphasis for Local Authorities remains more on operational resilience during a weather event, and any tracking of weather impact is not consistent or universal. • According to representatives of local roads organisations, local authorities tend to be under-resourced and more focused on immediate challenges. Where sustainability **capabilities** exist, they tend to be focused on net zero. A few advanced organisations are investing in leadership/people/process capabilities like climate risk assessment (referenced above), but these are not systematically tracked. • **Information-sharing** between organisations within the mode tends to be quite advanced during a weather event, including through local resilience forums, highways alliances, and data exchanges via mayoral authorities. Information sharing across modes and other sectors is limited. This is not systematically tracked.	• For local roads, it is particularly challenging to develop a consolidated list of **relevant hazards** for the sector because of the varied prevalence and impact of hazards on assets/the network in different geographies. • These variations also make it difficult to identify a consistent sector-level '**asset metric**' beyond cost or recovery minutes, and for expected levels of performance or asset condition to be defined. • In general, **weather-attributed data cannot be estimated centrally** by DfT or regulatory bodies without organisational input. Regional variation in weather hazards precludes generalisation of the mode. • There are currently **limited mechanisms for holding local authorities to account** for reporting against these metrics – local authorities are governed and regulated by the Ministry of Housing, Communities and Local Government (MHCLG) which does not regulate climate resilience and seeks to limit the reporting burden on under-resourced local authorities. DfT provides policy, funding and guidance to local authorities in maintaining their roads but does not currently regulate climate resilience. • Very **limited information on capability** can be drawn from ARP reports for participating local authorities. This information would have to come directly from the organisation or a coordinating group for local authorities (e.g. MHCLG, local resilience forums, or associations).
Phase 2: Weather-attributed leading metrics	• Advanced local authorities collect **weather hazard** data from the Met Office about projections. • There is very limited analysis of the **future operational and asset impacts** of the hazards, partly due to a lack of analytical capacity.	• There are challenges with identifying relevant sector-level metrics, particularly around **asset and operational performance** (as above) • As above, there are no mechanisms through which data can be collected and monitored on **organisational performance**.
Phase 3: Cost and efficacy metrics	• A few advanced organisations have started to assess the **cost of adverse weather events**, for example the spend on surface road maintenance during periods of high temperatures or resource requirements due to incident response. However as described above, most organisations do not have the required capacity.	• There are challenges with identifying consistent sector-level metrics, particularly around **avoided costs and wider impacts**, due to differences in size, geography, asset classes, and therefore impacts. This is particularly true for wider social impacts because of how communities may be impacted across the country. • From a sector perspective, for **cost projections and wider impacts**, it may be possible to analyse the underlying data to develop the overall sector-level metric without directly gathering organisational input. • As with the above categories, there are currently **no holding-to-account mechanisms** for these types of metrics, but they could be included in funding settlements.

	Modal perspective	Sector perspective
Phase 4: Longer-term systems metrics	• Organisations are not currently equipped to report on these metrics, although development of metrics from preceding phases would directly facilitate the definition of phase 4 metrics.	• These metrics will have to be developed over time using the data collected in previous phases. • All challenges described in previous phases like holding-to-account mechanisms, and capability would have to be unblocked. • From a sector perspective, it may be possible to analyse the underlying data to develop the overall sector-level metric without directly gathering organisational input.

4.2.3 Rail assessment

Table 4.4: Metric feasibility assessment for the rail sector

	Modal perspective	Sector perspective
Phase 1: Weather-attributed lagging metrics	• Some rail organisations, particularly infrastructure managers, link past **asset data** (e.g. damage to electrical equipment, and asset performance) to weather events, but this is not widespread, and the granular data for asset performance is not available. The level of detail and consistency varies significantly across organisations. Some TOCs track data relevant to asset performance (e.g. train wheel condition, air conditioning functionality), but this is not consistently linked to weather events. • Both infrastructure owners and TOCs primarily focus on **operational performance**, capturing delay minutes associated with weather-related incidents. Network Rail collects weather-attributed performance data through Schedule 8. This mechanism attributes causes to service disruptions, including weather, and facilitates a cyclical compensation between Network Rail and train companies. These data provide a good indication of weather impacts on the rail mode and are recorded across 9 categories of climate hazard. Advanced TOCs also record this data – however, data variability, quality, and inconsistent reporting practices hinder accurate attribution and geolocation of weather impacts. • Organisations are investing in **leadership/ people/ process capabilities** through ARPs, WRCCA plans, and dedicated sustainability teams (though resource availability varies). However, a consistent, sector-wide focus on climate resilience is lacking, with some organisations prioritising other areas (e.g. net zero). Information sharing is improving but is not systematically tracked. Data aggregation is a significant challenge, with multiple systems and inconsistent reporting practices hindering comprehensive analysis. Cross-modal information sharing is limited despite some initiatives (e.g. TfL-Network Rail MOU for collaboration on asset management, maintenance, and environmental sustainability).	• Developing relevant sector-level metrics, particularly for **asset performance**, is challenging due to variations in asset types and data inconsistencies in attribution. Consistent metrics (e.g. costs or maintainability) are possible but require significant data harmonisation. • Like with the roads sector, weather-attributed data **cannot be estimated centrally** without organisational input due to the decentralised nature of data collection and reporting. • Like with the roads sector, a circular challenge exists in the sector, with organisations asking for '**expected levels of service/asset condition**' to be defined in order to start reporting, but some historic data being needed to define those standards. This hinders the development of consistent, comparable metrics across the sector. • **Holding-to-account** mechanisms are generally limited. While the ORR regulates some organisations, their role in climate resilience is not yet fully developed and the industry operating model is currently in flux. Existing climate resilience reporting channels (ARPs, WRCCA plans) are not binding. Network Rail's Schedule 8 facilitates some weather-attributed accountability. The mechanism attributes responsibility for weather-related passenger delay compensation payment, although this process is binary, and does not capture complexity or the shared nature of operational disruptions across multiple parties. • Very limited information on **capability** can be drawn from ARP reports for participating organisations. • Information on **information-sharing** would have to come directly from organisations within the sector.
Phase 2: Weather-attributed leading metrics	• Advanced organisations (both infrastructure owners and TOCs) collect **weather hazard data** from the Met Office, but the timeframe of projections varies. While climate projections form part of five-yearly planning cycles, no specific leading metrics have been identified. • Organisations are not currently analysing **future operational and asset impacts of hazards**, due to a lack of analytical capacity and data being spread across departments.	• Challenges in developing relevant sector-level metrics, particularly around **asset performance**, persist (as above) • There are currently **no holding-to-account mechanisms** for future weather/climate resilience, but these could potentially be tied into resilience-specific funding settlements in the future.

	Modal perspective	Sector perspective
Phase 3: Cost and efficacy metrics	• Some infrastructure managers and TOCs calculate **backward-looking weather-related compensation costs and financial losses** disaggregated by weather event (e.g. heatwaves or flooding), which cover both operational costs and asset repair/damage costs. • However, organisations shared that it is easier for them to analyse **operational costs** due to weather events (e.g. from delays) than analyse weather-attributed asset investment due to a lack of capacity and data. • Organisations are yet to develop **forward looking projections** for weather and climate-attributed asset and operational investment	• As with roads, it is challenging to develop sector-level metrics for **avoided costs and wider impacts** due to variations in size, geography and asset classes. This is particularly true for social impacts. • Projecting from past data might be possible without organisational input, but this would require significant sector-level capacity. • Holding-to-account mechanisms are absent but could be incorporated into funding settlements.
Phase 4: Longer-term systems metrics	• Organisations are not currently equipped to report on these metrics, although development of metrics from preceding phases would directly facilitate the definition of phase 4 metrics. Two advanced organisations interviewed for this study are actively thinking about these metrics.	• These metrics require development using data from previous phases. • Addressing challenges in data collection, aggregation, reporting and holding-to-account mechanisms is crucial. • Analysing underlying data might allow for sector-level metrics without direct organisational input, but this requires significant investment in data infrastructure and analytical capabilities.

4.2.4 Aviation assessment

Table 4.5: Metric feasibility assessment for the aviation sector

	Modal perspective	Sector perspective
Phase 1: Weather-attributed lagging metrics	• Some advanced international airports are already attempting to link past **operational data** to hazards (notably some airports which have undertaken back dated weather and operational data mapping through 1990- present). ANSPs and regulators are also disaggregating operational data such as delay minutes by weather causes, especially for individual significant shocks (e.g. severe storms). This operational data is extensive and has been recorded for many years, allowing for a back-dated analysis. • Weather attribution of **asset-level data** is generally limited. However, some advanced aviation stakeholders are beginning to consider the impact of weather hazards on key assets like buildings and runway damage owing to flooding or other weather events. • Many organisations are investing in **leadership/people/process capabilities** including ARP, TCFD and risk governance, as has been noted at a regulator, an ANSP and a major airport, where climate risk has been embedded into organisational risk registers. Smaller airports tend to have less maturity and capability around climate resilience. • **Information-sharing** between organisations within the mode tends to be quite advanced but less so across modes and other sectors. This is not systematically tracked.	• There is a challenge around pulling together relevant and consistent sector-level metrics particularly for **asset performance**. Hazards are location-specific, where risks to a certain airport may not apply to others (e.g. flooding at Gatwick). Hazards at airports are driven in part by wind direction in a way that does not impact organisations with dispersed asset-bases in the same way. • For **operational** metrics, there is work to define and agree a sector-level metric, for example, recovery minutes. • **Weather-attributed data** cannot be estimated centrally without organisational input. • There is a **circular challenge** at play because organisations expect standards or expected levels of performance and asset condition to be specified in order to start reporting the data, but some data is needed to define the standards. • There are currently **no holding-to-account mechanisms** for these metrics – whilst Civil Aviation Authority (CAA) regulates airports and ANSPs for safety, this does not extend to weather – in fact, weather-attributed delays are removed from the ANSP delays on weather as this is something that is considered outside their ‘control’. CAA does collect monthly performance data from airports, but this too is non-weather attributed. • Some information on **capability** can be drawn from ARP reports for advanced airports, but a consistent sector-level framework would have to be developed for the organisation to report on this. • This information would have to come directly from the organisation; however, to enable this a framework needs to be developed first.
Phase 2: Weather-attributed leading metrics	• Almost all organisations in the sector collect **weather hazard data** from the Met Office about projections, though there are variations in how far into the future organisations utilise this data for projections. • Some advanced airports have started to analyse **future operational and asset impacts** of the hazards (for instance winter weather), as was highlighted by an airport. However, this is not done systematically or regulated, partly due to a lack of analytical capacity.	• There are challenges with developing relevant sector-level metrics, particularly around **asset performance** (as above). One airport operator conducts back-dated analysis on weather impact on assets, but results did not evidence climatic effects. • At a sector level, there are currently **no mechanisms** by which organisations can be held to account for reporting on leading metrics, as airports and ANSPs are private organisations who are not directly funded by the government.

	Modal perspective	Sector perspective
Phase 3: Cost and efficacy metrics	• Whilst some advanced airports have started to assess the **financial materiality** of climate risk as part of TCFD materiality assessments, this is still quite nascent with no specific numbers around costs or avoided costs. One ANSP calculates the loss of revenue from reduced services due to a weather event. One airport calculates the depreciation cost of plant and equipment. Other organisations in the sector have not yet started to do this, and capacity is a significant constraint.	• There are challenges with developing relevant **sector-level metrics**, particularly around avoided costs and wider impacts, due to differences in size, geography, asset classes, and therefore impacts across different organisations. • From a sector perspective, for **cost projections and wider impacts**, it may be possible to analyse the underlying data to develop the overall sector-level metric without directly gathering organisational input. • As with the above categories, there are currently **no holding-to-account mechanisms** for these types of metrics.
Phase 4: Longer-term systems metrics	• Organisations are not currently equipped to report on these metrics, although development of metrics from preceding phases would directly facilitate the definition of phase 4 metrics. Some advanced international airports have mature climate resilience capabilities and would be keen to be involved in the development of these metrics, as noted in knowledge exchange forums by European airports. One airport has a forward-looking CCRA on upstream vulnerabilities from 2020-2049.	• These metrics will have to be developed over time using the data collected in previous phases. Existing climate resilience forums, e.g. European Aviation Safety Agency (EASA) could be leveraged for this. • All challenges described in previous phases like holding-to-account mechanisms, and capability would have to be unblocked. • From a sector perspective, it may be possible to analyse the underlying data to develop the overall sector-level metric without directly gathering organisational input.

