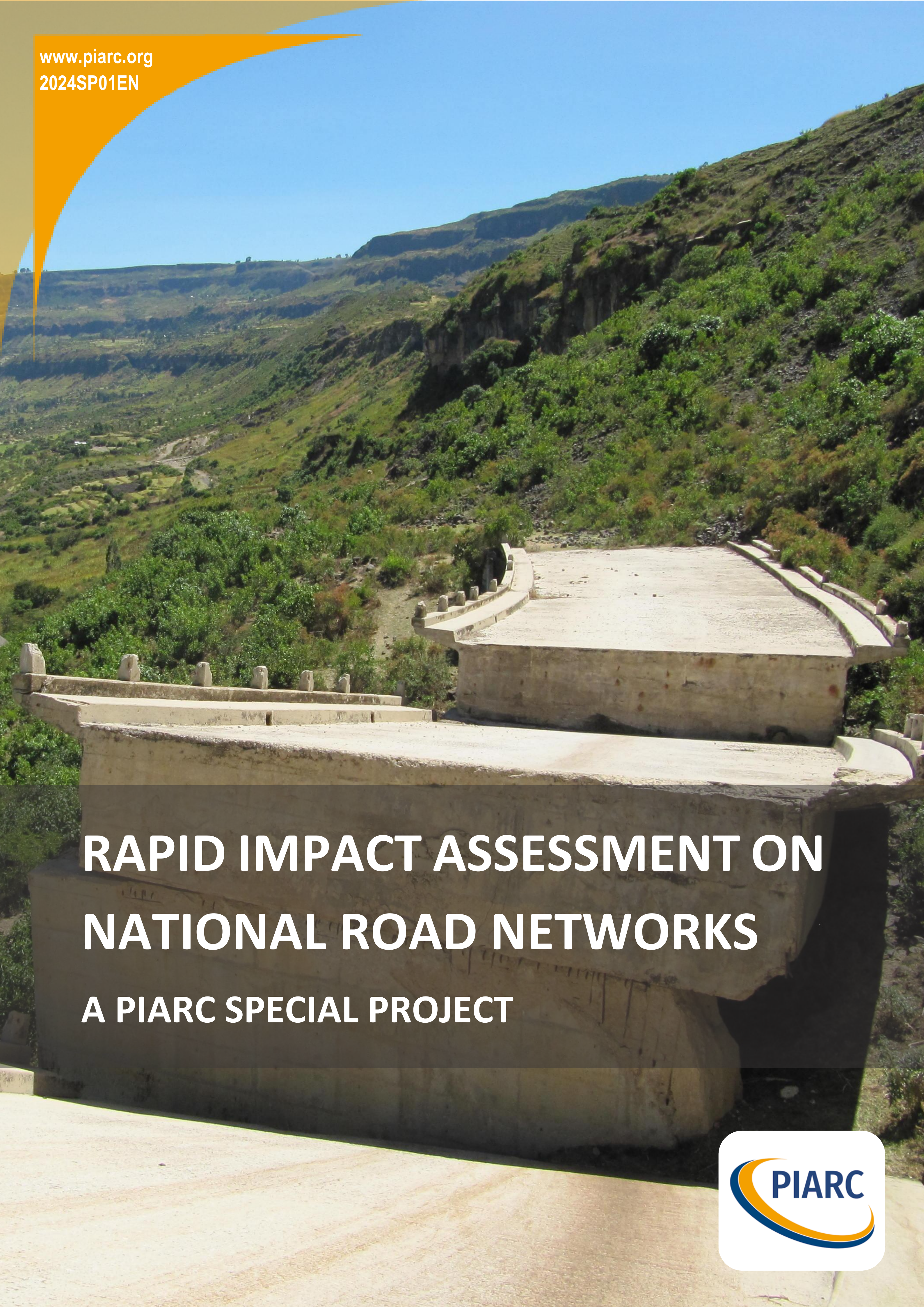

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2024SP01EN

RAPID IMPACT ASSESSMENT ON NATIONAL ROAD NETWORKS

A PIARC SPECIAL PROJECT

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was developed by Hearn Geoserve Ltd and its consortium partners: , and supervised and approved by the Project Oversight Team, whose members are representatives of the member national governments. The members of the Project Oversight Team responsible for this report were appointed by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and the Project Oversight Team members, and do not necessarily reflect the views of their parent organisations or agencies.

This report is available from the internet site of the World Road Association (PIARC): http://www.piarc.org

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EXECUTIVE SUMMARY

2024SP01EN

RAPID IMPACT ASSESSMENT IN THE HIGHWAY SECTOR

A PIARC SPECIAL PROJECT

Introduction

This review combines information derived from a number of sources: literature review; a questionnaire survey of PIARC members; face-face discussions; and case studies provided by member organisations in order to develop a framework for common operating procedures in the implementation of Rapid Impact Assessment (RIA).

Need for RIA

Most road networks around the world are impacted by natural and man-made hazards. Natural hazards are mostly climate- and geologically-induced, and landslides, debris flows, inland and coastal floods, earthquakes and drifting snow are among the most common. Man-made hazards include collisions and sabotage, for example, while forest fires can be sparked by extreme heat and careless or intentional ignition by the general public. The more severe of these hazards can impact large areas for long durations, posing significant risk to communities, their livelihoods and critical infrastructure. Road networks can suffer major damage during these events. Furthermore, the disruption and loss of service that result can have significant socio-economic impact across a much broader area than the damaged locations, jeopardising relief efforts, cutting off vulnerable communities and creating knock-on effects across the much wider road network. Critical infrastructure, facilities and services are usually reliant on a safe and functioning road network and it is imperative for highway authorities to be able to respond immediately, and in conjunction with other emergency partners.

What is RIA?

RIA is at the heart of a highway authority's ability to respond rapidly and effectively when hazards occur. In this context RIA is defined as follows:

> *A systematic and tested procedure, defined before the natural or man-made hazard occurs, which is activated immediately after the disaster to offer, in a very short-period of time, a first assessment of the condition of the road network and its assets, the services that it can offer to road transport and emergency responders, the works that would be needed for the repairs, the funding that would be needed for the reparation works and the wider impact of the damage, so that repairs and reinstatement can be prioritised and programmed.*

What are the benefits of RIA?

RIA ensures optimum damage data gathering and data sharing among emergency responders and critical infrastructure providers in the immediate aftermath of a hazard strike, so that decisions over priority and response can be made quickly and effectively. Without this, highway authorities may tend to work in isolation, may be under- and ill-informed and can make decisions that later prove to be incorrect and potentially harmful to other stakeholders.

What does RIA involve?

RIA requires preparedness, because without this the highway authority and its emergency response partners will have no structures and procedures in place to follow. They will lack the resources (human and physical) required to respond effectively and timely because they will not have learnt from previous disasters and will not have been able to anticipate potential outcomes. Preparedness also requires having a system in place that is emergency-ready, with fixed operating procedures for collecting the required damage data and transmitting it to a central emergency management centre for analysis, impact assessment and prioritisation. The RIA itself, is the activation of these procedures and the pooling of damage data to so that the broader, cumulative impact of a hazard event can be determined over the wider network using the following assessment: Impact = Damage x Consequence x Duration of disruption.

Each damaged asset, whether it is a bridge or a section of road for example, will have its own impact on the wider network, its traffic and the critical infrastructure and communities that rely on it. The impact assessment therefore needs to identify critical highway assets in terms of the role they play in network functionality while at the same time taking into account the locations of critical facilities, such as hospitals and fire stations, and the need to maintain safe access to these, to emergency hotspots and vulnerable communities that may have become isolated by the event. This requires a holistic overview by trained staff, able act upon damage data as it is returned by field inspection teams and other sources, and with all the facts in front of them.

Speed and reliability are the key requirements of damage data collection. Conventionally, damage and impact data are obtained during an initial (Fast Reconnaissance) phase, preferably within the first 8 hours of the event. It is vitally important for information to be verifiable, using multiple sources, but it is also important to gather information rapidly across large areas if the extent of damage or impact is great, as would be the case for widespread flood inundation. Quality-controlled information gathered via a 'central command' emergency management centre that is also able to provide early-warning of incoming weather extremes, for example, is also vital.

A second phase, referred to as the Preliminary Damage Assessment, systematically collects asset damage data and makes a rapid assessment of the operational stability of that asset and the temporary works and time needed to restore it to a safe operating condition. If this is not possible then further inspection, forming part of a Detailed Damage Assessment is scheduled. Situational awareness and coordination with other partners during data collection and impact assessment is critically important. Some highway authorities do this via shared GIS platforms and files, others using more conventional forms of communication.

Is advanced technology essential to RIA?

RIA can be made more time-effective by the use of supporting software. Software can aid RIA in preparedness, in emergency notification, in electronic field data collection, data transmission to the emergency management centre and the analysis of damage data in the impact analysis for emergency prioritisation. Juggling several sources of data can be difficult manually and may be prone to oversight. Having data layers in a GIS, for example, can make the process more efficient and enables information to be shared among emergency response partners more readily. As the damage data is uploaded it can be received in real-time by inspection teams and emergency responders who will be able to use it to plan continuing field operations and emergency access routes.

Drones, and other remote sensing and monitoring aids can assist RIA and the broader preparedness and response process, however, it is not imperative that highway authorities are equipped with high-tech hardware and software. Many State Departments of Transportation in the USA, for example, use paper-based data collection systems, though there is a general trend towards electronic systems.

Effective RIA is dependent fundamentally on the following:

- Commitment
- Preparedness
- Adequately trained staff (in-house or contracted)
- Adequate resources and budgets to implement robust data collection
- Standardised procedures for field damage assessment, data collection and rapid transmission to the designated emergency management centre
- Collaboration
- Multi-agency situational awareness
- Informed, collective and peer-reviewed decision-making.

Effective RIA is not, therefore, the preserve of high-income countries. Low- and -middle income countries have, arguably, far more to gain from its integration into standard operating procedures. This does not require significant investment, bearing in mind that the most important element of RIA is the rapid derivation, sharing and analysis of reliable information and its use in situational awareness and informed decision-making.

Some simple messages for Highway Authorities

1. While RIA may be a recent addition to the highway management list of acronyms, the procedure it describes is nothing new and should already be integral to your operating procedures. What is important is the need to ensure that the system you have in place to collect and analyse damage and impact data during emergency events is fit for purpose. You need ensure as well that you have standard operating procedures that are fully integrated with the central command authority responsible for emergency response in your operational area. This facilitates real-time sharing of verified wide-area impact data, otherwise referred to as *situational awareness* through a *common operating picture*.

2. Do not feel that the guidance in this document does not apply to you. If your network is impacted to any degree by natural or man-made hazards, it does.

3. Do not feel that, because you do not have the resources to purchase expensive computer hardware and software and sophisticated monitoring and telecommunications, you cannot apply RIA, you can and you must.

4. Take an honest look at how your organisation has responded to previous hazards and disasters. How can you improve your performance?

5. Do you have sufficient staff resources, both in number, skills and training, to be able to collect damage data and facilitate objective decision-making as a disaster unfolds? If not, you must invest in these resources. If you do not have the finances available to do this you must apply for them, presenting a cast-iron case for justification.

6. Do you have standard procedures for collecting and reporting damage data? If not, you need to develop them; they are not expensive and should already be integral to your existing procedures in any case.

7. Among the most significant constraints faced by highway authorities during emergencies is the problem of reliable communications between field staff collecting damage data and the head office processing and acting upon it. How can you address communication problems that you might have? Would satellite communications help? If so, request the resources to provide them. As climate-related hazards intensify, the justification for these investments will become ever-more apparent.

8. Are you able to quickly examine incoming damage data in relation to your road network and the strategic importance of its links, its traffic volumes and the locations of critical infrastructure, such as hospitals, fire stations and emergency supplies, to make informed decisions over priority response? If not, you need to establish this capability quickly.