4.2.5 Maritime assessment

Table 4.6: Metric feasibility assessment for the maritime sector

	Modal perspective	Sector perspective
Phase 1: Weather-attributed lagging metrics	• Some port operators are already linking past **operational outcomes** to hazards using vessel tracking system (VTS) data although challenges persist in the reliability and verifiability of the associated weather data, as the port authorities have minimal oversight on the entry process for VTS data. A wide range of indicators are used for weather-attributed operational impacts including vessel/pilotage delays and navigational incidents, however there is no agreed metric used by the industry. • There is less focus by port operators on the direct impact of climate change on **assets**, although non-weather attributed data on damage to harbour authority assets is collected. One operator indicated their capturing of asset-level effects of hazards in their risk assessment, although no underlying data is available. Two sources from non-port operators provide high-level estimates of hazard-damage to ports.	• A relevant sector-level metric measuring delay time could be consolidated to measure **performance**, although significant variance in average delay according to voyage length could impede the utility of this unit, as well as attribution of weather based challenges across multiple geographies (e.g. ports that receive vessels from primarily European destinations would likely have lower absolute delay minutes than ports receiving vessels from other continents). • Consistent units for **asset-performance** metrics would likely be challenging due to variance across structures, geolocations, sea levels and vessel-type requirements. • Units for leadership/people/process **capabilities and information sharing metrics** would be easy to develop due to their binary nature. However, the information would have to come directly from the organisations as ARP reporting is limited in the sector.

	Modal perspective	Sector perspective
	● Organisations in the mode do not currently collect metadata for their **leadership/people/process capabilities**, although some are investing in climate change risk assessment and reporting through ARP. ● There are few existing **information sharing channels** between organisations, although some data sharing occurs between port authorities in geographical localities. Conversely, there are disincentives to exchange information particularly between competitive ports. Some information exchange occurs between port authorities and highway authorities (e.g. Operation Brock), however this does not currently extend to the sharing of weather information.	● Organisational input would be needed to estimate and produce **weather-attributed data**. ● Organisations are not currently **held to account by the regulator** for any phase 1 metrics, and no existing mechanisms are in place to facilitate this. Limited ARP reporting by port operators impedes monitoring of accountability.
Phase 2: Weather-attributed leading metrics	● Most port operators monitor short term **weather data**, with many also collecting long-term climate data from the Met Office. Both data types focus to a lesser extent on terrestrial weather data, with a greater focus on chronic changes to sea levels, storm event incidence, and their implications for bathymetry and vessel navigation. Visibility of the extent to this data collection is hampered by the limited number of organisations reporting through ARP, and lack of existing mechanisms to hold organisations to account. ● Projecting the impact of **hazards** on both operations and assets would require significant analytical capacity and organisational input for their development.	● The same challenges faced in developing units for phase 1 asset and operational performance would be contingent in the development of phase 2 metrics. It is considered difficult to develop leading metrics in the absence of post-facto datasets. ● **Projecting hazard frequency and severity** may not require organisational input since data can be obtained from the Met Office, yet understanding implications for the sector would require context provided by organisational data the availability of which is still unclear within the maritime sector. ● While organisations are not widely reporting on the projected impacts of hazards on performance, the extensive historical data of the maritime sector could be leveraged to contextualise understanding of potential impacts and provide capacity to develop **leading performance metrics**. Known quality issues with weather-attributed VTS data would pose challenges. ● As with phase 1 metrics, there are **no current mechanisms for holding organisations to account**, although these could be developed and implemented through funding settlements or by the regulator.
Phase 3: Cost and efficacy metrics	● Port operators have not linked **financial data** to projections of operational or asset impacts, although there is some monetisation of current impacts. ● The current capacity of organisations to achieve this is limited owing to significant capacity constraints and the need to validate existing data. Port operators have expressed interest in conducting this work, using VTS data, evidencing that this work is feasible with adequate resource and data validation. ● Port operators do factor climate change adaptation into design and planning processes, as has been highlighted by port operators in interviews, yet no metrics exist to measure this.	● There are significant challenges associated with developing aggregate units for phase 3 metrics associated primarily with capacity limitations. ● Some estimates of **investment costs and wider socioeconomic and environmental impacts** could be made without organisational input, yet these metrics would benefit from their involvement and data. ● As with phase 1 and 2 metrics, there are no current mechanisms to hold organisations to account on these metrics.

	Modal perspective	Sector perspective
Phase 4: Longer-term systems metrics	• Organisations are not currently equipped to develop these metrics, although development of metrics from preceding phases would directly facilitate the definition of phase 4 metrics.	• These metrics will have to be developed over time using the data collected in previous phases. • All challenges described in previous phases like holding-to-account mechanisms, and capability would have to be unblocked. • From a sector perspective, it may be possible to analyse the underlying data to develop the overall sector-level metric without directly gathering organisational input.

4.2.6 Summary of the gap assessment

As described in the methodology, this assessment is a high-level indicative view of the feasibility of reporting on sector-level metrics across the modes.

The gaps identified across the four modes based on the primary and secondary research exhibited some variability, but largely demonstrated the following characteristics:

Metrics and data development

1. Several organisations collect relevant data on assets and operations (e.g. delays, cancellations and asset damage), but in most organisations, this is not **currently weather-attributed**. Across the modes considered, operational performance-based weather attribution (particularly where related to safety) was more widespread than asset performance weather attribution. However, the consistency of this data is variable.
2. Consistent and/or aggregable metrics are difficult to develop particularly for asset-level performance given variability in geography, geology, structures, and asset type. While DfT may be placed to identify and guide data collection, **the underlying data for most metrics will have to be collected directly from organisations.**
3. There is some **variability in the extent of projected hazard impacts**, with aviation and strategic roads having the most mature view of projected hazards and impact historically. As a whole, projections of weather hazards and their impacts on operations and assets require significant historical data which can attribute past weather to operational or asset impacts. This attribution process would be a requirement before the sectors can design Phase 2 forward-looking metrics. In addition, there is currently **no consistent list of hazards for the overall transport sector**, owing to modal variability, and distinct risks and weather hazards to assets in differing locations.
4. Some organisations are investing in building people/process/leadership capabilities (e.g. adapting design standards and improving controls) but not necessarily tracking them. Some advanced organisations publish ARP reports (reports produced under the Adaptation Reporting Power (ARP) of the Climate Change Act 2008, which detail how organisations are taking action to adapt to climate change) where this information can be found.
5. There is limited use of cost and efficacy metrics, though some organisations (e.g. airports) have started collecting this information for TCFD reporting. The cost implications of long-term action (or inaction) are particularly complex, and are not currently being assessed.

Capacity and capability

6. Based on interviews and workshops with transport organisations, many organisations do not generally have the **capacity and, in some cases, capability** needed to collect and report data exhaustively. For example, in many organisations the operational, asset, and weather data sit in different parts of the organisation and there is limited capacity to consolidate this. This challenge is particularly acute for smaller organisations (e.g. local authorities).
7. Conversely, many organisations engaged through this project recognise that the data **is needed to make the investment case for – and build – resilience capability**, thereby creating a vicious cycle.
8. Organisations realise the value of appropriate **information-sharing** between themselves, but this is limited to sharing in high-level working groups, including due to the capacity constraints referenced above and commercially sensitive data.

Governance

9. In general, the research and stakeholder engagement showed that **mechanisms to hold organisations to account for their weather or climate resilience** are limited, albeit existing governance and funding settlements could potentially be adapted to hold some

public sector organisations to account. For private sector organisations, particularly in the rail, maritime and aviation sectors, there is a challenge around sharing commercially sensitive data.

10. Organisations across modes consistently raised the challenge of **expected levels of asset and operational performance** in different weather conditions having to be defined first as a baseline for reporting and holding-to-account mechanisms to be developed and applied.

5 Potential high-level next steps

5.1 Overview

This chapter sets out some high-level potential next steps that could be considered to build on the status quo and achieve the sector-level metrics set out in the roadmap. The actions are informed by the gap assessment detailed in Chapter 4. This report is not government policy but, rather, contains findings arising from this research with considerations for the transport sector to improve the maturity of climate resilience metrics and management techniques.

5.2 Methodology and structure for potential next steps

In order to develop a set of purpose-driven and feasible potential next steps, a methodology was developed to help ensure that they are rooted in the purpose that sector-level metrics are meant to serve and address specific feasibility gaps identified in the gap assessment. **These are based on the findings of the report and should be explored in the context of wider actions that need to be undertaken in the transport sector to improve its resilience to weather events and climate change.**

The specific logic used for each parameter is detailed in the table below.

5.2.1 Type of gap

Gaps have been broadly categorised into three types based on the six feasibility parameters identified in the previous chapter.

Feasibility parameters	Type of gap
P1: Potential to develop aggregate units for the sector	Metric and data development
P2: Existence of current data	
P3: Capability requirements within the organisations	Capabilities
P4: Potential to analyse the metric at a DfT level	
P5: The need for expected service levels to be defined	Governance
P6: The need for holding-to-account mechanisms	

5.2.2 Gap assessment

The main gaps identified in Chapter 4 have been detailed here in order to inform next steps that could help address these gaps. It is worth noting that some of these have been repeated because several different actions may be required from different organisations to address them.

5.2.3 Next steps

The next steps have been developed to answer the specific question of '*What could be done to close the gap between the sector-level roadmap (Chapter 3) and the status quo within the sector (Chapter 4)?'* These have been consolidated for all modes, with more detail presented for individual modes in Section 5.3 for some specific actions.

5.2.4 Phase

The next steps have been linked to the specific phases of metrics from the sector-level roadmap:

- Phase 1: Weather-attributed lagging metrics.

- Phase 2: Weather-attributed leading metrics.
- Phase 3: Cost and efficacy metrics.
- Phase 4: Long-term adaptation action metrics.

Where an action has to be started in a particular phase but matured over time, this has been specified by citing multiple phases.

5.2.5 Proposed owners

Most next steps would require action at both a transport sector level (i.e. from DfT, regulators, other national bodies) and a modal level (i.e. the specific organisations within modes and modal associations). Since the purpose of the sector-level metrics is around sector-level consistency, most of the next steps are more relevant to central government or regulators. However, these cannot be achieved without input and collaboration from the modes and the organisations therein. Where intervention would be needed from the modes, these are clearly highlighted as actions below.

5.2.6 Level of effort

The next steps below require different levels of effort from the owners and collaborators. Some are enabling actions that can be delivered quickly to catalyse other actions, whereas others are more systemic, complex interventions that will require significant coordination and complicated decision-making. The next steps are therefore characterised into three levels of effort – low/quick wins, medium, and high – based on consultation with stakeholders.