9. These messages are not meant to sound patronising. They are made to spell out, in clear terms, what a highway authority's role should be and how they *can step up to the mark* to fulfil it, if they are not doing so already.

10. To conclude, if you are a highway authority towards the bottom of the RIA ladder be assured that you can achieve much progress with very little spend. This is because preparedness, through standard operating procedures and full integration with emergency management central command, is fundamental and carries little cost. Ensure you have sufficient staff resources and communication systems in place to collect the required damage data and relay it between the field and the head office and that you share information and decision-making with other emergency responders within an overarching central command. If this central command does not exist or is not fit for purpose, you must spare no effort in lobbying for its establishment or improvement.

If you are a highway authority towards the top of the RIA ladder there is much you can do to get yourself onto the top rung. Electronic field data collection, satellite telecommunications, GIS spatial analysis of impact are among the technology-driven improvements you can make. However, you may face institutional blockages and inter-agency barriers that prevent effective communication and collaboration. These constraints can negatively affect situational awareness and multi-agency response just as much as they do for those highway authorities towards the bottom of the ladder. Until these blockages and boundaries are broken down, RIA will never reach its full potential.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Most road networks around the world are impacted by natural and man-made hazards. Natural hazards are mostly climate and geologically-induced, and landslides, debris flows, inland and coastal floods, earthquakes and drifting snow are among the most common. Man-made hazards include collisions and sabotage, while forest fires can be sparked by extreme heat and careless or intentional ignition by the general public. The more severe of these hazards can impact large areas for long durations, posing significant risk to communities, their livelihoods and critical infrastructure. Road networks can suffer major damage during these events. Furthermore, the disruption and loss of service that results can have significant socio-economic impact across a much broader area than the affected locations, jeopardising relief efforts, cutting off vulnerable communities and creating knock-on effects across the much wider road network. Critical infrastructure, facilities and services are usually reliant on a safe and functioning road network and it is imperative for highway authorities to be able to respond immediately, and in conjunction with other emergency partners.

To do so, the highway authority requires an accurate and complete assessment of the damage across its network in the shortest possible time. The highway authority must also be able to determine the broader impact associated with loss of function at each damaged location so that repair and restoration can be prioritised. To achieve this, a pre-determined system of damage data collection and impact analysis is required. It needs to assimilating information from available sources, collect field data using dedicated teams and share this information with emergency responders and other providers of critical infrastructure. Information on road closure needs to be relayed to the public as quickly as possible to avoid escalating congestion and worsening public safety.

Rapid Impact Assessment (RIA) is at the heart of a highway authority's ability to respond in this way. In this context RIA is defined as follows:

A systematic and tested procedure, defined before the natural or man-made hazard occurs, which is activated immediately after the disaster to offer, in a very short period of time, a first assessment of the condition of the road network and its assets, the services that it can offer to road transport and emergency responders, the works that would be needed for the repairs, the funding that would be needed for the reparation works and the wider impact of the damage, so that repairs and reinstatement can be prioritised and programmed.

1.2. OBJECTIVES AND SCOPE OF THIS DOCUMENT

The objective of this document is to present the findings of a short, desk-based research study undertaken to gauge RIA practices among highway authorities around the world and to use this, together with other published information, to outline an optimum model for RIA. Although practice across the globe is relevant, especially in relation to available technologies, the needs and challenges faced by highway authorities in Low- and Middle-Income Countries (LMICs) form an important element of the research together with the opportunity to develop RIA recommendations specific to LMICs, where applicable.

2. METHODOLOGY

In order to yield sufficient information to complete the task, the following activities were undertaken:

- A review of published literature, together with any relevant information contained on highway authority websites (Section 3)
- A questionnaire survey, distributed to national and state highway authorities in PIARC member countries, available online in English, French and Spanish, with which to gauge RIA practice (Section 4)
- Direct communications with highway authority representatives, selected from the questionnaire survey responses, together with other contacts available from within the research team and made available by members of the PIARC Project Oversight Team (POT) (Section 5)
- Review of case studies provided by the same highway authority representatives (Section 6)
- Broad guidelines for road authorities in the establishment and strengthening of RIA (Section 7)
- Review of Rapid Impact Assessment for Low- and Middle-Income Countries (Section 8).

3. LITERATURE REVIEW

The text below summarises the findings of a review of published cases where RIA or similar exercises have been undertaken and where highway authorities have published their procedures and requirements in the context of RIA. The literature review also took into account those publications that dealt with data collection techniques and technologies that might be usable when carrying out an RIA.

It is worth noting here that the literature review found no cases where highway authorities or their consultants or contractors had published examples of how RIA and similar procedures were used to respond to specific emergencies. There are numerous published reviews of natural and man-made disasters, and how disaster management agencies have responded to them, but none of those reviewed contained any information on how damage to road networks was assessed and analysed. There are third-party reviews, often published in a critical sense, but these usually lack full knowledge of the facts and some lack objectivity.

The term Rapid Impact Assessment has been used in the environmental sector for at least the last 20 years. The first reference to its use as a means of determining the effects of natural and man-made hazards on land, built infrastructure, public safety and well-being appears to have been by the Ministry of Civil Defence and Emergency Management in New Zealand (MCDEM 2013). This document is intended for the wider emergency response community and states that the purpose of an RIA is to:

- Determine initial response activities
- Direct the initial distribution of resources, and
- Serve as a precursor or first step to more detailed assessments, such as needs assessments or in-depth 'structural' assessments.
- According to MCDEM (2013), the rapid impact assessment framework provides processes and tools to:
- Plan and prioritise areas required for assessment
- Gather information to assist response activities
- Rapidly determine the impact of the emergency and identify areas for more in-depth assessment
- Provide information about the impact of the emergency to responding agencies, emergency services and local and national government, and
- Establish a standard process for collection, collation, analysis and reporting impact-related information.
- Two stages, or levels, are identified (Fig 3.1). Level 1 is an initial situation overview that is to be completed in 8 hours of the event. Level 2 is an initial damage assessment to be completed within 48 hours. Sample forms are contained within the annex of the document.

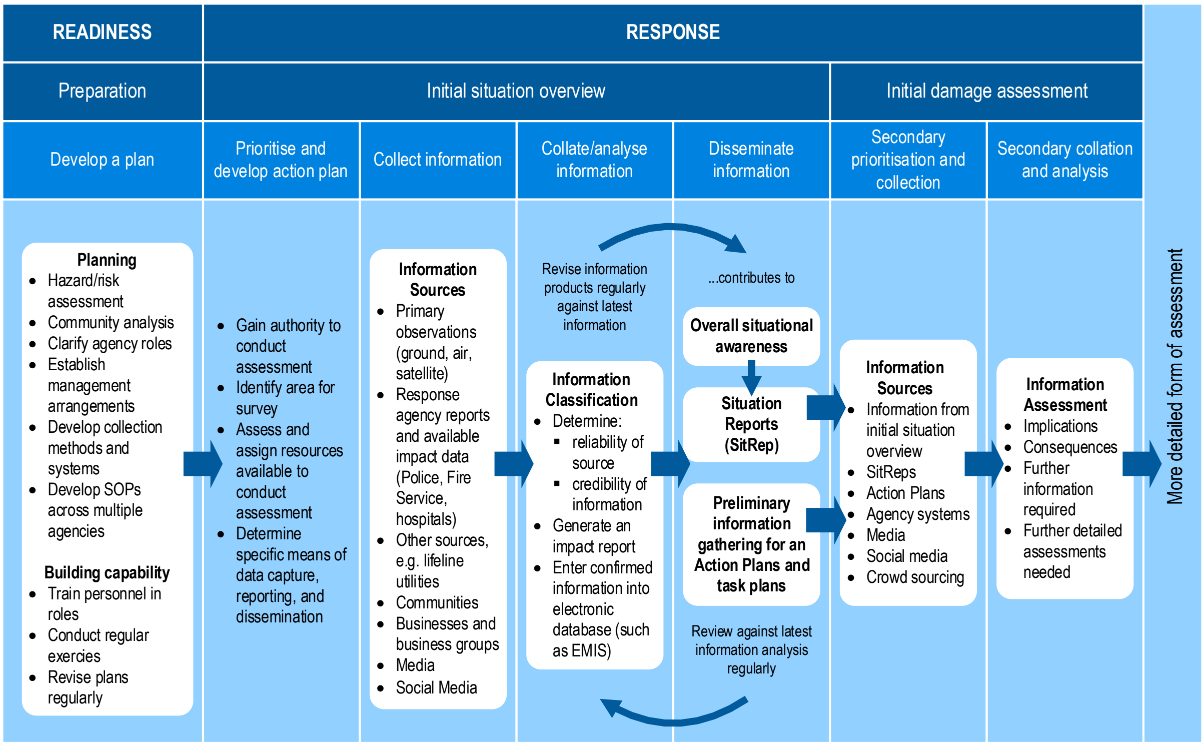


Fig 3.1. Overview of two stage Rapid Impact Assessment (from MCDEM 2013). SOPs: Standard Operating Procedures

According to the MCDEM, RIAs can be carried out by emergency services, local authorities, critical infrastructure providers and technical experts. The use of common report forms increases operational effectiveness, and supports efficient data collation. These report forms should provide information on the following:

- Name of the emergency
- Report number
- Date and time of issue
- Name of agency, function or team who prepared the report
- Description, or map, of areas assessed
- Status of assets and locations
- Priority actions.

GIS mapping information, as background to the RIA, might include:

- Known hazards and impact zones
- Demographic information
- Community vulnerabilities
- Critical buildings and facilities, such as hospitals
- Lifeline utilities
- Other infrastructure such as roads.

In 2020, the National Emergency Management Agency (NEMA 2020) of New Zealand provided guidance for the multi-agency coordinated approach for pre-emergency event planning and preparedness, event reconnaissance and impact assessment. Phase 1 (MCDEM Level 1) is referred to as the Wide Area Impact Assessment and Phase 2 (MCDEM Level 2) the Rapid Impact Assessment. A third phase (Phase 3) is described as a Specialised Detailed Assessment (Fig 3.2). The document stresses the importance of multi-agency co-operation and shared situational awareness, data sharing and a clear understanding of roles and responsibilities.

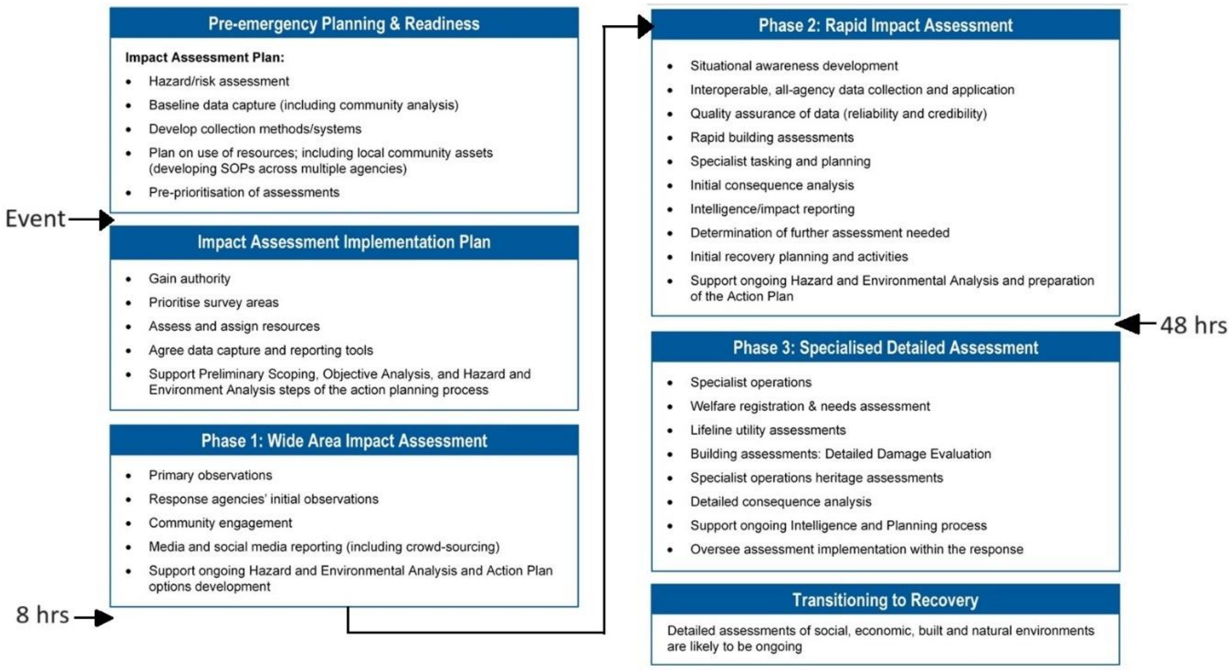


Fig 3.2. Impact assessment phases (NEMA 2020)

At the outset, the MCDEM document states that RIA is an essential component of emergency response planning and the implementation of immediate response activities. The same applies to most other countries, though the term RIA is generally not used. GFDRR (2015), for example, described the implementation of Initial Rapid Damage Impact Assessment to roads and bridges on the island of Dominica following Storm Erika in 2015. Unfortunately, the method of rapid damage assessment used is not described.