5.3 Long-list of high-level potential next steps

This table consolidates next steps that could potentially fill the gaps identified through the analysis in Chapter 4. The details of how these actions can be achieved - including level of effort and importance - are covered in Section Error! Reference source not found.**.**Table 5.1: Potential next steps to address gaps

Type of gap	Gaps (as per Chapter 4)	Potential actions	Phase	Potential accountability	Level of effort
Capability	Organisations do not have the capacity needed to collect and report data exhaustively.	**1.1 Define asset criticality:** A phased approach to data collection, which takes into account the cost and reporting burden on organisations, is critical to the success of the system. DfT could work with NISTA, sector regulators and modes to define the most critical assets within the transport network for which leading and lagging metrics are needed in the first instance, which can then be matured over time. It is expected that organisations within the transport sector will already have a high degree of understanding of the assets which are most critical. This information would be valuable for the DfT.	1	DfT	Medium
		1.3 Examine internal capability: Given the growing impact of weather events and climate change on the BAU operations and financial position of all organisations, climate resilience would benefit from being considered at a Board level and the required capability from being integrated into their asset management, operations, and finance teams along with the consideration of climate change impacts within associated policies, processes and activities.	1	Modes (at Board level)	Medium
		1.4 Aggregate information, and facilitate knowledge exchange, within each mode: Modal associations (e.g. UKRLG, ADEPT, ports and airports associations) have an important role to play in aggregating information at a modal level and facilitating exchange of information between larger and smaller organisations. This could be done through existing working groups and conducting surveys. E.g. For the local roads sector, existing tools such as HIRAM (network-based resilience monitoring tool for climate risks and socioeconomic impacts) could be utilised to inform hazard prioritisation for different parts of the network and to assess mitigation options across local and national scales. Larger and more advanced organisations (especially among airports, ports, and local authorities) can share frameworks with smaller organisations (taking into account commerciality within the private sector.)	1-4	Associations	Medium
Capability	Information-sharing across modes and other sectors is currently limited because of the significant effort required, although	**1.6 Develop Interdependent Risk Maps:** DfT could support organisations across the transport sector to identify and assess interdependent risks by undertaking a project to develop systems thinking-informed interdependency maps for each transport mode that can be used by modes as part of their climate change risk assessments. This could include the clear definition of cross-sector linkages, for example with the energy and water sectors. By carrying out this activity centrally, there will be a consistency in method and interfaces reducing the likelihood of missed connections.	1	DfT	Low: Quick win

	organisations realise the value of it.	**1.7 Share information <u>across</u> modes through existing forums and channels:** Operational resilience teams tend to be fairly joined up within modes (e.g. SRN and local highways, airports and ANSPs, and infrastructure managers with TOCs), however almost all organisations have an ambition to be more joined up across modes and sectors (particularly energy and water). Organisations can work together through existing forums and leveraging past examples (e.g. Operation Brock and Storm Desmond) to share information and support the development of a robust methodology for measuring interdependency. DfT could also work with organisations to identify the existing mechanisms, forums, networks and tools (such as local resilience forums) used for sharing information between transport modes to determine what (if any) additional steps are required to enable effective information sharing between transport mode organisations, particularly addressing commerciality concerns.	1-4	Modes (with DfT support)	Low: Quick win
		1.8 Establish information sharing between transport and other sectors: DfT could work with organisations in other sectors (e.g. Defra, Ofwat, Ofgem) to help the development of a cross-sector interdependency framework, including governance (accountabilities and responsibilities), shared analytical tools, and data-sharing mechanisms. Existing initiatives can be leveraged to support this activity, e.g. the CREDO tool being developed by Connected Places Catapult for the energy sector and Asset Health study being conducted by Ofwat could be leveraged by DfT.	1	DfT	Medium
Governance	Expected levels of asset and operational performance are needed if organisations are to be held to account.	**2.1 Define expected levels of performance:** Organisations could work closely with DfT, NISTA, sector regulators, and modal organisations to develop expected levels of service (for operational performance and asset condition) so that performance can be reported against a standard. The degree of leeway and circumstantial adjustment to performance expectations under extreme weather conditions should also be defined to guide adaptation and preparation for these events. This would require a review of existing standards and thresholds for guidance (e.g. Delay Attribution Board (DAB) for Network Rail, or NATS thresholds for storms and turbulence) to support the definition of modal specific extreme weather conditions where adjustment to performance expectations is allowable. Organisations would also need to establish a strong counterfactual (i.e. baseline of "normal/expected weather" or threshold) and attribution analysis to allocate potential adverse weather-related impacts. Some historic weather-attributed data on asset and operational performance would be needed to inform the development of expected levels of performance (for extreme weather conditions). Advanced/larger organisations within each mode could work with DfT to provide these, though smaller organisations could also share their specific challenges and requirements through associations (e.g. UKRLG, British Ports Association, British Aviation Group).	1	Modes (in consultation with DfT and sector regulators)	High

Governance	Holding-to-account mechanisms are limited for large parts of the sector.	**2.2 Define operating and administrative governance over time:** DfT could develop an operating model (in consultation with Defra, MHCLG, and regulators), setting out how climate and weather resilience should be governed across the sector, given the complexities associated with differing governance structures, regulatory requirements, and funding arrangements. This operating model could consider the organisations involved, their responsibilities and accountabilities, the interfaces necessary, and how existing legislative/regulatory/licence conditions might have to evolve. This would benefit from alignment with the wider transport sector operating model and other priorities like decarbonisation, operational performance, and wider resilience.	1-4	DfT	High
		2.3 Review and adapt existing data governance where possible in the short term: DfT could work with other government departments and regulators to determine the best approach for collecting data on the Phase 1 and 2 metrics leveraging existing mechanisms like ARP, funding settlements, licence agreements etc. For example, DfT could be 'looped in' to existing information sharing channels between TOCs and Network Rail via Schedule 8, thereby minimising additional capacity required, and supplying DfT with weather-attributed data.	1-2	DfT	Medium
		2.4 Develop channels for collecting cost and efficacy metrics: DfT could work with Arm's Length Bodies (ALBs) to consider how funding settlements and licence agreements could and should factor in climate resilience. For private organisations that are not directly funded by DfT, other approaches could be explored which aligns with the updated governance.	3	DfT	Medium
Metrics and data development	Consistent, 'aggregable' metrics are needed at a sector level (particularly challenging for asset data)	**3.1 Develop consistent indicators:** DfT could work with modal organisations to develop consistent indicators for each transport mode including the scope of what would be included and excluded – e.g. delay or recovery costs for operational performance, and asset recovery and repair costs for asset performance – and any associated guidance or methodologies should be developed. This action would be informed by the definition of asset criticality. Existing modal forums and initiatives should be leveraged to develop these – e.g. RSSB's Climate Adaptation Metrics project, EASA (European Aviation Safety Agency), Major Ports Group, and UKRLG/ADEPT. The metrics and indicators could be published and updated iteratively as a 'guiding document' for the sector.	1	DfT	Medium
	Several organisations collect relevant data that is not currently weather attributed	**3.2 Support the development and dissemination of weather-attribution methodology:** DfT could support the modes, through engagement with organisations and associations, to develop technical methodologies for (1) correlating performance to weather/climatic factors, and (2) for using historic data to project future performance. As a sector-level organisation whose remit is cross-modal, DfT has the ability to identify similarities and differences across the modes to feed into the development of the mode-specific methodologies as well as to disseminate approaches from more advanced organisations to smaller organisations within each mode.	1-2	DfT	Medium

Several organisations collect relevant data that is not currently weather attributed	**3.3 Update existing datasets where possible to include weather attribution:** Many organisations tend to be quite advanced in operational resilience planning, asset management, and data collection, but not in linking operational and asset data and metrics to weather events and climate change. These organisations could **link data-sharing and decision-making across operational, asset management, and climate resilience teams**. For example, to begin with, this could be done by ensuring that time series data on health & safety incidents or asset repairs also record adverse weather events to enable comparison at different points in time.	1	Modes	Medium
Several organisations collect relevant data that is not currently weather attributed	**3.4 Develop a reporting template and terms of reference for data collection:** As demonstrated in the sector level roadmap (Chapter 3), DfT might ask modal organisations to report on some metrics (e.g. delays attributed to weather hazards, top 5 anticipated hazards for the following year, or estimated cost of asset damage). DfT could develop a simple template for collecting this data that considers Phase 1 data needs, the existing datasets within each organisation (Deliverable 2.2), consistency where possible across modes and organisations, and the level of effort required to periodically extract the data from ARP vis-à-vis asking organisations to report it. This template would evolve over time as the transport sector and all the organisations within it progress on their data maturity journey and more complex Phase 3/4 metrics are developed. Terms of reference would also have to be developed for different organisations that are aligned with the governance structure for that organisation and consider commercial/confidentiality challenges.	1-4	DfT	Medium
Organisations are investing in leadership, people, and process capabilities but not systematically tracking them.	**3.5 Develop a maturity measurement framework:** DfT could set out a capability maturity measurement framework for assessing leadership, people, and processes for adaptive capacity capabilities across the transport sector; and to develop a mechanism for this data to be collected, drawing on existing private or public frameworks such as Adaptation Scotland's publicly available climate adaptation capability framework[13] that informed the development of NHS England's climate adaptation framework[14]. The framework could use a phased approach to ease the reporting burden by initially only using simple (e.g. binary) reporting units that can form percentages at organisational types, modes and the sector when aggregated and disaggregated, but have the flexibility to be developed over time to inform Phase 4 metrics.	1-4	DfT	Low – Quick win
No consistent methodology for assessing effectiveness of long-term action	**3.6 Develop long-term metrics:** DfT could work with Defra, National Hub for Decarbonised Adaptable and Resilient Transport Infrastructures (DARe), research organisations, industry experts, and existing resilience forums to develop long-term metrics around adaptation and interdependency, leveraging the information from the previous phases – e.g. around maturity and interdependency measurement.	4	DfT	High

[13] Climate Adaptation Capability Framework - Adaptation Scotland

[14] NHS England » A climate adaptation framework for NHS organisations in England

5.4 Shortlisting of the potential next steps

A more detailed analysis of feasibility and impact would have to be conducted by the sector to achieve the sector-level metrics. However, it is helpful to assess the next steps at a high level based on level of effort and relative priority (from a logical sequencing perspective).

Potential prioritisation has been informed by assessing 'importance' (or how many other metrics an action enables). The detail of this assessment is shown in Table 7.2.

5.4.1 High-priority potential next steps

These are listed below in order of effort level.

Action 3.1 Develop consistent indicators (DfT)

This is the highest scoring step because it would enable the establishment of many metrics. Nevertheless, for it to be undertaken, several other steps already highlighted would need to have been undertaken. It is also expected that this might have to be taken concurrently with Action 2.1 discussed below. Workstream 2 started identifying the types of indicators that could be used consistently across transport modes or the sector; however, it did not identify specific indicators that should be applied across a transport mode or the sector as a whole. Therefore, consistent indicators need to be developed based on common methodologies and agreed performance levels.

Action 3.4 Develop a reporting template for data collection (DfT)

Developing a reporting template to enable organisations to report on sector-level metrics would, in time, allow the metrics to be displayed and trended in a way that enables consistency. Nevertheless, for this step to be meaningful, there are others that would be sensible to complete first, such as the development of consistent indicators (Action 3.1). A phased approach could be taken where the first iteration of the template only requires limited inputs from transport sector organisations, for example on relevant hazards. Later phases of the tool could build on the first iteration to allow additional information to be collected, compiled and displayed as other actions progress. Given the possibility of using simple binary inputs to report against the maturity measurement framework (Action 3.5), there is an advantage of developing that framework first.

Action 1.1 Define asset criticality (DfT)

Understanding the criticality of assets within the transport system through a risk-based approach would help to prioritise effort and minimise the reporting burden on transport organisations. This step has been given a medium effort score due to the potential complexity in developing a consistent approach for understanding the criticality of transport sector assets across the whole transport system. Nevertheless, it is recognised that many organisations might already have a detailed existing understanding of asset criticality within their organisational scope. Early coordinating effort on this action is expected to deliver efficiency savings later.

Action 1.3 Examine internal capability (Modes)

This action is for transport mode organisations to consider for themselves and their supply chains. It will be enabled by Actions 3.6, 1.5 and 1.2 already having been completed. The completion of those actions will provide a means for transport organisations to assess the maturity, understand their potential risks (if they have not already performed a CCRA), and have a means of understanding the benefits for investing in their climate adaptation and resilience capabilities.

Action 2.2: Define long-term governance (DfT)

This step is fundamental to the long-term climate resilience of the transport system. However, it is a challenging topic as a result of the number of organisations, their interfaces and their roles and responsibilities. As a first step, a stakeholder mapping exercise could be undertaken per transport mode, followed by the compilation of each stakeholder's roles and responsibilities, and current legislative, regulatory and/or licence frameworks in relation to climate change adaptation and resilience. Once the baseline understanding of the existing landscape has been reached, the next step would be to liaise with the relevant organisations to map potential governance structures and arrangements. However, this latter step is very much dependent on the completion of the first.

Action 2.1 Define expected levels of performance (Modes)

As identified in the gap assessment, this step would help define a baseline level of performance for modes to then report against and estimate investment requirements. This would involve engagement and coordination between a large number of stakeholders. It could be carried out in parallel with Action 2.2. It would also be enabled by Action 1.1 (define asset criticality) and Action 1.3 (share preliminary data) so that performance expectations are only defined for the most significant assets based on a shared understanding of past performance.

5.4.2 Quick wins

These are the steps that could potentially be less expensive and quicker to implement based on the analysis in Section 5.3. They are presented below in order of their relative priority.

Action 3.5 Develop a capability maturity measurement framework (DfT)

The development of a capability maturity measurement framework could be undertaken in parallel with Action 3.4 because transport sector organisations could be asked to report on the maturity of their climate resilience capability using Action 3.4's reporting template. The framework can be developed such that reporting against it only requires simple binary inputs or responses. This step is an individual package of work that could be undertaken using examples of existing good practice maturity measurement frameworks from other sectors and capabilities.