Highway authorities are providers of critical infrastructure. Most will have their own emergency response centre that co-ordinates RIA and emergency response when their infrastructure is impacted by natural or man-made hazards. These operations are usually implemented in close liaison with the Police or Law Enforcement where traffic control is required or where injuries or fatalities have occurred. Where a major incident or disaster is declared affecting large areas, multiple providers of critical infrastructure and multiple communities, the highway authority will usually operate under the general direction of the emergency management command centre in accordance with national, regional or state/county emergency response plans. The main task of the highway authority under these circumstances will be to reinstate and maintain designated priority routes along which emergency responders can gain safe access to the incident areas (e.g. UNDRR 2022). In the case of forest wildfires, the fire department and/or the forestry department will usually take the lead while the highways authority monitors and facilitates access, and repairs fire-damaged sections of road and associated structures.

The two-stage approach to RIA outlined from New Zealand above is reflected in standard practice applied by Departments of Transportation (DoTs) in the USA. The US Federal Highways Administration (FHWA) Emergency Relief Manual (FHWA 2013) provides guidance to DoTs on the information required to secure funds for emergency response and recovery following hazard events. Rapid Damage Assessments, as they are more commonly referred to in the USA, require the following information to be collected and submitted to FHWA for funding consideration:

- Location, cause, nature and extent of damage and traffic volume
- Most feasible and practical methods of repair
- Distinction between emergency (temporary) and permanent works
- Estimation of repair costs
- Accompanying photographs and a location map.

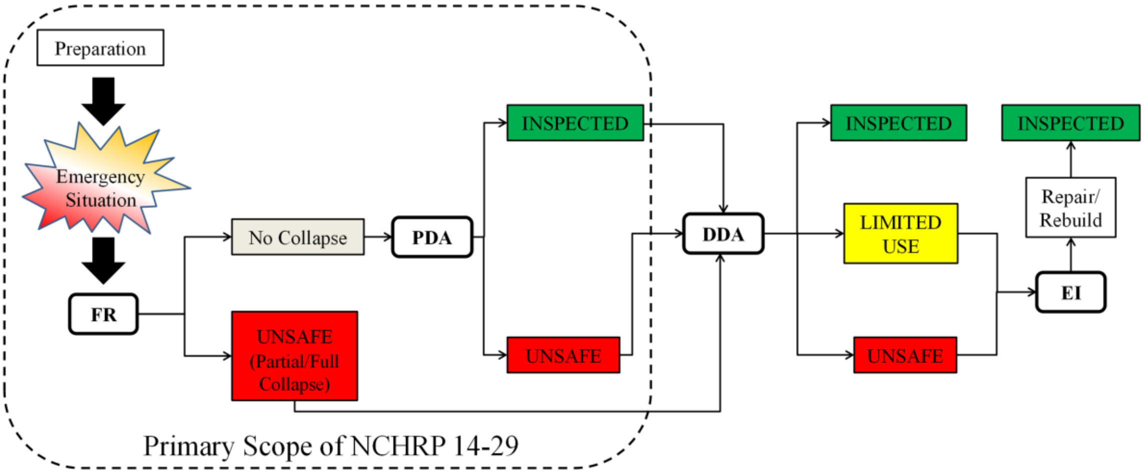
In 2016, the FHWA introduced its Mobile Solution for Assessment and Reporting (MSAR) Application that provides DoTs and other users with a means of rapidly and efficiently collecting and communicating damage data via a cloud-based web portal from a smartphone or tablet. The FHWA's MSAR fact sheet (MSAR-Fact-Sheet.pdf (dot.gov)) lists the following benefits of the system:

- The mobile app allows field personnel to rapidly deploy and perform Damage Assessments, write Detail Damage Inspection Reports, anytime, anywhere with mobile devices to assist Federal Lands Management Agencies and States in the event of a disaster;
- Utilizes off the shelf, widely available mobile devices and operating systems;
- Enables collection of data in a variety of formats including photos, voice, video, and geolocation information in real-time at the scene of a disaster or incident that has negatively impacted transportation resources;
- Provides management, program officials, and field staff information in near real-time to support prompt decision making and accelerate disaster declaration and funding;
- Provides a consolidated data source for information at the disaster, program, partner, unit, and site levels;
- Facilitates collaboration, standardization, reporting, and oversight of activities to ensure compliance with regulations;
- The Cloud-based Web Portal application provides integrated User Management, Workflow, Approvals, Reports, and Dashboards;
- Provides secure access and data for a variety of users including DOT, Federal, State, Local agency, and Tribal users.

Through the National Cooperative Research Program (NCHRP), the Transportation Research Board (TRB), in conjunction with the American Association of State Highway and Transport Officials

(AASHTO) and the FHWA, established a uniform methodology and consistent framework for coordinating emergency response in a safe and efficient manner (Olsen 2016). The recommended assessment process comprises four stages (Fig 3.3) that were stated to be based on methods already in use throughout the USA:

- Fast Reconnaissance (FR) – an overview to establish the geographical extent of damage
- Preliminary Damage Assessment (PDA) – an assessment performed for each structure within hours of an emergency event to assess the damage status of each structure and determine whether subsequent damage assessment stages are required
- Detailed Damage Assessment (DDA) – an evaluation of structural damage with decisions on functional restriction, conducted by structural, geotechnical and hydrological engineers
- Extended Investigation (EI) – in-depth inspections and investigations, after an UNSAFE rating has been assigned during the DDA.



UNSAFE = The structure requires further evaluation in the next assessment stage prior to being open to traffic.

Fig 3.3. Damage assessment stages, as defined by TRB/NCHRP (Olsen et al 2016).

This staged approach accommodates the need for rapid and reliable damage assessment as an emergency situation occurs and the immediate aftermath unfolds. It allows progressively more detailed assessment to be made, ensuring appropriate allocation of resources, including skill sets and capabilities, during the repair and recovery phase. It also provides guidance for determining appropriate response levels and mobilization based on incoming warnings.

These response levels are summarised in Table 3.1. Outline descriptions of FRs, PDAs and DDAs for bridges are provided in Table 3.2.

Level I Routine inspectors in the affected region(s) are placed on call to perform PDA. Teams are mobilized when the Managing Engineer (ME) determines that some damage has occurred based on Fast Reconnaissance (FR) observations.

Level II State Highway Agencies (SHAs) complete PDAs with their maintenance crews and DDAs using inspection crews. Additional personnel, such as design engineers, are placed on call and mobilized to assist with PDAs when the ME deems appropriate.

Level III Inspectors focus directly on DDAs, while maintenance crews, design engineers, and others (as needed) in the region are immediately mobilized to perform PDAs. Inspectors from other regions could be placed on call to assist. External consultants from local firms who are appropriately trained could be utilized, as necessary. Federal assistance and coordination may also be required.

Level IV In addition to the mobilization strategy in III, the SHA requests immediate assistance from inspectors, maintenance crews, design engineers, and external consultants from other regions to assist with the PDAs. Significant federal assistance and coordination will be necessary.

Table 3.1. Response levels relating to immediacy and the level of resources/effort required during an emergency event, as defined by TRB/NCHRP (Olsen et al 2016)

FR Method	Description
Pre-Event or Real time extreme event hazard mapping products	For several major emergency events such as earthquakes or hurricanes, pre-event or real-time disaster hazard mapping is often available, which provides the most rapid information indicating potentially severely damaged areas. When available, this information should be used, however, the start of the response process should not wait for this information because the timelines of the data can vary.
Windshield Survey	For lower response levels, personnel can be designated to drive highway routes (without stopping) to determine the nature and extent of the damage. These crews can utilize global positioning system (GPS) technology to log their routes and document where damage is observed.
Rapid remote sensing	Aerial imaging and LIDAR reconnaissance using helicopters or small fixed-wing aircraft that can quickly be mobilized are most appropriate for higher response levels
Crowd sourcing	Live video from state DOT cameras or other sources, such as the media or the general public, may be used for an initial assessment of the condition of severely damaged structures.
Small or micro unmanned aerial vehicles (UAV) i.e. drones	Small or micro unmanned aerial vehicle-based imaging is an emerging approach for hard-to-access disaster areas.
Visual aerial reconnaissance	Aerial reconnaissance (e.g. helicopter or small fixed-wing aircraft) is strongly recommended only for larger events (e.g. Response Level IV), where the damage is likely to be geographically dispersed.

PDA Summary	Description
Objective	Rapid route reconnaissance.
Scope	All bridges and culverts in the affected region, starting with priority routes.
Inspection Method	Drive through with a quick stop at each structure.
Personnel	Preliminary Damage Assessment Responders.
Time Frame	Immediately (within 24 hours).
Outcome	Determine the extent and type of damage. Identify/confirm unpassable routes and traffic bottlenecks. Close unsafe bridges. Code and mark the bridge. Recommend DDA for damaged or suspect bridges. Preliminary damage level estimate.
Deliverable	Digital PDA form, database entry (one entry per structure), and physical marking on the structure.
Coding Options	UNSAFE. INSPECTED.

DDA Summary	Description
Objective	Detailed inspection.
Scope	Bridge and site-specific.
Inspection Method	Inspection and access equipment as needed, load rating, and remaining strength analysis.
Personnel	Detailed Damage Assessment Inspectors.
Time Frame	As soon as possible (within 8 hours and continue as necessary).
Outcome	Code and mark as necessary. Close unsafe bridges. Recommendations for restriction, repair, or further investigation. Preliminary cost estimate for agencies such as FEMA or FHWA. Reopen structures deemed safe that were closed as precautionary measure during PDA survey. Element level damage estimates in accordance with the AASHTO Manual for Bridge Element Inspection (AASHTO 2019).
Deliverable	DDA report for each bridge and a daily summary report.
Coding Options	UNSAFE. LIMITED USE. INSPECTED.

Table 3.2. Summaries of Fast Reconnaissance (FR), Preliminary Damage Assessment (PDA) and Detailed Damage Assessment (DDA) for bridges as defined by TRB/NCHRP (Barbosa et al 2024)

Guidance is provided in Olsen et al (2016) for carrying out PDAs for bridges, tunnels, walls, culverts and overhead signage, using tablets to upload standardised damage assessment forms. The recommended PDA form for bridges is shown in Fig 3.4. Step-by-step procedures for damage assessment are provided for each of these structures, together with observations in relation to the main geohazards that affect them: earthquakes; tsunamis; hurricanes; floods and river scour. The use of paper-based forms is the least preferred means of data collection because backlogs can occur when these forms are scanned and emailed to central office and errors can occur in data transcription. Note that GPS-enabled tablets (referred to as Personal Digital Assistants) were already in use in 2003 for rapid recording of wildfire impacts in San Diego (Hitchens et al 2006).