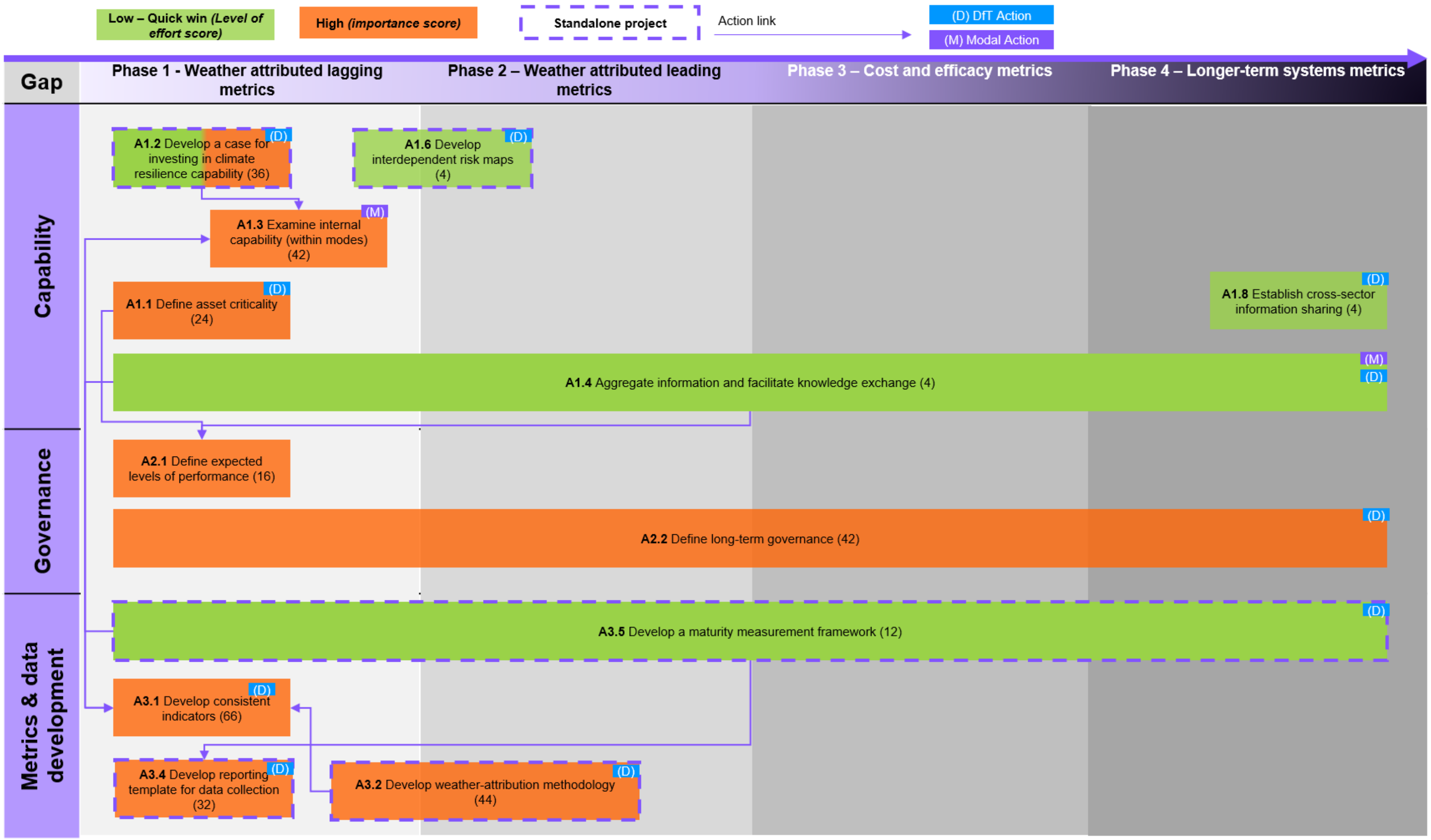
Action 1.2 Share information through existing channels and forums (Modes and associations)

This step has been categorised as a quick win because existing forums like local resilience forums or modal associations can enable information-sharing and metrics development with a focus on climate and weather resilience. Smaller-scale arrangements between transport organisations also exist as modal and inter-modal opportunities for DfT such as the MOU between TfL and Network Rail, Operation Brock (facilitating data-sharing between port authorities and highway authorities), data sharing between ANSPs and airlines, and between Eurocontrol and other ANSPs. In practice, this could be done by identifying priority forums for engagement, nominating DfT representatives to participate regularly, and establishing a structured agenda to incorporate climate resilience metrics and data-sharing protocols.

Action 1.6 Develop interdependency risk maps (DfT)

Throughout the stakeholder engagement on this project, the significance of interdependent risks was repeatedly highlighted as a topic that needs greater understanding. Recent examples in the UK and abroad have highlighted the reliance of transport infrastructure on other systems such as electrical power, where a failure in one system (electrical) can have effects on other infrastructure systems (rail services). Currently transport sector organisations are limited to considering these risks in isolation or in an ad hoc manner because the tools and interfaces are not prevalent enough to allow the interdependent risks to be identified. There is a significant opportunity for the transport sector to take the lead by developing interdependency risk maps for each transport mode that could be shared with the sector. By developing and providing these risk maps, transport sector organisations would have a consistent and complete starting point from which to identify and assess their organisational specific interdependencies.

Figure 5.1: Potential roadmap of modal actions



Source: Project Team

6 Conclusion

This report is the culmination of a detailed study on the potential importance and feasibility of introducing sector-level metrics to assess the resilience of the transport sector to weather events and climate change. It is based on extensive primary research (through interviews and workshops) and secondary research (through a literature review) of the impacts of weather events and climate change on the sector and what data, metrics and indicators organisations are currently using to assess these impacts. Across the transport sector, stakeholders agree that measuring the resilience of the transport sector to adverse weather events and climate change is critical to making improvements in how the sector responds to these. Conversely, the cost of inaction is severe – physically, societally, and economically.

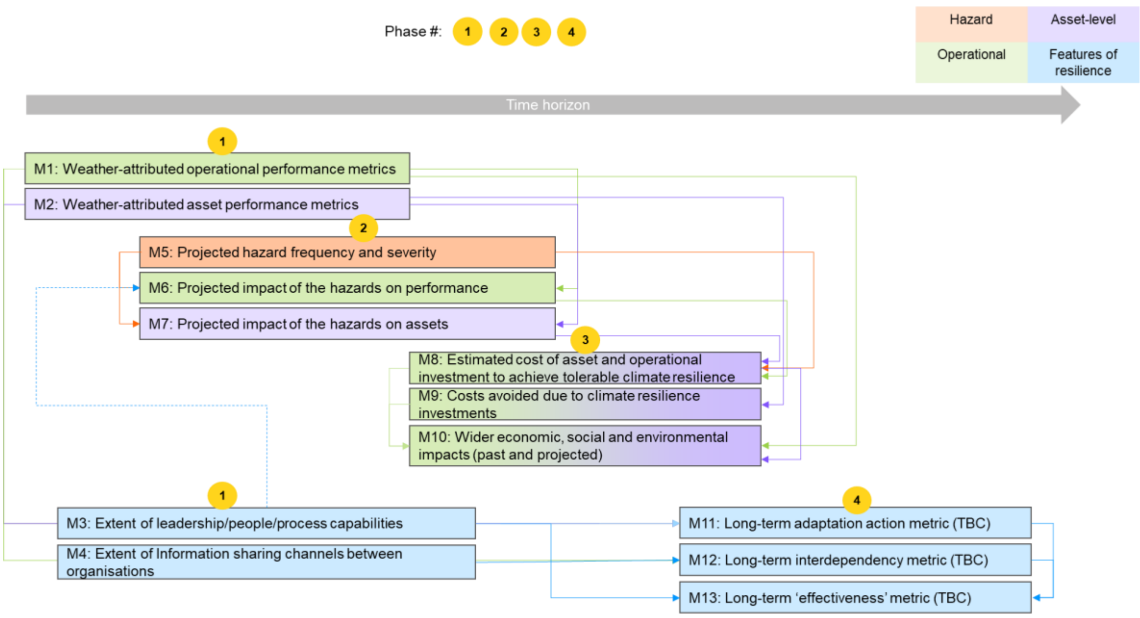
As discussed in Chapter 3, the metrics required to assess the resilience of the transport sector to climate resilience and weather events could be developed over time. The metrics are categorised into four types based on the framework developed in Workstream 1:

- **Hazard metrics:** Measures the extent (temporal/spatial) of climate hazards.
- **Asset-level outcome metrics:** Measures the impact on transport assets of a hazard occurring.
- **Operational outcome metrics:** Measures the operational impact of the hazard occurring.
- **Features of a resilient system:** Measures that quantify attributes of a resilient system.

The metrics derived in this work form part of an overarching approach to measuring the resilience of the transport sector, which assumes that metrics would feed into each other, and that some long-term metrics will be more difficult to develop. To illustrate the gradual development of metrics, 'phases' were prescribed which indicate the sequencing of metric development (rather than specific time periods, which would have to be developed based on the considerations of the feasibility assessment in Chapter 4, including the availability of good data).

An overview of the roadmap for metric development is shown in **Error! Reference source not found.**:

Figure 6.1 Sector level roadmap



Source: Project Team

However, as detailed in Chapter 4, there are significant gaps in achieving those metrics based on feasibility at both a sector and modal level. This assessment found that while some weather-related operational data is available across transport modes, consistent and comprehensive reporting, especially for asset-level and long-term resilience metrics is limited. Key gaps include the lack of standardised methodologies, limited organisational capacity (particularly among smaller organisations), and insufficient mechanisms for accountability and cross-sector data sharing. Metrics related to capability and hazard projections are most feasible to report, while those assessing long-term outcomes and investment efficacy remain underdeveloped.

Therefore, for the sector level metrics shown in the roadmap to be realised, a range of next steps may need to be considered by the government, regulators and transport organisations to establish the tools and capabilities to capture, analyse, and share supporting data and information. A selection of the most achievable (quick-win) and most impactful (longer-term, high-priority) next steps are summarised in Table 6.1, below.

Table 6.1: Potential 'quick win' and 'high-priority' next steps

	Quick wins	High-priority
DfT	• Develop a capability maturity measurement framework • Develop interdependency risk maps	• Develop consistent indicators • Support the development of weather attribution methodology • Define asset criticality for the sector • Define long-term governance • Develop a reporting template and terms of reference for data collection
Modes	• Improve information through existing channels and forums	• Examine internal capability • Define expected levels of performance

Scoping and delivering the 'quick win' actions as packages of work could help to generate early benefits and next steps. At the same time, starting the high-priority next steps early would be important because of their criticality to success.

Finally, it is important to remember that the findings of this report are focused on metrics and measurement, which is one critical aspect – alongside culture, funding, governance etc. – of building a weather- and climate-resilient transport sector. These next steps would have to be considered in the context of the Government's wider adaptation strategy.

7 Appendices

A.1 Appendix 1: Interview questions

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*

11. 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?
12. 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.

13. What data does your organisation collect to support the assessment of these indicators metrics?
14. 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.)

<u>For the identified data (metadata):</u>

15. Who is accountable/responsible for the metric, and for collecting the underlying data?
16. 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.)
17. How sensitive is the data? (e.g. public, commercially sensitive)
18. Can you share any information about the cost of the data?
19. What is the spatial coverage of the data? (e.g. site-specific, asset-specific, regional, national, etc.)
20. How often is the data available? (e.g. daily, monthly, annually, etc.)
21. What date range does the data cover? (e.g. 2000-2025, etc.)
22. 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.)

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

23. 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?
24. What are the barriers to using these metrics?
25. What data that your organisation is currently collecting or using for other purposes could also be used to assess these potential metrics?

Cross-Modal and Cross-Sector Metrics and Data

26. What metrics and data are your organisation currently receiving from other modes to help with your response to weather events and climate change?
27. 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?
28. How does your organisation receive these data? (e.g. shared portal, automatic feed, ad hoc information requests, etc.)
29. 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?
30. 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?
31. How does your organisation provide this data? (e.g. shared portal, automatic feed, ad hoc information requests, etc.)
32. What would you like to receive and report in the future?
33. What metrics and data do you think should be collected at a sector level vs. specific organisational level?

Attributes Of a Resilient System

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

    Examples:

    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

35. Does your organisation currently assess progress of these measures and capabilities? If yes, how?
36. 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?

Other

37. 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.

A.2 Appendix 2: Notable DMIs identified in Workstream 2

Key for metrics

M1	Weather-attributed operational performance metrics	**M2**	Weather-attributed asset performance metrics
M3	Extent of leadership/people/process capabilities	**M4**	Extent of Information sharing channels between organisations
M5	Projected hazard frequency and severity	**M6**	Projected impact of the hazards on performance
M7	Projected impact of the hazards on assets	**M8**	Estimated cost of asset and operational investment
M9	Costs avoided due to climate resilience investments	**M10**	Wider economic, social, environmental impacts
M11	Long term adaptation metric	**M12**	Long-term interdependency metric[3]
M13	Long term effectiveness metric		

Colour key

Hazards	Asset-level impacts	Operational impact	Features of resilience

Table 7.1: Notable DMI types for sector level metrics

Sector-level Metric	Notable DMI type	Commentary
M1 M2	**Historic Meteorological & Flooding Data** ***Examples***: *Average annual temperature* *Average daily precipitation rate*	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.
M5	**UKCP18 Climate Projection Data** ***Examples:*** *Projected average daily temperature* *Projected sea-level rise*	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.
M2 M7	**Asset repair cost** ***Example***: *Cost of flood damage to assets*	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.
M2 M7	**Frequency of hazard-induced damage** ***Example***: *Incidence of flood damage to electrical equipment*	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.
M2	**Maintenance costs** ***Examples***:	This metric can be trended over time and through association with weather-data, could be used to quantify

Sector-level Metric	Notable DMI type	Commentary
M7	*Cost of asset surveys and maintenance*	both the impacts of acute weather events and chronic changes over time.
M2 M7	**Asset performance in extreme weather** ***Examples***: *Equipment depreciation rates* *Asset damages due to weather*	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.
M7	**Projected damage costs** ***Examples:*** *Projected heatwave damage cost* *Projected flood damage cost*	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.
M1 M6	**Weather-related delay / cancellation compensation costs** ***Examples:*** *Passenger compensation costs* *Schedule 8 cyclical compensation*	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.
M8 M10	**Costs of adaptation** ***Examples:*** *Cost of improvements to service provision*	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.
M1	**Weather-delay attribution** ***Examples:*** *Delay Attribution Service* *Flooding related delay minutes*	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.
M1	**Weather cancellation attribution** ***Examples***: *No. of cancellations due to weather events*	This metric measures the impact of weather on cancellations. The underlying data could be used with climate projection data to understand potential future cancellations.
M1	**Downtime due to climate events** ***Examples:*** *Downtime recovery rates*	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.
M1 M10	**Weather-related near misses / incidents** ***Examples:*** *No. minor incidents due to fog*	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.

Sector-level Metric	Notable DMI type	Commentary
	No. weather-related incidents on construction sites	
M1	**Weather-related revenue loss** ***Examples:*** *Revenue loss due to heatwaves*	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.
M9 M11	**Avoided weather-related disruption** ***Examples:*** *Days of avoided weather-related disruption*	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.
M3 M11	**Climate change risk assessment** ***Examples:*** *CCRA: Infrastructure and operations*	CCRAs demonstrate organisational considering climate impacts and resilience. The total number or percentage of organisations conducting CCRAs could form part of an aggregated sector-level dataset for resilience.
M3 M11	**ARP reporting** ***Examples:*** *Number of organisations reporting through ARP*	ARP 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.
M3 M8 M11	**Adaptive capacity assessment** ***Examples:*** *Adaptive capacity maturity score*	This indicator demonstrates an organisation's ability to adjust to climate change. If consistent methodologies are used, results could be aggregated to assess adaptive capacity at a sector-level.
M3 M11 M13	**Organisational capacity** ***Examples:*** *No. teams briefed on climate resilience* *Dedicated team for climate resilience*	This indicator provides a proxy with which to measure organisations' investment in adaptation capability.
M3 M8 M11	**Investment in climate adaptation** ***Examples:*** *Capital investment in climate adaptation*	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.

A.3 Appendix 3: Links between roadmap metrics and the actions

M1 – Weather attributed operational performance

- Objective - To assess the performance of the sector in response to acute weather events and chronic climate change
- Need – To understand how the sector is performing against expected level of service
- Requires action:

  - 1.3 Share preliminary data
  - 2.1 Define expected levels of performance
  - 3.1 Develop consistent indicators
  - 3.3 Develop weather-attribution methodology
  - 3.4 Update existing datasets where possible to include weather attribution
  - 3.5 Develop a reporting template and terms of reference for short-term data collection
- Supported by action:
  - 1.1 Define asset criticality
  - 1.5 Develop internal capability
  - 3.2 Report on relevant hazards
- Requires Metric:
  - None required
- Supports Metric:
  - M5 – Projected hazard frequency and severity
  - M6 – Projected impact of the hazards on performance
  - M10 – Wider economic, social and environmental impacts

M2 – Weather attributed asset performance metrics

- Objective - To assess the performance of the sector in response to acute weather
- Need – To understand how assets are performing against expected as condition
- Requires Metric:
  - None required
- Requires action:
  - 1.3 Share preliminary data
  - 2.1 Define expected levels of performance
  - 3.1 Develop consistent indicators
  - 3.4 Update existing datasets where possible to include weather attribution
  - 3.5 Develop a reporting template and terms of reference for short-term data collection
- Supported by action:
  - 1.1 Define asset criticality
  - 1.5 Develop internal capability
  - 3.2 Report on relevant hazards
- Supports Metric:
  - M5 – Projected hazard frequency and severity
  - M6 – Projected impact of the hazards on assets
  - M9 – Costs avoided due to climate resilience investments

M3 – Existence of Leadership / People / Process capabilities

- Objective - To assess the performance of the sector in response to acute weather
- Need – To understand organisations' investment in adaptation capabilities
- Requires Metric:
  - None required
- Requires action:
  - 3.5 Develop a reporting template and terms of reference for short-term data collection
  - 3.6 Develop a maturity measurement framework

- Supported by action:
  - 1.4 Examine internal capability
- Supports Metric
  - M11 – Long-term adaptation metric

M4 – Existence of information sharing channels between organisations

- Objective - To enable interdependencies to be effectively managed
- Need – To measure organisations' capacity to share information (within and beyond transport)
- Requires Metric:
  - None required
- Requires action:
  - 3.5 Develop a reporting template and terms of reference for short-term data collection
- Supported by action:
  - 1.6 Aggregate information, and facilitate knowledge exchange, for the mode
  - 1.8 Develop Interdependent Risk Maps
  - 1.9 Share information through existing forums and channels
  - 1.10 Establish cross-sector information sharing
- Supports Metric
  - M12 – Long-term interdependency metric

M5 – Projected hazard frequency and severity

- Objective - To project what hazards the sector might be faced with, when and where
- Need – To understand how hazards might impact the transport network in the future
- Requires Metric:
  - M1 – Weather attributed operational performance metrics
  - M2 – Weather attributed asset performance metrics
- Requires action:
  - 3.2 Report on relevant hazards
  - 3.5 Develop a reporting template and terms of reference for short-term data collection
- Supported by action:
  - 1.2 Develop a simple business case methodology
  - 1.3 Share preliminary data
  - 1.4 Examine internal capability
  - 1.5 Provide initial guidance
  - 1.9 Aggregate information, and facilitate knowledge exchange, for the mode
  - 3.1 Develop consistent indicators
- Supports Metric
  - M6 – Projected impact of the hazards on performance
  - M7 – Project impact of the hazards on assets

M6 – Projected impact of the hazards on performance

- Objective - To project what hazards the sector might be faced with, when and where
- Need – To understand how hazards might impact the transport network in the future
- Requires Metric
  - M1 – Weather attributed operational performance metrics

  - M5 – Projected hazards frequency and severity
- Requires action:
  - 2.1 Define expected levels of performance
  - 2.2 Define long-term governance
  - 2.3 Adapt existing governance where possible
  - 3.1 Develop consistent indicators
  - 3.3 Develop weather-attribution methodology
  - 3.5 Develop a reporting template and terms of reference for short-term data collection
- Supported by action:
  - 1.1 Define asset criticality
  - 1.2 Develop a simple business case methodology
  - 1.3 Share preliminary data
  - 1.4 Examine internal capability
  - 1.5 Provide initial guidance
  - 1.6 Aggregate information, and facilitate knowledge exchange, for the mode
  - 1.7 Develop internal capability
  - 2.4 Develop channels for collecting cost and efficacy metrics
  - 3.2 Report on relevant hazards
  - 3.4 Update existing datasets where possible to include weather attribution
- Supports Metric
  - M8 – Estimated costs of asset and operational investment

M7 – Projected impact of the hazards on assets

- Objective - To project what hazards the sector might be faced with, when and where
- Need – To understand how hazards might impact the transport network in the future
- Requires Metric:
  - M2 – Weather attributed asset performance metrics
  - M5 – Projected hazards frequency and severity
- Requires action:
  - 2.1 Define expected levels of performance
  - 2.2 Define long-term governance
  - 2.3 Adapt existing governance where possible
  - 3.1 Develop consistent indicators
  - 3.3 Develop weather-attribution methodology
  - 3.5 Develop a reporting template and terms of reference for short-term data collection
- Supported by action:
  - 1.1 Define asset criticality
  - 1.2 Develop a simple business case methodology
  - 1.3 Share preliminary data
  - 1.4 Examine internal capability
  - 1.5 Provide initial guidance
  - 1.6 Aggregate information, and facilitate knowledge exchange, for the mode
  - 1.7 Develop internal capability
  - 2.4 Develop channels for collecting cost and efficacy metrics

  - 3.2 Report on relevant hazards
  - 3.4 Update existing datasets where possible to include weather attribution
- Supports Metric
  - M8 – Estimated costs of asset and operational investment

M8 – Estimated costs of asset and operational investment

- Objective - To inform investment cases for the sector
- Need – To understand how much it will cost to be weather/climate resilient
- Requires Metric
  - M6 – Projected impact of hazards on performance
  - M7 – Projected impact of hazards
- Requires action:
  - 2.2 Define long-term governance
  - 2.4 Develop channels for collecting cost and efficacy metrics
  - 3.1 Develop consistent indicators
  - 3.5 Develop a reporting template and terms of reference for short-term data collection
  - 3.7 Develop economic appraisal methodology
- Supported by action:
  - 1.1 Define asset criticality
  - 1.4 Examine internal capability
  - 2.2 Define long-term governance
  - 2.3 Adapt existing governance where possible
  - 3.4 Update existing datasets where possible to include weather attribution
- Supports Metric
  - M10 – Wider economic, social and environmental impacts

M9 – Costs avoided due to climate resilience investments

- Objective - To inform investment cases for the sector
- Need – To understand whether the investment provides value for money
- Requires Metric
  - M2 – Weather attributed asset performance metrics
- Requires action:
  - 3.1 Develop consistent indicators
  - 3.7 Develop economic appraisal methodology
- Supported by action:
  - 1.4 Examine internal capability
  - 2.2 Define long-term governance
  - 2.4 Develop channels for collecting cost and efficacy metrics
  - 3.3 Develop weather-attribution methodology
  - 3.4 Update existing datasets where possible to include weather attribution
- Supports Metric
  - M10 – Wider economic, social and environmental impacts

M10 – Wider economic, social and environmental impacts

- Objective - To enable interdependencies to be effectively managed
- Need – To ensure that actions are effective in the long term

- Requires Metric
  - M1 – Weather attributed operational performance metrics
  - M8 – Estimated cost of asset and operational investment
  - M9 – Costs avoided due to climate resilience investments
- Requires action:
  - 3.1 Develop consistent indicators
  - 3.7 Develop economic appraisal methodology
- Supported by action:
  - 1.4 Examine internal capability
  - 2.2 Define long-term governance

M11 – Long-term adaptation metric

- Objective - To inform investment cases for the sector
- Need – To understand whether the sector is adapting to climate change in the long term
- Requires Metric
  - M3 – Existence of leadership, people and process capabilities
- Requires action:
  - 2.2 Define long-term governance
  - 3.1 Develop consistent indicators
  - 3.8 Develop long-term metrics
- Supported by action:
  - 1.1 Define asset criticality
  - 1.4 Examine internal capability
  - 2.3 Adapt existing governance where possible in the short term
  - 3.6 Develop a maturity measurement framework
- Supports Metric
  - M13 – Long-term effectiveness metric