Alipour (2017) reviewed techniques of rapid damage assessment and response strategies for highway bridges in the USA. From a survey of state DOT bridge engineers, visual inspection techniques were the most popular, but other techniques included *inter alia*: sonar surveys for underwater damage survey of abutments and piers; LiDAR and 3D laser scanning, tilt meters, accelerometers and remote cameras.

Preliminary Damage Assessment (PDA) Form – Bridges

Inspector 1 Name/ID:	______	Structure ID:	______	**PDA Outcome:**
Inspector 2 Name/ID:	______	Highway:	______	☐ INSPECTED (Green)
Agency:	______	Milepost:	______	
Date and time:	______	Route Carried on:	______	☐ UNSAFE (Red)
Latitude/Longitude:	______	Route Carried under:	______	
Structure material:	☐ Steel	☐ Concrete	☐ Other ______	

Damage Summary:	**Traffic Level:**	**Overall Comments:**
☐ 1 – None (0%)	☐ No traffic at all	______
☐ 2 – Slight (0-1%)	☐ Traffic on all lanes	______
☐ 3 – Light (1-10%)	☐ Traffic on some lanes	______
☐ 4 – Moderate (10-30%)	**Scour:**	______
☐ 5 – Heavy (30-60%)	☐ Unknown	______
☐ 6 – Major (60-100%)	☐ Unlikely	______
☐ 7 – Destroyed (100%)	☐ Likely, but cannot see	______
	☐ Definitely	

Feature Description:					**Notes: (additional notes on back)**
1. Approach/ Embankments	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
2. Parapets, Handrail, and Curb Line	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
3. Deck	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
4. Expansion Joint	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
5. Abutments and Wingwalls	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
6. Girder	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
7. Bearings	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
8. Bent Cap and Column	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
9. Foundation	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
10. Geotechnical	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
Other______	☐ None	☐ Minor	☐ Moderate	☐ Severe	______

Recommendations: Choose a recommendation based on the evaluation and team judgment. DDA evaluations should only be recommended with an UNSAFE posting. Provide comments on the recommendations below.

☐ **None** ☐ **DDA (Low Priority)** ☐ **DDA (High Priority)**

Record any recommendations:______

(QR Code)

Fig 3.4. Preliminary Damage Assessment form for bridges (from Olsen et al 2016)

In 2019, the US Federal Emergency Management Agency (FEMA) introduced its concept of ‘community lifelines’ which include critical transportation links, including highways. According to FEMA (2019), ‘a lifeline enables the continuous operation of critical government and business functions and is essential to human health and safety or economic security.’ In its 2021 Preliminary

Damage Assessment Guide[1], FEMA (2021) noted that 'when a community lifeline is disrupted, impacts to the community will be significant and action must be taken to stabilize that lifeline.' FEMA requires the submission of Preliminary Damage Assessments in order to allocate funds for emergency response when the serviceability of these lifelines is compromised. The 2021 PDA Guide sets out the information required for funding assistance and reimbursement in relation to debris removal, emergency protective measures and the emergency repair and restoration of disaster-damaged, publicly-owned facilities, including non-federal highways. The PDA Guide distinguishes between Initial Damage Assessments and Preliminary Damage Assessments. The former are undertaken to determine the location, extent and scale of damage; the latter are undertaken (sometimes jointly with the regional FEMA office) to detail the damage and determine repair and restoration cost estimates. The following information *inter alia* is required to be recorded during the PDA:

- Type of damage, such as debris damage, emergency protective activities, and/or private and public facilities;
- Location and geographic spread of the damage, urban or rural area, type of terrain, and accessibility to the area;
- Magnitude and severity of damage and all estimates required from Initial Damage Assessment (IDA);
- Immediate known problems, such as the following:
  - Areas inaccessible because of debris, high water, or damage to streets, roads, and bridges;
  - Serious health hazards;
  - Requirements for emergency protective measures;
  - Damage to critical infrastructure; and
  - Widespread loss of essential utilities and shortages of food, water, medical supplies, and facilities.

FEMA requires the following support documentation:

- Annotated maps
- Photographs
- Debris quantity calculation sheets (if applicable)
- Brief statements of percentage of work completed at the time of assessment
- Brief statements about whether work is force account, contract, or a combination thereof
- Labour cost summary
- Labour contracts/agreements
- Equipment cost summary
- Supply cost summary
- Contractor bids or invoices.

[1] 2024 version available in draft @ fema_pad-pda-guide_operational-draft_v1.1.pdf

The PDA Guide stresses the importance of effective readiness and preparation in advance of emergency events. Table 3.3 describes the activities recommended to contribute to readiness for and planning of damage assessments.

Activity	Description/ Benefit
Standard Operating Procedure	Developing a standard operating procedure (SOP) that identifies event triggers and supplements/ complements the content of this document. An SOP can help with planning and operational decision making, clarify roles and responsibilities, establish protocols, and streamline decisions following a disaster.
Identify Risks to Critical Infrastructure	Identifying high-risk areas and developing a list of critical infrastructure assets can help expedite analysis following a disaster. Planning and zoning maps, as well as Geographic Information System (GIS) technology, can aid in this effort.
PDA Plan of Action Template	Developing a standard template for joint preliminary damage assessments (PDA) that disaster information can be plugged into, to expedite development of the PDA plan of action. The plan template may be included as an addendum to the SOP.
Assembling the Right Team	Assembling the right team prior to a disaster ensures alignment of available resources for life-sustaining operations. In some cases, non-emergency management personnel (who do not have responsibilities immediately following a disaster) can stabilize teams that would otherwise be impacted by diversions of emergency management personnel.
Pre-Positioned Contracts and Memoranda of Understanding	Having pre-positioned contracts or memoranda of understanding for services, including mobile applications, remote sensing, or GIS capabilities, can expedite data collection during the initial damage assessment (IDA).
Training	Offering training to personnel preselected to support damage assessment is important in maintaining pre-incident readiness. Training should ensure staff are familiar with damage assessment plans, SOPs, and protocols.
Exercises	Conducting exercises can help validate protocols and processes, provide staff with opportunities to operationalize plans, and encourage relationship-building among FEMA and state, local, tribal, and territorial (SLTT) governments.
Technologies	Understanding the technologies available (e.g., aerial imagery and ground-level photography) and ensuring the relevant stakeholders are familiar with the technologies being acquired and used for damage assessment is important for pre-incidents readiness.

Table 3.3 Pre-incident damage assessment readiness and planning activities (from FEMA 2021)

Finally, the TRB/NCHRP (Matherly et al 2024) have developed an Emergency Management Playbook for State Transportation Agencies. Among the key headings for damage assessment are the following:

- Identify who should be involved
- Establish a standardised damage assessment process (see below)
- Identify the designated damage assessment team in advance
- Identify requirements for participants
- Determine information and equipment required
- Document the damage assessment process and procedures
- Establish regular training
- Document and evaluate repeatedly damaged assets.

The guidance notes that 'establishing a standardized damage assessment classification system with supporting tools, such as damage assessment forms, can improve the quality and speed of the information obtained after the event. Standardized procedures and forms for damage assessments facilitate a common understanding of the extent of damages and therefore facilitate contracting repairs and reconstruction work.'

In United Kingdom, a good practice guide is provided by HMGUK (2013) on multi-agency preparedness, response and recovery in relation to emergencies. The document stresses the importance of Integrated Emergency Management (IEM) and describes eight 'guiding principles' that help to define it: anticipation; preparedness; subsidiarity; direction; information; integration; co-operation; and continuity. The *information* element of IEM is described as follows:

'Information is critical to emergency response and recovery and the collation, assessment, verification and dissemination of information must be underpinned by appropriate information management systems. These systems need to support single and multi-agency decision making and the external provision of information that will allow members of the public to make informed decisions to ensure their safety.'

The document notes that particular challenges may need to be addressed to realise the collation, assessment, validation and dissemination of information under emergency conditions. These might include:

- information management procedures may vary between agencies;
- perspectives on the event or situation may differ;
- mistakes and misunderstandings may occur under pressure; and
- communications can become overloaded.

In 2021, The United Kingdom Department for Transport (DfT 2021) released a document titled 'Emergency Preparedness, Response, & Recovery: Identifying Lessons Learned by the UK Highway Sector from Extreme-Weather Emergencies (2015-2020)' prepared by HD Research Ltd for the DfT and the Local Government Technical Advisers Group. The document emphasised the importance of Shared Situational Awareness for co-ordinated multi-agency emergency response and noted that the lack of a systematic RIA process in the sector leads to inconsistencies in authorities' ability to apply risk-based approaches to the management of impacts to highway assets.

The concept of designating critical infrastructure as 'community lifelines' (FEMA 2019), including transportation, was used to underline the importance of adopting risk-based approaches to asset management. During emergency conditions, damaged assets on the road network deemed to be critical to the operation of the broader network and other lifeline infrastructure, need to be stabilised to prevent further failure and the escalation of secondary and tertiary impacts. Integrated Emergency Management and network resilience form much of the remainder of the topics covered in the DfT document.

Deeming (2021) published a document titled 'Emergency Preparedness, Response and Recovery: Guidance on Rapid Impact Assessment for Highway Networks.' The author refers to a rapid impact assessment cycle comprising: planning; capability building; preparedness; activation during response and programme development for recovery (Fig 3.5).

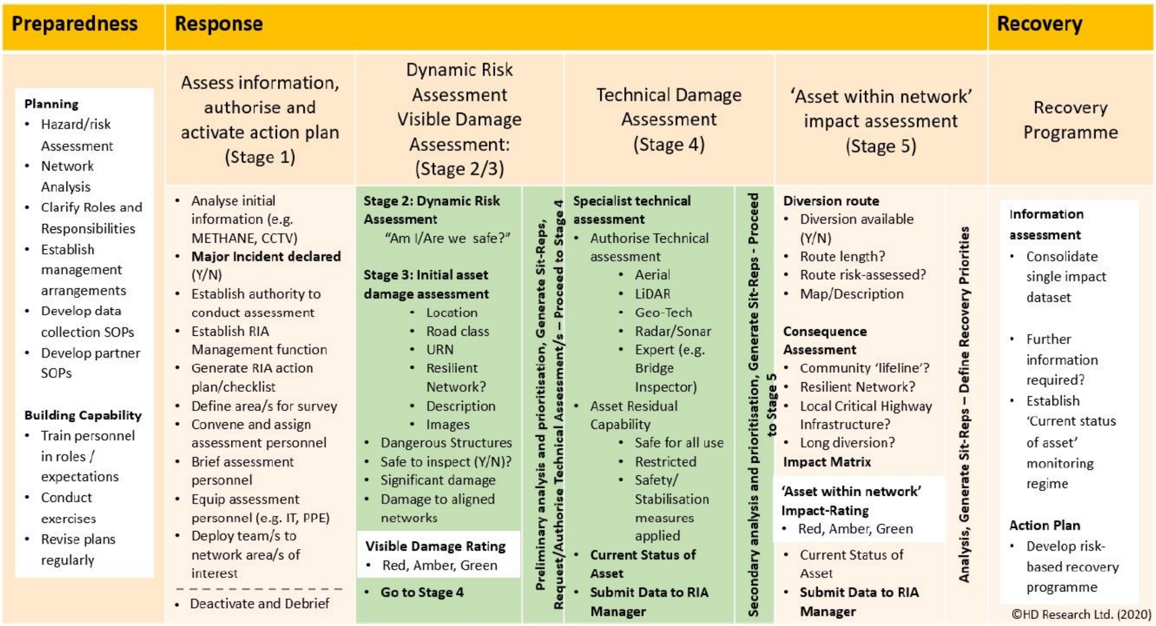


Fig 3.5. The Rapid Impact Assessment Cycle (from Deeming 2021)

The document defines RIA as:

'the preliminary (i.e. rapid) assessment of *damage* to assets, of the *consequences* such damage may have for those using the network within which the asset is positioned and the potential *impact* these two factors bear on the communities, businesses and services the highway network links together.'

It emphasises the importance of preparedness and the need to ensure inter-agency co-operation and interoperability when responding to emergencies. It stresses the need to establish an RIA management structure and RIA action plans that address situational overview, key network attributes, RIA objectives, priorities and resources, safety considerations, data collection techniques and reporting formats and timeframes. Impacted areas should be defined, subdivided with subdivisions allocated to assigned damage assessment field teams. These teams should carry out dynamic risk assessment to identify health and safety aspects of working around assets in hazardous conditions.

They should be given copies of relevant Standard Operating Procedures (SOPs), appropriate personal protective equipment (PPE), cameras, tablets or other devices to complete damage assessment forms electronically, paper copies of these forms in case of device difficulties, maps and means of communication (e.g. radio and mobile telephone). They should also be provided with a hand-held GPS independently of the use of GPS-enabled tablets.

As well as assessing damage to highway assets, field teams should also record damage to adjacent (‘aligned’) infrastructure. Although not specifically stated, the advantages of doing this include: multi-agency sharing of data; consideration of enhanced levels of consequence (and hence priority) should further damage take place; and the opportunity to accommodate this infrastructure in the design of reinstatement works, where appropriate. Field teams send data electronically or manually to an RIA co-ordinator. All information is entered into a central database along with that derived from other sources, including Multi-Agency Information Cells (MAICs), news bulletins and crowdsourced information.

The document sets out a recommended five-stage approach to RIA:

1) The selection of a defined Network Area of Interest (NAOI)
2) Declaration of a Major Incident
3) Initial asset damage assessment
4) Technical Damage Assessment
5) ‘Asset within network’ Impact Assessment

Stages 3, 4 and 5 are outlined below.

Stage 3: Initial asset Visible Damage Rating (VDR)

This initial damage assessment is undertaken to classify each highway asset in the NAOI with an integrity classification using the following categories:

RED - Complete loss of structural integrity (collapse) and/or danger from damaged aligned services

AMBER - Damaged but structural integrity retained

GREEN - Structure appears undamaged.

The document recommends that, even if no physical damage is visible and a green rating is applied, if conditions suggest there may be invisible damage (e.g., a suspicion of unseen scour to bridge foundations) a **RED** rating should be applied, and expert technical assessment conducted before the asset is opened for use.

The recommended asset description information to be recorded during the VDR includes:

- RIA inspection Unique Reference Number (URN)
- Highway authority asset URN
- Time and date of inspection
- Road classification and number
- Asset type
- GPS location
- Is the asset part of the local critical infrastructure?

- Asset description
- Photographs taken and uploaded (if possible) from all angles
- Are the structure and its surroundings sufficiently safe for a full initial assessment without technical support?
- For the asset damage assessment, the inspection team should:
- Record the most significant damage
- Use tick boxes to allocate asset condition for direct comparability between assets and use free text for descriptions
- Record damage to or exposure of 'aligned' services (presumably within the road reserve), such as gas or electricity, and make the service owner/provider aware of the damage as soon as possible.

The field sheet for Stage 3 assessment is shown in Fig 3.6.

Stage 2: Major Incident: Network Infrastructure Rapid Impact Assessment (RIA) Form		
Has a Major Incident been declared by your authority or a partner agency?		Y/N
	If No: As a Cat 1 responder, are conditions such that you should consider declaring a Major Incident for your authority?	Y/N
	If Major Incident declared: time/date of declaration:	
	Local Authority Incident/Log number:	

Stage 3: Initial asset damage assessment		
Site-specific Dynamic Risk Assessment (DRA) conducted and recorded	Date/Time of Dynamic Risk Assessment and inspection start:	
RIA inspection URN [*Task-area_asset number, e.g. RIA_004_1*]:		
Road classification and number:		
Asset type:	[*e.g. bridge, culvert*]	
Precise location of asset (i.e. 8 or 10-figure Grid reference):	[*For linear carriageway enter start and end points of assessment*]	
Highway Authority Inventory: unique reference number (URN) for asset [*if known*]:	Uniclass2015 entity code: [*if known, e.g. Code for fixed bridge: EN_80_94_50*]	
	EN_	
Is this an 'Local Critical Highway Infrastructure' [*i.e. is it listed in the local authority LCHI inventory*]?		Y/N/Do not know
Is this asset located on the local authority's Resilient Network?		Y/N/Do not know
Asset description: [*Describe asset type, e.g. "One lane single span stone masonry arch bridge over stream"*]		
Attach images of asset: [*The asset and damage should be photographed and labelled systematically from all points of the compass (N,E,S,W) if safe access is possible. All images of damage should include a reference scale (e.g. a survey pole)*]		

Dangerous structures	
Are the structure and its surroundings sufficiently safe for a full initial assessment to be conducted without additional technical support?	Y/N
If No, what elements of the assessment is the assessor unable to carry out? *NB. It is important to understand the effect that technical support will be needed to achieve. For example, understanding the assessor cannot carry out an assessment of a bridge pier's foundations for scour (i.e. the effect), allows the RIA coordination team to consider all available options for achieving that effect (e.g. civilian or military divers, sonar, cameras)*	

Stage 3 (cont'd) Damage Assessment:			
Record the most significant damage [*tick box*]			[*Damage assessment: provide free text description*]
Complete collapse – deck structure	1		
Partial collapse – deck structure	2		
Complete collapse – retaining wall/parapet	3		
Partial collapse – retaining wall/parapet	4		
Carriageway surface failure/instability	5		
Foundation damage (e.g. scour)	6		
Mass movement: landslide	7		
Non-structural debris (e.g. fallen tree, lines)	8		
Damage to adjacent structure presenting risk to carriageway	9		
Drainage: outfall blockage / debris			
Pipe/culvert +1.2m diameter	10		
Pipe/culvert -1.2m diameter	11		
Traffic Signal: damage/failure	12		
Other: [*describe*]	13		
	14		

Damage to aligned networks

Damage to / exposure of aligned services (*Mark all relevant boxes*)

		Damaged/ Exposed (*Tick*)	Image attached (Y/N)	Owner/operator	Owner/operator informed (Y/N)	Date/Time
Rail	1					
Gas	2					
Electric: Buried	3					
Electric: overhead	4					
Water - Main	5					
Water - Foul	6					
Water - Surface	7					
Telecom/Fibre: buried	8					
Telecom/Fibre: overhead	9					
Other:	10					

Stage 3 (cont'd): Initial Visible Damage Rating (VDR)			
Initial Asset status assessment: Consider: **Damage to this asset only** NB. If conditions suggest there may be invisible damage (e.g. significant scour to bridge foundations) a RED rating should be applied, and expert technical advice sought.	Complete loss of structural integrity (collapse) and/or danger from damaged aligned services	RED	
	Damaged but structural integrity retained	AMBER	
	Asset appears undamaged	GREEN	

Assessment completed by [*Print name*]:	Signed:	Time/Date

Fig 3.6. Stage 2 and 3 assessment forms (from Deeming 2021).

Stage 4: Technical Damage Assessment

If Stage 3 is carried out by non-expert personnel, the priority should then be placed on coordinating sufficient suitably qualified personnel to carry out a Technical Impact Assessment on all **GREEN**-rated assets before they are opened for public use. Ensuring **GREEN**-rated assets are safe to be re-opened should take priority over the technical assessment of more seriously damaged infrastructure (**AMBER** and **RED**). This ensures that the assets deemed undamaged are returned to service as soon as possible, whilst also ensuring that unidentified damage is minimised. Stage 4 involves specialist assessment using more complex techniques than straightforward visual inspection, such as LiDAR, geotechnical investigation, structural engineering investigations and sonar equipment to inspect bridge foundations below water level. An assessment is then made as to whether the asset can be made:

- Open to all permitted traffic (with/without safety measures, i.e. speed control)
- Open to emergency responders only (with/without safety measures)
- Closed awaiting safety/stabilisation measures
- Closed to all traffic.

The field sheet for Stage 4 assessment is shown in Fig 3.7.

Stage 4: Technical Damage assessment					
RIA inspection URN [*Task-area_asset number*]:					
Specialist technical assessment					
Has a secondary technical assessment of this asset been carried out					Y/N
		Type	Carried out by	Time/date	Report Attached Y/N
Aerial					
Photographic/visual	1				
LiDAR	2				
Geo-technical					
Radar/Sonar/DGPS	3				
Vehicle-deployed damage analysis	4				
Other geo-tech:	5				
Structural					
Qualified Expert [*e.g. bridge inspector*]	6				
Other:	7				

Asset Residual Capability		
Considering the findings of the initial and any secondary assessment, is the highway safe to be used by the public at this asset location? (*Y/N or tick*)		
Asset is safe for **unrestricted** use by all permitted traffic	Y/N	1
If No: can asset be used by the *public* with safety/stabilisation measures in place:		2
Measures taken/required: [*e.g. further technical inspection; weight limit; lane closure; "landslip taped and coned off"*]		
No: the asset cannot be used by the *public* – due to damage		3
If No: Is the highway usable by Emergency Responders (Blue/Yellow light), if necessary, with safety/stabilisation measures in place?	Y/N	4
Measures taken/required: [*e.g. further technical inspection; weight limit; lane closure; "landslip taped and coned off"*]		

Current Status of Asset		
Current status of asset [*delete as appropriate*]:	1	Open to all permitted traffic
	2	Open to emergency responders only
	3	Closed awaiting safety/stabilisation measures
	4	Closed to all traffic
Secondary assessment and status update completed by [*Print name*]:	Signed:	Time/Date

Stage 5: 'Asset within network' impact assessment			
RIA inspection URN [*Task-area_asset number*]:			
This form is to be completed if asset has not been assessed as safe for all permitted traffic following initial and/or secondary assessments			
Diversion route			
Is a local diversion route available?			Y/N
If YES: estimated length of proposed diversion (km)			km
Has the diversion route been risk-assessed?	For public use	1	Y/N
	For emergency responders' use	2	Y/N
	Diversion route risk assessment is required	3	Y/N
Describe diversion route, including limitations (e.g. any known weight/width restrictions) [*attach map and route risk assessment if available*]:			
Consequence Assessment			
Describe the effect that the damaged asset may have on the functionality of the wider network as a community resource [*e.g. Is it on the local authority's Resilient Network? Is this the sole access route for a community (i.e. a community 'lifeline')? Does it carry or provide access to critical infrastructure, is this a Local Critical Highway Infrastructure asset (LCHI)? Does closure of this asset necessitate a long diversion?*]			

Fig 3.7. Stages 4 and 5 assessment forms (from Deeming 2021)

Stage 5: 'Asset within Network' Impact Assessment

This Stage helps set priority for reinstatement works (Fig 3.7), and is undertaken for all assets assessed to be unsafe for 'all permitted traffic'. The first step is to determine whether there is a suitable temporary diversion to safely accommodate traffic. The length of the diversion and the road standard will determine whether it is a practical solution.

Impact assessment

Deeming (2021) defines *impact* as the product of *damage* and *consequence*. Damage has been assessed in Stages 3 and 4. Consequence is assessed in terms of the criticality of the asset within the broader highway network and especially in terms of the provision of access to affected communities.