M12 – Long-term interdependency metric

- Objective - To enable interdependencies to be effectively managed
- Need – To understand whether information is being effectively shared (within and beyond the transport sector)
- Requires Metric
  - M4 – Existence of information channels between organisations
- Requires action:
  - 2.2 Define long-term governance
  - 3.1 Develop consistent indicators
  - 3.8 Develop long-term metrics
- Supported by action:
  - 1.4 Examine internal capability
  - 1.6 Aggregate information, and facilitate knowledge exchange, for the mode
  - 1.8 Develop interdependent risk maps
  - 1.9 Share information through existing forums and channels
  - 1.10 Establish cross-sector information sharing
  - 2.3 Adapt existing governance where possible in the short term

- Supports Metric
  - M13 – Long-term effectiveness metric

M13 – Long-term effectiveness metric

- Objective - To enable interdependencies to be effectively managed
- Need – To ensure that adaptation actions are effective in the long term
- Requires Metric
  - M11 Long-term adaptation metric
  - M12 – Long-term interdependency metric
- Requires action:
  - 2.2 Define long-term governance
  - 3.1 Develop consistent indicators
  - 3.7 Develop economic appraisal methodology
  - 3.8 Develop long-term metrics
- Supported by action:
  - 1.4 Examine internal capability
  - 2.3 Adapt existing governance where possible in the short term
  - 2.4 Develop channels for collecting cost and efficacy metrics
  - 3.6 Develop a maturity measurement framework

A.4 Appendix 4: Required (R) and supporting (S) actions for the roadmap metrics

- Importance: An action is considered to be more important if it enables more metric types and vice versa. Each action enables the sector-level metrics in two ways – it is either an action which is required to be in place for the metric to be usable, or it can support the metric to be developed. In Table 7.2, each action is 'mapped' to each metric type with an 'R' showing it is required (assigned 3 points), and 'S' showing support (assigned one point). Actions cannot both support and be required by each sector level metric (i.e. each action can receive a total score of either 0, 1, or 3 for each metric).
- Urgency: If the actions are required for Phase 1 and 2 metrics to be developed, they are considered to be urgent. To factor in urgency, the 'importance' score is multiplied by 2.

The resulting 'priority' score is shown in **Error! Reference source not found.** below to shortlist the highest 'priority actions'. The level of effort score from Table 5.1 is used to shortlist the 'quick wins'.

Table 7.2: Required (R) and supporting (S) actions for the roadmap metrics

Action	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	Required Score	Support Score	Importance	Urgency & Importance
1.1 Define asset criticality	R	R				S	S	S	S	S	S			6	6	12	24
1.2 Develop a case for investing in climate resilience capability	R	R	R	R	S	S	S	S	S	S				12	6	18	36
1.3 Examine internal capability (within modes)	R	R	R	R	S	S	S	S	S	S	S	S	S	12	9	21	42
1.4 Aggregate information and facilitate knowledge exchange				S		S	S					S		0	4	4	4
1.5 Develop internal DfT capability	S	S	S	S	S	S	S	S	S	S	S	S	S	0	13	13	13
1.6 Develop interdependent risk maps				R								R		6	0	6	6
1.7 Share information through existing forums and channels				R	S							R		6	1	7	7
1.8 Establish cross-sector information sharing				R								R		6	0	6	6
2.1 Define expected levels of performance	R	R				S	S							6	2	8	16
2.2 Define long-term governance						R	R	R	R	R	R	R	R	24	0	24	48
2.3 Adapt existing governance where possible in the short term	S	S	S	S		S	S	S	S	S	S	S	S	0	12	12	12
2.4 Develop channels for collecting cost & efficacy metrics						S	S	R	R	R			S	9	3	12	12
3.1 Develop consistent indicators	R	R	S	S	S	R	R	R	R	R	R	R	R	30	3	33	66

3.2 Develop weather attribution methodology	R	R				R	R		S		R	R	R	21	1	22	44
3.3 Update existing datasets to include weather attribution	R	R				S	S	S	S					6	4	10	20
3.4 Develop reporting template and terms of reference for data collection	R	R	R	R	S	S	S	S						12	4	16	32
3.5 Develop a maturity measurement framework			R	R							R		R	12	0	12	12
3.6 Develop economic appraisal methodology								R	R	R			R	12	0	12	12
3.7 Develop long term metrics											R	R	R	9	0	9	9

Key for metrics

M1	Weather-attributed operational performance metrics	**M2**	Weather-attributed asset performance metrics
M3	Extent of leadership/people/process capabilities	**M4**	Extent of Information sharing channels between organisations
M5	Projected hazard frequency and severity	**M6**	Projected impact of the hazards on performance
M7	Projected impact of the hazards on assets	**M8**	Estimated cost of asset and operational investment
M9	Costs avoided due to climate resilience investments	**M10**	Wider economic, social, environmental impacts
M11	Long term adaptation metric[15]	**M12**	Long-term interdependency metric[3]
M13	Long term effectiveness metric[3]		

Colour key

Hazards	**Asset-level impacts**	**Operational impact**	**Features of resilience**

[15] This is explored further in Section 3.5.

A.5 Appendix 5: Rated modal feasibility assessment scorecards

Table 7.3: RAG rating criteria used in feasibility assessment scorecards

Parameters assessed	Green (3 points)	Amber (2 points)	Red (1 point)
How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Consistent units are not needed	Consistent units are needed at a modal level and would be relatively easy to develop	Consistent units are needed at a modal level but would be difficult to develop
To what extent is the data already collected?	Data is already available across a large number of organisations	Some data is available, but only in a few organisations	Data is not currently collected
Do organisations have the capacity to collect and report on the metric?	Yes, and they are already collecting the data	Varies across the sector – some organisations have capacity	No – would require significant analytical capacity
Could the metric be analysed without organisational input?	Data is already published/available as open data	Could be analysed at a sector level using other proxy data	No – input would be required from organisations
Do standards/ expected levels of performance have to be defined first?	Standards/ expected levels of performance would not have to be defined	N/A	Yes, for the data to be collected meaningfully
Can organisations be held to account for reporting against the metric through existing mechanisms?	Governance is already in place for a large part of the organisation	Some governance but not consistent or binding	No mechanisms exist

Road assessment

Figure 7.1: Strategic Roads Network RAG metric feasibility assessment (1/2)

	Phase 1				Phase 2		
Metrics / Parameters	**M1: Weather-attributed operational performance metrics**	**M2: Weather-attributed asset performance metrics**	**M3: Extent of leadership/people/ process capability**	**M4: Extent of information channels between organisations**	**M5: Projected hazard frequency and severity**	**M6: Projected impact of the hazards on performance**	**M7: Projected impact of the hazards on assets**
P1: How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Consistent units like delay minutes/costs could be developed	Assets vary significantly and consistent units are difficult to capture	Binary, although there may be organisational variation	Binary, although there may be organisational variation	Consistent unit not needed	Consistent units like delay minutes/costs could be developed	Assets vary significantly and consistent units are difficult to capture
P2: To what extent is the data already collected?	Limited post-facto weather attribution of operational data	Some post-facto weather attribution for SRN	Some tracking through ARP	Some data-sharing but not specifically tracked	Weather and climate projections are being collected from UKCP18	Limited analysis done for the SRN (e.g. wind speed impact on bridges)	Predictive impact of hazards currently not studied
P3: Do organisations have the capacity to collect and report on the metric?	Some capacity if linked to BAU operational processes	Some capacity if linked to BAU asset management processes	Easy to track and report	Could be binary and relatively straightforward	Data is already being collected	Would require more analytical capability but could draw on past data	Would require more analytical capability but could draw on past data
P4: Could the metric be analysed without organisational input?	No – requires organisational input	No – requires organisational input	Process data can be obtained from Defra (N/A for leadership/ people)	No – requires organisational input	Data can be obtained directly from the Met Office but relevance would have to be assessed	No – requires organisational input	No – requires organisational input
P5: Do standards/ expected levels of performance have to be defined first?	Standards/expected levels of service needed	Standards/expected levels of service needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed
P6: Can organisations be held to account for the metric through existing mechanisms?	Potentially through wider ORR safety/operational KPIs	Potentially through wider ORR asset management KPIs	Through non-binding ARP/existing DfT forums	No existing mechanisms	Limited mechanisms beyond non-binding ARP	Potentially, through funding settlements for SRN	
Total score	**10**	**10**	**15**	**12**	**16**	**11**	**9**

Figure 7.2: Strategic Roads Network RAG metric feasibility assessment (2/2)

	Phase 3			Phase 4		
Metrics / Parameters	**M8: Estimated cost of asset and operational investment**	**M9: Costs avoided due to climate resilience investments**	**M10: Weather-attributed economic, social, environmental impacts**	**M11: Long-term adaptation action metric**	**M12: Long-term interdependency metric**	**M13: Long-term effectiveness metric**
P1: How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Can be monetised using past weather-attributed data	Can be monetised using past weather-attributed data	Can be monetised using past weather-attributed data	Very challenging – no known methodology	Very challenging – no known methodology	Very challenging – no known methodology
P2: To what extent is the data already collected?	Not measured at the moment	Not measured at the moment	Not assessed systematically	Not currently measured	Not currently measured	Not currently measured
P3: Do organisations have the capacity to collect and report on the metric?	Significant capacity required to apply past weather attributed data	Significant capacity required to calculate this	Would require significant analytical capacity	Would depend on how the metric is defined	Would depend on how the metric is defined	Would depend on how the metric is defined
P4: Could the metric be analysed without organisational input?	High-level projections could be made using past sector-level data	No – requires organisational input	Could be analysed at a sector level using weather-attributed operational and asset data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data
P5: Do standards/ expected levels of performance have to be defined first?	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined
P6: Can organisations be held to account for the metric through existing mechanisms?	Through funding settlements for some organisations	Through funding settlements for some organisations	No existing mechanisms	No existing mechanisms	No existing mechanisms	No existing mechanisms
Total score	**11**	**9**	**10**	**9**	**10**	**10**

Figure 7.3: Local Roads Sector RAG metric feasibility assessment (1/2)

	Phase 1				Phase 2		
Metrics / Parameters	**M1: Weather-attributed operational performance metrics**	**M2: Weather-attributed asset performance metrics**	**M3: Extent of leadership/people/ process capability**	**M4: Extent of information channels between organisations**	**M5: Projected hazard frequency and severity**	**M6: Projected impact of the hazards on performance**	**M7: Projected impact of the hazards on assets**
P1: How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Consistent units like delay minutes/costs could be developed	Assets vary significantly and consistent units are difficult to capture	Binary, although there may be organisational variation	Binary, although there may be organisational variation	Consistent unit not needed	Consistent units like delay minutes/costs could be developed	Assets vary significantly and consistent units are difficult to capture
P2: To what extent is the data already collected?	Limited post-facto weather attribution of operational data	Limited post-facto weather attribution of operational data	Limited capability except at some advanced LAs	Some data-sharing but not specifically tracked	Some advanced LAs collect weather projection data	Future impacts are currently not projected	Future impacts are currently not projected
P3: Do organisations have the capacity to collect and report on the metric?	Limited capacity at local authority level, with a focus on net zero	Limited capacity at local authority level, with a focus on net zero	Easy to track and report	Could be binary and relatively straightforward	Data is being collected by some advanced LAs	Would require more analytical capability but could draw on past data	Would require more analytical capability but could draw on past data
P4: Could the metric be analysed without organisational input?	No – requires organisational input	No – requires organisational input	No – requires organisational input	No – requires organisational input	Data can be obtained directly from the Met Office but relevance would have to be assessed	No – requires organisational input	No – requires organisational input
P5: Do standards/ expected levels of performance have to be defined first?	Standards/expected levels of service needed	Standards/expected levels of service needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed
P6: Can organisations be held to account for the metric through existing mechanisms?	No binding mechanisms for local authorities through UKRLG						
Total score	**8**	**7**	**12**	**12**	**11**	**9**	**9**

Figure 7.4: Local Roads Sector RAG metric feasibility assessment (2/2)