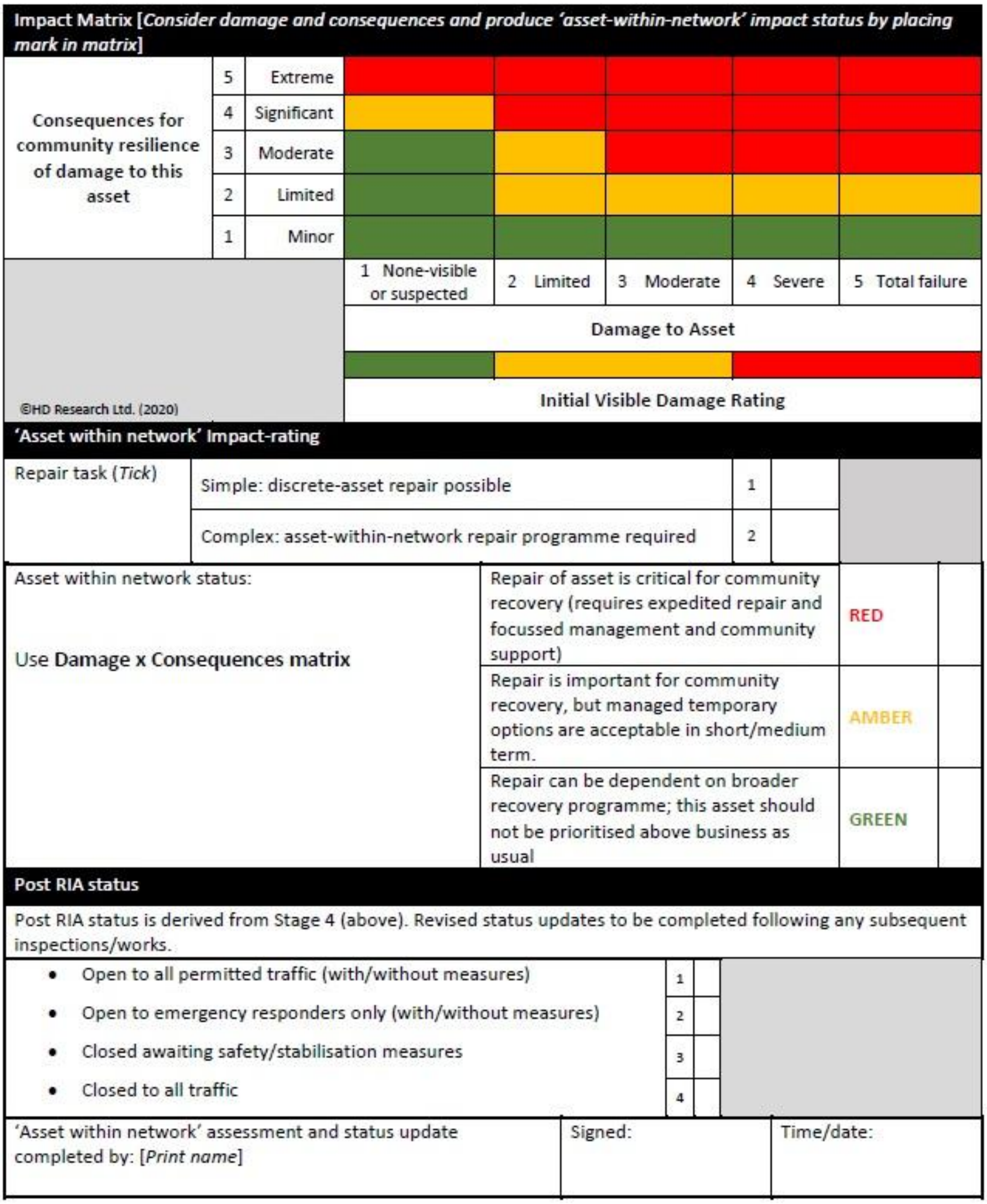
If no diversion is available this may increase the potential impact loading of even quite minor damage to a single asset. For example, a small community might only have access via a single-track road. Accordingly, if that road is made impassable to traffic this would represent a high impact for the community and as such would justify a priority repair (Deeming 2021).

When determining the consequences of loss of asset function, Deeming (2021) suggests that it is useful to consider the following:

- Does it comprise part of the local authority's Resilience Network?
- Does it constitute the sole access/egress route for a community (i.e. is it a community lifeline)?
- Does it carry (e.g. key fibre) or provide access to critical infrastructure (e.g. a hospital)?
- Is it a 'Local Critical Highway Infrastructure' asset?

Impact matrix

Considering all of the information collected and collated from the Stage 3 and 4 damage assessments, the asset's residual capability, available diversions and the consequences of lack of asset function, the RIA coordinator or assessor is required to use an impact matrix (Fig. 3.8) to rate the impact in terms of damage and consequences. Five damage categories are assigned, based on the damage assessment of Stage 4. Deeming (2021) notes that the matrix weights consequences in a way that allows smaller assets whose disruption would have moderate to extreme consequences for an affected population to be RED rated (see explanation in Fig. 3.8). This means that even very small communities can receive enhanced assistance if, for example, their day-to-day life was affected by damage to a small bridge, whose repair would not normally meet cost-benefit criteria.



Impact Matrix [*Consider damage and consequences and produce 'asset-within-network' impact status by placing mark in matrix*]							
Consequences for community resilience of damage to this asset	5	Extreme					
	4	Significant					
	3	Moderate					
	2	Limited					
	1	Minor					
©HD Research Ltd. (2020)			1 None-visible or suspected	2 Limited	3 Moderate	4 Severe	5 Total failure
			Damage to Asset				
			Initial Visible Damage Rating				

'Asset within network' Impact-rating			
Repair task (*Tick*)	Simple: discrete-asset repair possible	1	
	Complex: asset-within-network repair programme required	2	
Asset within network status: Use **Damage x Consequences matrix**	Repair of asset is critical for community recovery (requires expedited repair and focussed management and community support)	RED	
	Repair is important for community recovery, but managed temporary options are acceptable in short/medium term.	AMBER	
	Repair can be dependent on broader recovery programme; this asset should not be prioritised above business as usual	GREEN	

Post RIA status		
Post RIA status is derived from Stage 4 (above). Revised status updates to be completed following any subsequent inspections/works.		
• Open to all permitted traffic (with/without measures)	1	
• Open to emergency responders only (with/without measures)	2	
• Closed awaiting safety/stabilisation measures	3	
• Closed to all traffic	4	
'Asset within network' assessment and status update completed by: [*Print name*]	Signed:	Time/date:

Fig 3.8. Asset within network impact matrix and repair priority (from Deeming 2021).

Note that the use of Red, Amber and Green (RAG) in this table relates to community vulnerability and not the RAG used in the Initial asset VDA for asset integrity (Stage 3)

Although Deeming (2021) refers to risk assessment and risk management as key considerations in RIA and emergency response, the impact matrix uses the term *impact* rather than *risk*. Because the assessment of risk involves the probability of a potentially damaging event over a given time period, it is automatically representative of future events, and is therefore more relevant to resilience than RIA. For RIA, the damage has already happened or, in real-time, is happening, which has a probability of 1.0, hence the use of the concept of actual impact. Many of the concepts and considerations outlined above and described in detail by Deeming (2021) are reiterated in Deeming and Lamb (2022).

In Scotland, severe winter weather and debris flow hazards have had significant impacts on Transport Scotland's road network. The severe winter events of 2010, of example, are referred to by Gillies (2014), who describes the development of a Multi-Agency Response Team (MART) to improve communications between responders and with the general public. The MART approach was designed to address the following deficiencies that were seen to have aggravated the 2010 effects:

- Agencies working in isolation
- Warning messages not clearly understood by the public
- Limited situation reports describing actual conditions
- No prior agreement for mutual aid between agencies
- Lack of an effective mobile information platform, providing information to users 'on the move'
- Traffic and travel information websites with insufficient capacity to cope with peak demand.

Further information on Transport Scotland's MART is provided by Legget (2016). The importance of Integrated Emergency Management, combining: Assessment; Prevention; Preparation; Response; and Recovery, is stressed in the policy guideline published by Scottish Government (2016). This document emphasises the need to build resilience into critical infrastructure to reduce its vulnerability to man-made and natural hazards. Critical National Infrastructure is defined by the UK National Cyber Security Centre as 'national assets that are essential for the functioning of society, such as those associated with energy supply, water supply, transportation, health and telecommunications' (Critical National Infrastructure (CNI) - NCSC.GOV.UK)

As part of the Framework for Risk and Resilience Assessment, the United States TRB/NCHRP (Pena et al 2023) also defined criticality as a measure of the importance of an asset to the system. The criticality of a bridge or a road link in the highway network is determined by several factors including traffic volume, AASHTO road function classification, location on the National Highway System, emergency evacuation routes, distance from emergency services and location of susceptible communities that are dependent upon its continuing operation. In the TRB document, risk is defined as the product of asset vulnerability, consequences of disruption and threat probability because it is more aligned towards resilience.

Deeming and Lamb (2024) provide further discussion on the importance of RIA, triage, prioritisation, asset stabilisation and recovery. They describe how the RIA procedure described by Deeming (2021) has been operationalised into an app-supported, browser-based GIS tool, named StormChain. The GIS automatically generates an impact score based on visible damage and consequence. The tool allows highway managers to justify diverting resources away from high-profile assets to stabilise and repair assets whose restoration has greatest effect in reducing levels of disruption to affected communities. The authors note that the system should be able to maximise the use of a range of 'information streams', including socio-demographic data, CCTV, field intelligence, expert knowledge, partner knowledge, contractor-supplied reports, telemetry, news bulletins and social media.

Chamorro et al (2023) describe the development of a web-based GIS for natural hazard risk management on the road network of Chile. The toolkit superimposes seismic, hydrometeorological and volcanic hazard maps with social vulnerability index maps and the road network to simulate the impacts of hazard events and help prioritise mitigation strategies. Consequence is determined in terms of the exposure of critical infrastructure, such as schools, healthcare, drinking water and other lifeline utilities and the additional travel times required when links in the road network are closed due to hazard impacts on highway assets. The toolkit is more of a 'what-if' and cost-benefit modelling approach to preparedness and resilience than RIA or emergency response, but is a good example of how decision-support tools can be developed to assist in risk reduction strategies on highway networks. The use of the toolkit to model the hazard and risk posed by volcanic lahars on the road network and associated social vulnerability is described by Chamorro. As far as can be ascertained, this is a research exercise and has not been applied in practice. Operational resilience strategies in the context of co-seismic landslides are discussed by Aydin et al (2018) for parts of the Nepal road network following the 2015 Gorkha earthquake.

Returning to the need to rapidly collect impact data as close to the onset of an emergency event as possible, several authors have noted that it is physically impossible to do this instantaneously and safely over large areas. Guang and Chen (2014) reviewed the use of tweets posted on social media to provide information on the location and intensity of disasters using Hurricane Sandy on the east coast of USA in 2012 as an illustration. Chen et al (2020) examined the use of social media to generate flood impact data on the highway network during Hurricane Harvey in Houston, Texas in 2017. Social media tweets required data cleaning and filtering before they were used to map the location and severity of flooding. They referred to the use of 'Tweepy' which is a Python package for implementation of the Twitter streaming application programming interface. The outcome was a strong correlation (R=0.76) between the mapped social media data and the high-water incidence data collected by Texas DoT. Three main steps were involved in data adaptation:

Data Cleaning

Data cleaning, a process of detecting and removing errors and inconsistencies, and to remove unnecessary noise and slang. Five cleaning steps were described.

Data Mapping

Cleaned tweets were mapped to each highway using a set of rules through direct and indirect highway reference.

Data Filtering

Tweets capable of indicating disaster impacts on highways need to be distinguished from non-hazard related tweets using key word searches.

Yuan and Li (2018) took this a stage further by examining crowdsourced data in relation to Hurricane Matthew that impacted Florida in 2016. In one particular county, approximately 30% of the recorded tweets were disaster or damage related. They concluded that the collection of timely crowdsourced information can be used to support rapid damage assessment during disasters.

Zhu et al (2024) describe the combination of satellite remote sensing and social media crowdsourced data to assess the impact of flooding on the urban road network and traffic disruption in Henan Province, China. The authors provide a review of the issues concerning the use of satellite data for real-time monitoring. During rainfall-induced flood events, cloud cover may seriously reduce visibility of the ground surface and the extent of inundation. Consequently, the authors used Sentinel-1 GRD SAR imagery to determine the extent of waterlogged ground during major flooding in July 2021. They combined this interpretation with textual messages sent on the Sina Weibo social media platform. This allowed access to 83,000 geo-tagged data entries during the flood period through various media formats including web, email, apps, instant messaging, SMS, PCs and mobile devices. Significant pre-processing of data was required, including Jieba Python text segmentation software and Word2Vec encoding. Flooding impacts were categorised into levels of 'disaster', as shown below:

Level 0 Significant impact, roads are submerged and closed

Level 1 Heavy damage, with deep water accumulation and traffic congestion

Level 2 Moderate damage, where partial submergence leads to reduced driving speeds

Level 3 Slight damage, with virtually no standing water and normal flow of traffic

Level 4 A submerged state from remote sensing data, without supporting crowdsourced information.

It is unclear why Level 4 is not accommodated in Level 0 as a variant and why the 0-4 numbering scheme has not been reversed. Nevertheless, the research provides a useful example of the combined use of the techniques. The study used a confidence interval-based threshold algorithm with accuracies recorded at 0.86-0.89.

Masuo (2022) describes the use of a traffic monitoring and information management system to record road closures in Japan and relay information to road users. The system was implemented by the Ministry of Land, Infrastructure, Transport and Tourism in 2014 and involves 4 million private car owners who voluntarily agreed to take part. Rainfall-induced flooding and landslides in 2020 led to the removal of several bridges and the damage to roads and railways in the Kyushu region. Roadside communications technology was able to monitor vehicle movements to determine, in real time, the extent of road closures while at the same time relaying this information to road users. The system was supported, and the data verified, using CCTV and drone observations. A sample of the onscreen mapping is shown in Fig. 3.9. The same system, referred to as the Vehicle Information and Communication System, is described by Shimizu et al (2022) who refer the operation of 3000 roadside probes that record and upload traffic data every 15 minutes. The system appears to have *revolutionised* the collection of road closure data during disaster events in a country with a road network of 1.2 million kilometres in an area of 380,000 km^2.

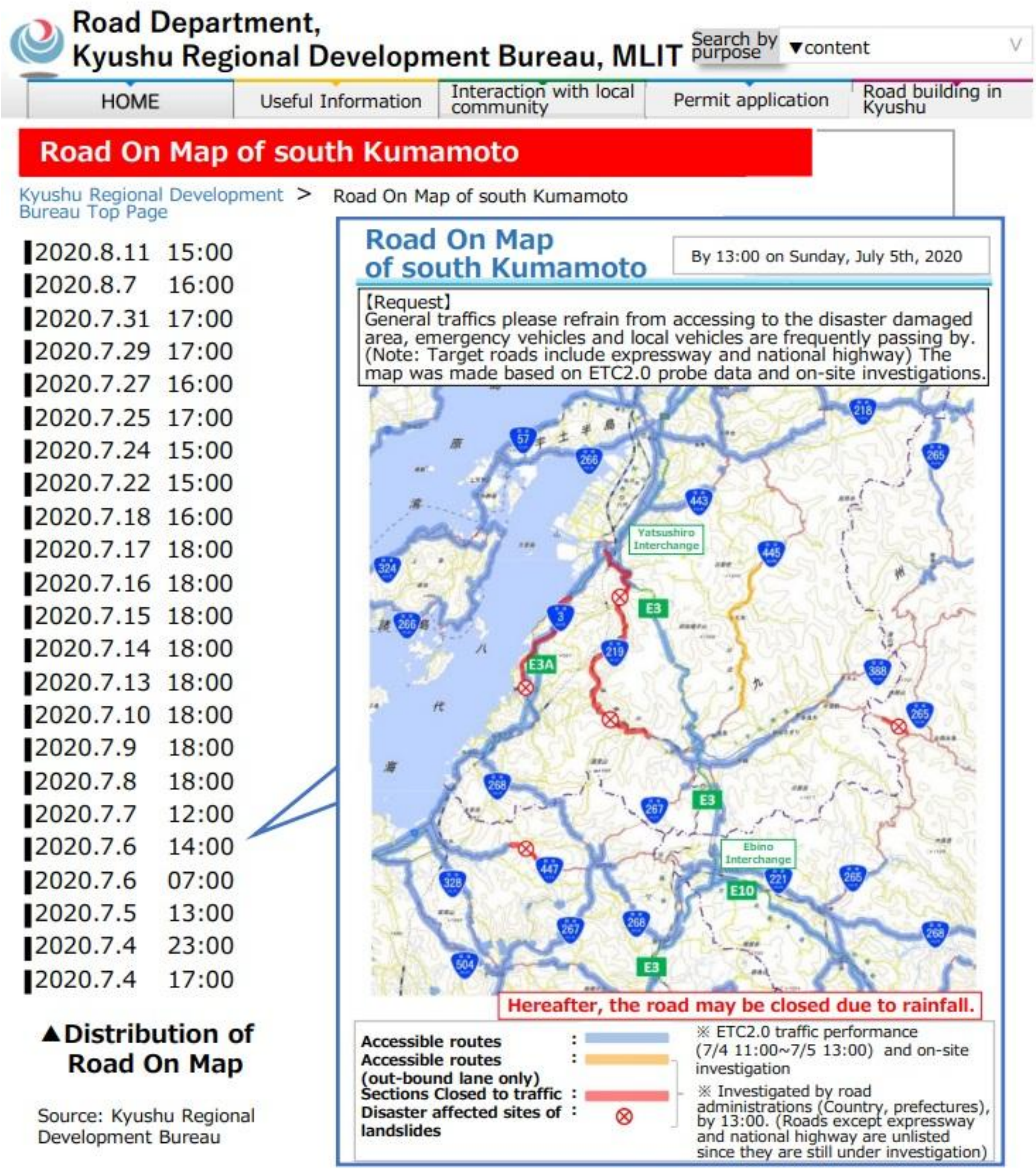


Fig 3.9. Onscreen mapping of near-real time road closures using road-side probes for traffic management purposes during rainfall-flood events (from Masuo 2022).

The PIARC Disaster Management Manual (2022)

The PIARC Disaster Management Manual describes the conventional disaster management cycle comprising: Preparedness; Mitigation; Disaster; Response; and Recovery. It refers to the implementation of Post-Disaster Needs Assessments that comprise the following stages:

- Activation
- Preparation
- Data collection
- Data analysis
- Reporting.

The Manual distinguishes between emergency measures implemented to reinstate damaged infrastructure (emergency response) and those aimed at restoring the functionality of the asset to its original state, taking advantage of lessons learnt and resilience enhancement, i.e. 'build back better'. Among the key elements of response and recovery are: co-ordination; communication; asset inventory; damage assessment; needs assessment; impact assessment; hazard assessment and the review of organisational capacity, human resources, roles and responsibilities. In terms of impact assessment, the Manual differentiates between a first step quick assessment that determines:

- The general level of damage to infrastructure
- The areal extent or 'coverage' of the 'disaster area'
- The local government's capacity to respond.

The second step involves rehabilitation and reconstruction assessment. The need for inter-agency co-ordination and communication is emphasised as is the requirement to have standard procedures in place and disaster response units on standby to service vulnerable parts of the network. It also refers to the need to have established Disaster Management Plans in place to ensure effective emergency response and recovery.

Concluding remarks

The RIA-related documentation summarised above from New Zealand, USA and the UK, all refer to the need for robust preparedness as a precondition for effective RIA and emergency response. They also emphasise the need to adopt standardised procedures and maximise inter-agency cooperation and data-sharing in both preparedness, RIA and emergency response. TRB/NCHRP (Olsen et al 2016; Allen 2020; Barbosa et al 2024) note that many state highway authorities will benefit from uniform procedures for response planning, assessment and rapid restoration of services. Access to hazard maps and sources of seismic, meteorological and coastal flooding data and tsunami alerts, for example, is an important part of preparedness, while the use of social media data should be maximised as long as it is independently verified.

Learning from previous disasters is an important part of preparedness and helps to streamline RIA and emergency response. According to Allen (2020), the California DoT (Caltrans) has developed an extensive database of emergency events, including the costs of temporary and permanent repairs since 1985. Oregon DoT is perhaps the leading US DOT in the management of rock fall hazards along its road network, with over 4,000 entries. Datasets such as these are extremely useful helping to pre-plan RIA and emergency resources.

Despite the operational advantages of standardising methods of RIA, it is important to bear in mind that each emergency event is different and the RIA will need to be implemented accordingly. The process of recording damage and evaluating impact (and risk) cannot be too prescriptive and there needs to be flexibility built into the RIA methodology to allow it to be adapted to suit different emergency circumstances. None of the published cases of RIA and IDA/PDA equivalents discuss how different hazard mechanisms might be better catered for in bespoke RIA methods. Obviously, highway authorities need rapid and simple systems that are not overly-complicated, but it is evident that the impacts from some natural and man-made hazards might not fit entirely comfortably within the frameworks developed.

4. SUMMARY OF RIA QUESTIONNAIRE RETURNS

4.1. INTRODUCTION

At the outset of the research, i.e. before the Literature Review commenced, it was recognised that there may be limited published information on RIA practice, especially directly by highway authorities. Consequently, a questionnaire was devised with the intension of inviting PIARC members to contribute their information and describe how they implement RIA. Issues concerning preparedness, the availability of impact records and hazards maps, liaison and data sharing with partner agencies and emergency responders, the use of remote sensing imagery, techniques of field data collection, quantity and cost estimation, risk assessment for emergency works prioritisation, and the use of software, were included in the questionnaire.

The format and contents of the questionnaire were discussed with PIARC POT members and the final version was translated from the original English into French and Spanish. The invitation and links to complete the questionnaire online were issued by PIARC to First Delegates and National Committees on 4 July 2024. The original deadline for receipt of returns of 22 July was extended to 31 July, with the last return received on 8 August 2024. The questionnaire is copied in Annex 1. This annex also contains graphs, tables and commentary that summarise the information provided. In total, 25 questionnaires were returned from 17 countries (Table 4.1). An overview of this information is provided below.

Table 4.1 Returned questionnaires by country and organisation

Country	**Organization**
Argentina	National Road Directorate
Australia	Department of Transport and Main Roads (DTMR)
Bulgaria	Road Infrastructure Agency
Canada	British Columbia Ministry of Transportation and Infrastructure
Canada	Transport Canada - Pacific Region
Canada-Quebec	Ministry of Transport and Sustainable Mobility
Chile	Roads Administration (Department of Roads)
China	Southwest Jiaotong University (TC1.5_Working Group 3)
China	The Inner Mongolia Transportation Department
France	French Ministry for Transports
Italy	Azienda Nazionale Autonoma delle Strade (ANAS)
Japan	Disaster Prevention Div., Safety, Disaster Prevention and Engineering Dept. Honshu-Shikoku Bridge Expressway Company Limited
Luxembourg	National Road Administration
Mozambique	National Roads Administration (ANE-IP)
Nepal	Department of Roads
New Zealand	New Zealand Transport Agency (NZTA)
Saudi Arabia	Unstated, possibly a consultant to road authority
South Africa	South African National Roads Agency Limited
United States	Missouri Department of Transportation
United States	Alaska Department of Transportation and Public Facilities
United States	Minnesota Department of Transportation
United States	Alabama Department of Transportation
United States	Arkansas Department of Transportation
United States	California Department of Transportation
Zimbabwe	Ministry of Transport and Infrastructural Development

4.2. General Overview

This section provides a general overview of the data provided through yes/no and tick box answers. A more detailed review, included a summary of textual responses is provided below on a regional basis.