	Phase 3			Phase 4		
Metrics / Parameters	**M8: Estimated cost of asset and operational investment**	**M9: Costs avoided due to climate resilience investments**	**M10: Weather-attributed economic, social, environmental impacts**	**M11: Long-term adaptation action metric**	**M12: Long-term interdependency metric**	**M13: Long-term effectiveness metric**
P1: How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Can be monetised using past weather-attributed data	Can be monetised using past weather-attributed data	Can be monetised using past weather-attributed data	Very challenging – no known methodology	Very challenging – no known methodology	Very challenging – no known methodology
P2: To what extent is the data already collected?	Limited measurement by advanced county councils	Not measured at the moment	Not assessed systematically	Not currently measured	Not currently measured	Not currently measured
P3: Do organisations have the capacity to collect and report on the metric?	Significant capacity required to apply past weather attributed data	Significant capacity required to calculate this	Would require significant analytical capacity	Would depend on how the metric is defined	Would depend on how the metric is defined	Would depend on how the metric is defined
P4: Could the metric be analysed without organisational input?	High-level projections could be made using past sector-level data	No – requires organisational input	Could be analysed at a sector level using weather-attributed operational and asset data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data
P5: Do standards/ expected levels of performance have to be defined first?	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined
P6: Can organisations be held to account for the metric through existing mechanisms?	No binding mechanisms for local authorities through UKRLG					
Total score	**10**	**7**	**9**	**9**	**10**	**10**

Rail Assessment

Figure 7.5: Rail RAG metric feasibility assessment (1/2)

	Phase 1				Phase 2		
Metrics / Parameters	**M1: Weather-attributed operational performance metrics**	**M2: Weather-attributed asset performance metrics**	**M3: Extent of leadership/people/ process capability**	**M4: Extent of information channels between organisations**	**M5: Projected hazard frequency and severity**	**M6: Projected impact of the hazards on performance**	**M7: Projected impact of the hazards on assets**
P1: How easy is it to develop an 'aggregate' unit for the metric	Consistent units like delay minutes/costs are already in use and could be developed	Asset performance metrics are widespread in network and could be used	Binary, although there may be organisational variation	Binary, although there may be organisational variation	Consistent unit not needed	Consistent units like delay minutes/costs are already in use and could be developed	Asset performance metrics are widespread in network and could be used
P2: To what extent is the data already collected?	Some infrastructure owners & TOCs analyse weather-attributed delay minutes	Limited post-facto weather attribution data of some assets (e.g. OLE, air conditioning)	Good tracking through WRCCAs	Some data-sharing but not specifically tracked	Weather and climate projections collected by some organisations	Predictive impact of hazards currently not studied	Predictive impact of hazards currently not studied
P3: Do organisations have the capacity to collect and report on the metric?	Some capacity within organisations but more needed for systematic analysis	Some capacity within organisations but more needed for systematic analysis	Good tracking through WRCCAs	Could be binary and relatively straightforward	Data is being collected by advanced infra managers and TOCs	Would require more analytical capability but could draw on past data	Would require more analytical capability but could draw on past data
P4: Could the metric be analysed without organisational input?	No – requires organisational input	No – requires organisational input	No – requires organisational input	No – requires organisational input	Data can be obtained directly from the Met Office but relevance would have to be assessed	No – requires organisational input	No – requires organisational input
P5: Do standards/ expected levels of performance have to be defined first?	Standards/expected levels of service needed	Standards/expected levels of service needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed
P6: Can organisations be held to account for the metric through existing mechanisms?	Through ORR for some organisations – industry operating model in flux	Through ORR for some organisations – industry operating model in flux	Through ARP for some organisations, but not binding	No existing mechanisms	Limited mechanisms beyond non-binding ARP	Through funding settlements for some organisations	Through funding settlements for some organisations
Total score	**11**	**9**	**15**	**12**	**13**	**10**	**10**

Figure 7.6: Rail RAG metric feasibility assessment (2/2)

	Phase 3			Phase 4		
Metrics / Parameters	**M8: Estimated cost of asset and operational investment**	**M9: Costs avoided due to climate resilience investments**	**M10: Weather-attributed economic, social, environmental impacts**	**M11: Long-term adaptation action metric**	**M12: Long-term interdependency metric**	**M13: Long-term effectiveness metric**
P1: How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Can be monetised if past weather-attributed data is developed first	Can be monetised if past weather-attributed data is developed first	Can be monetised if past weather-attributed data is developed first	Very challenging – no known methodology	Very challenging – no known methodology	Very challenging – no known methodology
P2: To what extent is the data already collected?	Limited analysis of weather-related compensation costs and financial losses	Not measured at the moment	Not assessed systematically	Not currently measured	Not currently measured	Not currently measured
P3: Do organisations have the capacity to collect and report on the metric?	Significant capacity required to apply past weather attributed data	Significant capacity required to calculate this	Would require significant analytical capacity	Would depend on how the metric is defined	Would depend on how the metric is defined	Would depend on how the metric is defined
P4: Could the metric be analysed without organisational input?	High-level projections could be made using past sector-level data	No – requires organisational input	Could be analysed at a sector level using weather-attributed operational and asset data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data
P5: Do standards/ expected levels of performance have to be defined first?	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined
P6: Can organisations be held to account for the metric through existing mechanisms?	Through funding settlements for some organisations	Through funding settlements for some organisations	No existing mechanisms	No existing mechanisms	No existing mechanisms	No existing mechanisms
Total score	**12**	**8**	**9**	**9**	**10**	**9**

Aviation assessment

Figure 7.7: Aviation RAG rating metric feasibility assessment (1/2)

	Phase 1				Phase 2		
Metrics / Parameters	**M1: Weather-attributed operational performance metrics**	**M2: Weather-attributed asset performance metrics**	**M3: Extent of leadership/people/ process capability**	**M4: Extent of information channels between organisations**	**M5: Projected hazard frequency and severity**	**M6: Projected impact of the hazards on performance**	**M7: Projected impact of the hazards on assets**
P1: How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Consistent units like delay minutes/costs could be developed	Assets vary significantly and consistent units are difficult to capture	Binary, although there may be organisational variation	Binary, although there may be organisational variation	Consistent unit not needed	Consistent units like delay minutes/costs could be developed	Assets vary significantly and consistent units are difficult to capture
P2: To what extent is the data already collected?	Good post-facto weather attribution data for operational performance in advanced airports	Some post-facto weather attribution data for asset performance in advanced airports	Not specifically tracked but organisations are aware	Some data-sharing but not specifically tracked	Short and long-term weather and climate projections extensively collected	Some discrete studies but not done systematically/ regularly	For some hazard impacts (e.g. flooding impact on buildings or high temperatures on assets) in airports
P3: Do organisations have the capacity to collect and report on the metric?	Varies across the sector – some organisations have the capacity	Varies across the sector – some organisations are doing this	Easy to track and report	Could be binary and relatively straightforward	Data is already being collected by most organisations	Would require significant analytical capability but could draw on past data	Would require more analytical capability but could draw on past data
P4: Could the metric be analysed without organisational input?	No – requires organisational input	No – requires organisational input	Process data can be obtained from Defra (N/A for leadership/ people)	No – requires organisational input	Data can be obtained directly from the Met Office (UKCP18)	No – requires organisational input	No – requires organisational input
P5: Do standards/ expected levels of performance have to be defined first?	Standards and expected levels of service needed	Standards/expected levels of service needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed
P6: Can organisations be held to account for the metric through existing mechanisms?	Through the CAA for some organisations	No existing mechanisms	Most major organisations report through ARP	No existing mechanisms	Adaptation reporting for most international operators but not binding	Challenging as most organisations in the sector are private	Challenging as most organisations in the sector are private
Total score	**10**	**8**	**14**	**12**	**17**	**11**	**10**

Figure 7.8: Aviation RAG rating metric feasibility assessment (2/2)

	Phase 3			Phase 4		
Metrics / Parameters	**M8: Estimated cost of asset and operational investment**	**M9: Costs avoided due to climate resilience investments**	**M10: Weather-attributed economic, social, environmental impacts**	**M11: Long-term adaptation action metric**	**M12: Long-term interdependency metric**	**M13: Long-term effectiveness metric**
P1: How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Can be monetised using past weather-attributed data first	Can be monetised using past weather-attributed data first	Can be monetised using past weather-attributed data first	Very challenging – no known methodology	Very challenging – no known methodology	Very challenging – no known methodology
P2: To what extent is the data already collected?	Not measured at the moment, some plans by advanced organisations	Not measured at the moment	Not assessed systematically	Not currently measured	Not currently measured	Not currently measured
P3: Do organisations have the capacity to collect and report on the metric?	Significant capacity required to apply past weather attributed data	Significant capacity required to calculate this	Would require significant analytical capacity	Would depend on how the metric is defined	Would depend on how the metric is defined	Would depend on how the metric is defined
P4: Could the metric be analysed without organisational input?	High-level projections could be made using past sector-level data	No – requires organisational input	Could be analysed at a sector level using weather-attributed operational and asset data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data
P5: Do standards/ expected levels of performance have to be defined first?	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined
P6: Can organisations be held to account for the metric through existing mechanisms?	Challenging as most organisations in the sector are private	Challenging as most organisations in the sector are private	No existing mechanisms	Through the CAA for some organisations and ARP which is non-binding	No existing mechanisms	Through ARP but this is non-binding
Total score	**10**	**8**	**10**	**10**	**10**	**10**

Maritime assessment

Figure 7.9: Maritime RAG rating metric feasibility assessment (1/2)

	Phase 1				Phase 2		
Metrics / Parameters	**M1: Weather-attributed operational performance metrics**	**M2: Weather-attributed asset performance metrics**	**M3: Extent of leadership/people/ process capability**	**M4: Extent of information channels between organisations**	**M5: Projected hazard frequency and severity**	**M6: Projected impact of the hazards on performance**	**M7: Projected impact of the hazards on assets**
P1: How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Consistent units of operational impacts are not currently decided	Assets vary significantly and consistent units are difficult to capture	Binary, although there may be organisational variation	Binary, although there may be organisational variation	Consistent unit not needed	Consistent units of operational impacts are not currently decided	Assets vary significantly and consistent units are difficult to capture
P2: To what extent is the data already collected?	Some post-facto weather attribution for operational performance (VTS)	Limited post-facto weather attribution for assets	Not specifically tracked but organisations are aware	No known information sharing channels	Short and long-term weather and climate projections extensively collected	Some understanding but not done systematically/ regularly	Some understanding of asset-weather threshold, yet limited weather-attributed asset data available
P3: Do organisations have the capacity to collect and report on the metric?	Varies across the sector – some ports have the capacity	Varies across the sector – few ports have the capacity	Easy to track and report	Could be binary and relatively straightforward	Data is already being collected by most organisations	Would require significant analytical capability and past data	Would require significant analytical capability and past data
P4: Could the metric be analysed without organisational input?	No – requires organisational input	No – requires organisational input	Process data can be obtained from Defra (N/A for leadership / people)	No – requires organisational input	Data can be obtained directly from the Met Office (UKCP18)	No – requires organisational input	No – requires organisational input
P5: Do standards/ expected levels of performance have to be defined first?	Standards and expected levels of service needed	Standards and expected levels of service needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed	Standards not needed
P6: Can organisations be held to account for the metric through existing mechanisms?	Through the MCA for some organisations	Through the MCA for some organisations	Limited number of organisations reporting through ARP	No existing mechanisms	Limited number of organisations reporting through ARP	Challenging as most organisations in the sector are private	Challenging as most organisations in the sector are private
Total score	**9**	**8**	**13**	**11**	**16**	**9**	**8**

Figure 7.10: Maritime RAG rating metric feasibility assessment (2/2)

	Phase 3			Phase 4		
Metrics / Parameters	**M8: Estimated cost of asset and operational investment**	**M9: Costs avoided due to climate resilience investments**	**M10: Weather-attributed economic, social, environmental impacts**	**M11: Long-term adaptation action metric**	**M12: Long-term interdependency metric**	**M13: Long-term effectiveness metric**
P1: How necessary/easy is it to develop a consistent unit for the metric at a modal level?	Can be monetised if past weather-attributed data is developed first	Can be monetised using past weather-attributed data first	Can be monetised using past weather-attributed data first	Very challenging – no known methodology	Very challenging – no known methodology	Very challenging – no known methodology
P2: To what extent is the data already collected?	Not measured at the moment	Not measured at the moment	Not assessed systematically	Not currently measured	Not currently measured	Not currently measured
P3: Do organisations have the capacity to collect and report on the metric?	Significant capacity required to apply past weather attributed data	Significant capacity required to calculate this	Would require significant analytical capacity	Would depend on how the metric is defined	Would depend on how the metric is defined	Would depend on how the metric is defined
P4: Could the metric be analysed without organisational input?	High-level projections could be made using past sector-level data	No – requires organisational input	Could be analysed at a sector level using weather-attributed operational and asset data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data	Could potentially be developed at a sector level using other data
P5: Do standards/ expected levels of performance have to be defined first?	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined	Standards not needed	Some expectations may have to be defined
P6: Can organisations be held to account for the metric through existing mechanisms?	Challenging as most organisations in the sector are private	Challenging as most organisations in the sector are private	No existing mechanisms	Through the MCA for some organisations and ARP which is non-binding	No existing mechanisms	Through ARP but this is non-binding
Total score	**10**	**7**	**9**	**10**	**10**	**10**

A.6 Appendix 6: Required metrics and associated example indicators

Table 7.4: Required metrics and associated example indicators

Required Metrics	Example indicators			Commentary
M1: Weather-attributed operational performance metrics	Total annual delays where 'beyond-threshold' adverse weather was a contributing factor	Minutes	Trended - Disaggregated by weather type	• Not all weather-related operational disruption might be attributable to climate change (i.e. some adverse weather may be 'expected' or 'within acceptable risk') – however developing the thresholds and expected service levels still requires data around weather to be recorded/collected alongside data on performance (see action 2.1) • Delays may not be the appropriate performance metric for all modes (e.g. maritime, where recovery may be more appropriate). Work is required to determine the performance metrics required for each transport mode (see action 2.1) • Understanding performance may only be relevant for the critical aspects of the transport system. Work is required to determine the critical aspects of the transport system per transport mode based on a risk assessment (see action 1.1) • The maritime network benefits from significant port availability as such it is possible to reroute cargo to other ports if a single port was unavailable. Therefore, focussing on ferry services is a potential means of measuring performance as the services run between specific (and often significant) ports (see action 3.1). • **Required actions:** 1.3, 2.1, 3.1, 3.3, 3.4, 3.5
	Share of service cancellations where 'beyond-threshold' adverse weather was a contributing factor	% Share of total services	Trended – Disaggregated by weather type	
M2: Weather-attributed asset performance metrics	Total annual asset recovery costs (labour, materials, etc.) following 'beyond-threshold' weather-related events	GBP	Trended – Disaggregated by weather type and cost type	• Not all weather-related asset disruption might be attributable to climate change (i.e. some adverse weather may be 'expected' or 'within the threshold') – however developing the thresholds and expected service levels still requires data around weather to be recorded/collected alongside data on asset performance. • Asset performance or health is often measured in terms of availability (time available for use) or reliability (time between failures). However, availability is covered by M1 and reliability does not have a weather attributed component. • To ensure consistent reporting of Total annual asset recovery costs and Maintainability would require guidance on both the costs to include and the events to be considered (see action 3.1). • Condition Index or Health Score would require guidance or methodology to ensure consistent reporting across modes and the sector (see action 3.1).
	Maintainability – Average time to return to service following a 'beyond threshold' weather-related event	Time	Trended – Disaggregated by weather type	
	Condition Index or Health Score – A composite metric (made up of quantitative and/or qualitative data) that quantifies the overall physical state or performance of an asset.	0-100	Trended	

Required Metrics	Example indicators			Commentary
				• For all asset performance metrics, as discussed in Section 3.4, the use of consistent units (e.g. cost or time) would enable data to be collected and analysed more meaningfully at a sector level, though this may be challenging given variations in assets. Aggregability is less meaningful for asset performance given these variations. • If organisations were not already collecting the data required to compile a Condition Index or Health Score, the additional effort and resources involved in collecting data to support this metric could be very high. • **Required actions:** 1.3, 2.1, 3.1, 3.3, 3.4, 3.5
M3: Extent of leadership / people / process capabilities	(Leadership) Percentage of transport sector Executive Leadership Teams that have an individual responsible for climate change risk	%	Trended – Disaggregated by mode and organisational type	• Both resilience frameworks considered as part of this work (NIC and BS65000) recognise the significance of climate change resilience capabilities. The determination of all or the most significant aspects of these capabilities is beyond the scope of this project. Nevertheless, the next steps to fully develop this have been considered (see actions 3.6). • As discussed in Section 3.4, a consistent framework around assessing the extent of climate and weather resilience capabilities would enable comparability – this would require a set of indicators (such as the ones shown here) to be agreed. • Required actions: 3.5, 3.6
	(Leadership) Percentage of transport sector organisations where internal decision making processes require the consideration of climate change	%		
	(People) Percentage of transport sector organisations with an individual or team managing climate change risk	%		
	(People) Percentage of transport sector organisations with internal climate change risk training	%		
	(Process) Total coverage of the transport sector by a climate change risk assessment	%		
	(Process) Percentage of transport organisations using internal design standards where climate change has been fully integrated	%		
M4: Extent of Information sharing	Percentage of transport sector organisations participating in recognised climate change risk information sharing channels such	%	Trended – Disaggregated by	• Currently there is a limited understanding of the information sharing channels that are available for transport sector organisations to use. To determine the

Required Metrics	Example indicators			Commentary
channels between organisations	as forums, networks or working groups		mode and organisational type	extent of their use, the first step is to determine the channels that exist (see action 1.9)
	Percentage of transport sector organisations assessing and sharing information on interdependent climate change risks in line with best practice guidance/techniques	%		● Industry stakeholders have repeatedly highlighted the significance of interdependent and cascading risks between the transport organisations, modes, and other sectors. However, their assessment is sporadic and inconsistent across the sector; with resource challenges and limited guidance being contributing factors. To support the resolution of this challenge, an action has been defined (see action 1.10) ● Required actions: 3.5, 3.6
M5: Projected hazard frequency and severity	Top 10 most significant climate change risks for each organisation, mode and sector	Rating	Trended – Disaggregated by mode and organisational type	● The current mechanism for identifying the most significant climate change risks is to review climate change risk assessments within ARP reports or financial end-of-year reports. This does not allow for ease of data extraction, as these text-based formats and differing report styles limit extensive comparison or analysis . Transport sector organisations could consistently report the priority climate change risks and their relative priority through a consistent format which would allow the data to be aggregated up across modes and the sector (see actions 1.3 and 3.2) ● Projected increases in priority risks and key performance thresholds may not be feasible to report for all organisations. For example, where assets cover large geographic areas with differences in how the risks change over time, or where many different performance thresholds exist across different assets. ● Required actions: 3.2, 3.5
	Projected increase in priority risks at given future time-horizons	% change	Per year in future time-horizon	
	Projected increase in priority hazard key performance thresholds (e.g. projected number of days above X°C)	% change	Per year in future time-horizon	
M6: Projected impact of the hazards on performance	Projected annual delays (based on projected changes in weather/climate)	Minutes	Per year in future time-horizon	● This metric would be based on three key sets of input data: current weather attributed delays or recovery minutes (depending on mode); current (baseline) relevant climate variables; future (projected) climate variables. All three would be necessary to provide an output. ● For this metric to be available to DfT, in-scope organisations would require the relevant internal data, a clear method for estimating the metric using their data (see action 3.3), the capabilities to apply the methodology (see action 1.2), and a platform to report the results of the analysis such that it can be aggregated at a transport mode and sector level (see actions 3.1, and 3.5). ● **Required actions:** 2.1, 2.2, 2.3, 3.1, 3.3, 3.5
M7: Projected impact of the hazards on assets	Projected total annual event recovery costs as a portion of overall asset maintenance costs	%	Per year in future time-horizon	● Similarly to M6, this metric would be based on three key sets of input data: current weather attributed annual event recovery costs; current (baseline) relevant climate variables; future (projected) climate variables. All three would be necessary to provide an output.

Required Metrics	Example indicators			Commentary
				• For this metric to be available to DfT, in-scope organisations would require the relevant internal data, a clear method for estimating the metric using their data (see action 3.3), the capabilities to apply the methodology (see action 1.2), and a platform to report the results of the analysis such that it can be aggregated at a transport mode and sector level (see action 3.5). • **Required actions**: 2.1, 2.2, 2.3, 3.1, 3.3, 3.5
M8: Estimated cost of asset and operational investment to achieve tolerable climate resilience	Estimated cost of asset and operational investment required within the next investment period to achieve tolerable climate/weather resilience	GBP	Per future investment period	• To provide an estimation of this metric organisations first must know the expected level of performance they are required to achieve (see action 2.1). Once they have this clarity, they will be able to use it along with information on the current state of their infrastructure and the climate challenges they may be subject to in the future to estimate the cost of investment to achieve the expected level of service. • Note that if an adaptation action has not been undertaken in the UK before, proxies may have to come from outside the UK and from other sectors. • **Required actions:** 2.2, 2.4, 3.1, 3.5, 3.7
M9: Costs avoided due to climate resilience investments	Estimated avoided direct[16] costs due to resilience investments Socio-economic benefits accrued due to resilience investments	GBP GBP	Per year in future time-horizon Per year in future time-horizon	• Estimating avoided costs can be very challenging as it requires extensive historic data to reconstruct counterfactual scenarios to isolate and measure the effects of resilience building. • Estimating socio-economic benefits requires the application of a consistent methodology (see action 3.7). • Note that if an adaptation action has not been undertaken in the UK before, proxies may have to come from outside the UK and from other sectors. • Required actions: *3.1, 3.7*
M10: Wider economic, social, environmental impacts	Socio-economic costs of climate risk being realised – GBP – Trended	GBP	Trended – Disaggregated by mode and organisational type	• There are existing methods and approaches (e.g. WebTAG) that provide a mechanism for estimating socio-economic costs from the loss of an activity or service. By applying an approach to the transport sector to develop guidance of a simplified methodology, transport sector organisations could report the socio-economic costs of associated with the loss of their services (see action 3.7). • Qualitative analysis of economic, social, and environmental benefits is an important precursor to future quantification. For example, understanding the impact of weather-related transport disruptions on marginalised or disabled

[16] Direct costs in this case refers to the avoided costs to the transport sector organisation. This would be aggregated up across transport modes and the sector as a whole.

Required Metrics	Example indicators			Commentary
				communities through qualitative research methods may allow quantitative methods to be developed in the future. ● Required actions: 3.1, 3.7
M11: Long term adaptation metric (TBC)	Completion of organisational adaptation actions	%	Trended – Disaggregated by mode and organisational type	● Trending the progress of adaptation action progress will provide a measure of whether the sector is adapting to climate change in the long term. Progress would see an increase in action completion over time while being able to disaggregate the data by mode and organisational type would provide an indication of the speed of progress across the sector. ● Significant challenges remain with this metric however as adaptation actions are developed within adaptation strategies and plans. These documents are updated over time with actions often evolving with increased understanding and progress. Therefore, guidance would need to be developed for this metric to allow reporting organisations to capture this nuance within their reporting (see action 3.1). ● Required actions: 2.2, 3.1, 3.8
M12: Long-term interdependency metric (TBC)	% of organisations in the mode with arrangements in place that enable or support a shared response to an interdependent climate risk	%	Trended – Disaggregated by mode and organisational type	● The purpose of understanding climate risk interdependencies is to ensure that organisations reduce the risk from climate change impacts through their interfaces. Ultimately, once the risks have been identified and assessed, the reduction of interfaced risk will require arrangement to be in place such that resources can be shared between organisations to manage the risk. Tracking the extent to which these arrangements are in place provides an indication of the extent to which transport sector organisations have reached this level of climate resilience maturity (see actions 3.6 and 3.8). ● It would be beneficial to have a metric assessing the ability of increased resilience in one mode to offset an unmitigated/insufficiently mitigated risk in another, and/or in the sector as a whole. However, this is a complex metric that requires further cross-modal thinking. ● Required actions: 2.2, 3.1, 3.8
	Percentage of critical infrastructure operators with arrangements in place that enable or support a shared response to an interdependent climate risk	%	Trended – Disaggregated by mode and organisational type	
M13: Long term effectiveness metric (TBC)	Change in system performance compared to the change in climate (compared to a baseline year)	Ratio	Trended – Disaggregated by mode and organisational type	● Tracking performance of the transport sector (using a previously established performance metric in M11) and comparing it to the extent to which the climate has changed over the same time period would provide an indication of the effectiveness of adaptation action. A steady performance would indicate increasing resilience over time as climate change impacts are increasing over time (see action 3.8). ● For example, if 50% of delays are from the rainfall above 20mm, then rainfall would be used to measure climate change. Comparing delays now to delays 10 years ago, divided by the increased frequency of rainfall above 20mm over that

Required Metrics	Example indicators	Commentary
		10-year period gives you a positive or negative number. The size of the number indicates increasing or decreasing resilience over the 10-year time period. ● Again, this would be a complex metric to develop because of the challenge of attributing changes in long-term climate impacts to the adaptation actions. ● Required actions: 2.2, 3.1, 3.7, 3.8

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