4.2.1. Significant hazards

Respondents were asked to rank hazard types according to their significance. Summing the 'Very High' hazards from each questionnaire, provides the following order of significance: debris flows, rainfall-induced floods; earthquakes; landslides; coastal flooding and tsunamis; snow avalanches; snow drifts, wind and glacial lake outburst floods; and fire. However, one respondent's opinion as to what constitutes 'Very High' may differ from the next, depending on circumstances. Consequently, those hazards identified as having the highest significance in each case were summed and the following order of significance was obtained: rainfall-induced floods; landslides; debris flows; wind; earthquakes and coastal flooding and tsunamis; fire; snow avalanches and snow drifts, followed by other hazards with only 1 or 2 cases. To conclude, rainfall-induced floods, landslides and debris flows are the most significant.

4.2.2. Preparedness

Preparedness was addressed in the questionnaire in terms of available background data, knowledge of vulnerable assets, pre-emergency collaboration and response planning (singularly and with other agencies), established procedures and disaster response exercises and drills. The responses in this category are bullet pointed below:

- 68% stated that they had access to hazard susceptibility maps, related reports and past hazard datasets;
- 64% said that they use satellite imagery and GIS datasets to help determine the most hazard-prone parts of their network;
- 72% of respondents confirmed that they stockpile resources and plant at strategic points on the network;
- 84% confirmed that they collaborate with other emergency response and critical service providers before an emergency and 92% do so immediately afterwards, i.e. virtually all;
- Despite these high collaboration figures, only 40% share impact data with other agencies, i.e. with emergency services, relief agencies and NGOs;
- 60% carry out regular disaster response exercises and drills.

4.2.3. Impact data collection

- 60% of respondents confirmed that they have set procedures for impact data collection;
- However, only 32% stated that they have standard RIA procedures in place that are systematically applied after each disaster;
- On average, 66% of all information on impact is recorded by field inspection. 13% is recorded from news and social media and 12% rely on regional offices. 6% of impact data is derived from UAV (drones);

- Interestingly, 60% of respondents confirmed that they use drones to collect data. Most used drones for photographic and video data, while the majority stated that they collect LiDAR DEM data from drones. There is therefore a potential discrepancy;
- 28% stated that they use satellite imagery to collect impact data. This must be at some stage after the event has occurred when the imagery becomes available, as it is unlikely to be real-time or near real-time.

4.2.4. Risk assessment, emergency works prioritisation and quantity-cost estimation

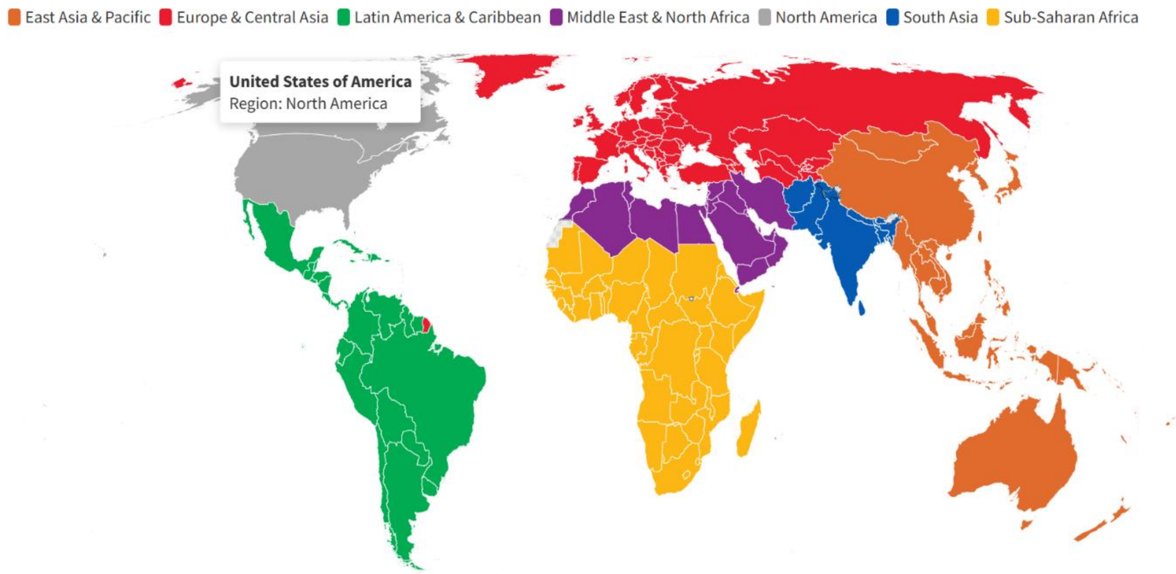
- 64% of respondents confirmed that they carry out some form of risk assessment to enable emergency works prioritisation;
- Prioritisation is undertaken on a location-by- location basis, rather than link-by-link in 70% of cases;
- 28% confirmed that they use RIA software, including RADAR (Recorded Asset Damage Restoration) by Gruntify, MAXIMO (IBM) and Orion Futurity. The remainder of the 28% use in-house software.

4.2.5. Critical challenges to effective RIA

- Safe access to the impact area was considered to be the main challenge in the event of an emergency, followed by insufficiently qualified and trained personnel;
- Communications, technology constraints, insufficient resources and problems over coordination with other response agencies were next important.

4.3. By Region

This section provides a summary of the specific details recorded in the returned questionnaires. The summary is provided by region, according to the map below.



4.3.1. East Asia and the Pacific

Returns received from this region were representative of one upper middle- and three high-income countries, though one country (Japan) provided six returns from independent expressway companies. The middle-income country provided two returns. One was from a research institute that confirmed the use of satellite imagery and terrain mapping for GIS-based hazard susceptibility and preparedness, and the use of UAV (drones) to collect field data. The other was from a transportation department that, despite recording a very high and high significance of earthquakes, landslides, floods and debris flows, recorded relatively low-levels of preparedness, multi-agency collaboration and data-sharing, and a lack of standard RIA procedure.

Other returns indicated a high-level of hazard preparedness, including 10 to 20-year records of hazard events on the road network, national disruption risk databases, hazard susceptibility maps and flood modelling for network vulnerability mapping. One respondent stated that they had almost 25 years of road damage data comprising: date; location; damage type; damage severity and restoration method. Most have established procedures for RIA, or its equivalent, though at least one does not. Field data is collected predominantly using tablets or mobile phone apps, though in some cases manual forms are used. Drones are used in most cases to collect photographic and video data. One highway authority uses RADAR (Recording Asset Damage and Restoration) provided by Gruntify emergency management software. Intelligent Transportation Systems are used by most respondents to monitor and control traffic flow using CCTV and VMS (Variable Message Signs) in the event of emergency situations. Two of the respondents confirmed they used RIA software: in one case purchased, the other developed in-house.

4.3.2. Europe and Central Asia

Four returns were received from this region, all from high-income countries. Generally, the level of preparedness for hazard events was low to middling and none of the respondents had standard procedures for RIA or its equivalent, though two respondents reported that they do collect field data electronically. Only one respondent stated that they use drones for field data collection. Hazard susceptibility maps were available in two of the countries, though they have no formal procedures for carrying out hazard and risk assessments. One respondent said they rely on external experts whenever they need these assessments to be undertaken.

Completed questionnaires were not received from any UK highway authorities within the survey timeframe. However, a composite return was received some time later on behalf of local highway authorities (LHAs) in England. While it has not been possible to include the LHA information in the summaries above, the information is summarised below because it has important implications for this review.

The most common hazards encountered are landslides, rainfall-induced floods, coastal erosion and wind, though they are ranked as moderate in significance. Records of these impacts have only been routinely collected since 2023/2024, which is surprising. LHAs have access to inland and coastal flood hazard maps provided by the Environment Agency and maps showing landslides and problematic ground conditions made available through the British Geological Survey. There is a gap, however, in relation to surface water and groundwater flooding. Some LHAs use GIS to map hazard hotspots, though none use satellite imagery to help in hazard assessment.

Emergency stockpiles are maintained for plant and construction materials, but it is unclear whether these stockpiles meet demand and whether their management and organisation are up to date.

Following the storms of 2015 and 2016 it became clear that the existing paper-based system of recording damage data was not fit-for-purpose, with inadequate collective situational awareness between LHAs, with some LHAs taking considerable periods of time to assemble their damage data. Consequently, the damage data collection and management system was overhauled with funding by the Department for Transport. Damage data is now collected electronically using StormChain software mounted onto portable devices. There are established systems of data collection and recording, some of which are outlined in the Literature Review in Section 3. Operations Managers receive this information and use it to assign impact for each damaged asset using the formula: Impact = Damage x Consequence x Time (i.e. duration of disruption) and a scoring system. Impact data is shared automatically with other emergency response partners. Third party (aligned) infrastructure providers (such as gas and electricity supply lines) are informed of the damage in near-real time (dynamically) using GIS. Field-based and drone photography are used as part of the RIA, including the collection and analysis of LiDAR. 80% of all damage data is recorded in the field, with a further 20% supplied from media and crowd sourcing.

Situational awareness is considered most important in RIA, followed by public/personal safety and the continued operation of lifeline routes, such as those that provide access to hospitals. The greatest challenges, in common with most other replies, are insufficient resources of qualified and trained inspectors and communication problems.

Further comments received are copied into the text box below for the reader’s information.

UK civil protection is delivered through a collaborative process defined by the Civil Contingencies Act (2004). The Emergency Services (Police, Fire, Ambulance) and Local Authorities (and by default Local Highway Authorities) are designated Category 1 Responders under the Act. This means they all have 7 duties: to cooperate; to share information; to assess risks in their area; to plan for emergencies; to communicate with the public; to ensure their own business continuity and, for local authorities only, to provide business continuity advice to businesses.

Although these duties apply to local highway authorities (LHA), it is often the case that the local authority duties are delivered by a central ‘Emergency Planning’ unit, so LHAs’ engagement will depend largely on the way emergency planning and highways departments are structured (e.g., if they are in the same directorate, it is likely they will collaborate by developing highways specific emergency contingencies and capabilities). Not all UK LHAs are closely linked to emergency planners and very few LHA personnel are trained and exercised in the principles of Integrated Emergency Management (IEM).

However, when an emergency occurs which affects highways, highway teams will be drawn into the response process and will be expected to provide representatives on the multi -agency Strategic, Tactical and Operational coordinating groups: regardless of whether they have been trained for this role or not.

Following serious flooding in the north of England, Scotland, and Northern Ireland during the winter 2015/16 (Storms: Desmond; Eva; Frank; Gertrude), national debriefs recognised that no consistent methods existing for describing highway impacts. This meant that during the events and subsequently, nobody really understood how the events had impacted other council areas. The 'paper and pen' methods of collecting impact data were also show and laborious ("it took weeks and months" for individual councils to collate their impact data).

This finding was picked up during the DfT-commissioned *Lessons from Extreme Weather Events* (2015-2020) review, where a recommendation was made that a consistent Rapid Impact Assessment process should be developed.

With funding from DfT, the UK RIA system 'Stormchain' was subsequently developed to provide all users with a consistent means with which to collect data and to present that data to decision-makers at individual asset, local authority, or National levels (using tiered reports).

The system comprises a browser-based GIS platform, into which categorical and descriptive information on damaged assets and local effects (e.g., road status, diversions) is uploaded from the field by operatives equipped with the Stormchain App (iOS or Android). The Operations manager then validates the RIA by assigning a consequences score (e.g., minimal > extreme) to describe the effect of this damaged asset on the user community (i.e., the consequences). Together, the damage and consequence ratings are combined to create an Impact score (1 to 50) for each asset inspected.

The equation used to understand this calculation can be understood as:

Impact = (Damage x Consequences) x Duration of disruption

Where *Duration* is the length of time it takes the authority to stabilise the asset and restore functionality (even if only basic *'lifeline'* functionality).

Being able to apply a high impact rating through a process that is defensible and 'time stamped' (i.e., a different decision can be made and a new rating easily applied if/when new information comes in), represents the state-of-the-art in respect to highways RIA, where no other system uses an impact matrix approach to support managers' deployment of finite operational resources and capabilities.

The system was tested in a major exercise FloodEx22, after which the exercise Director stated: "I am delighted to note how successful Stormchain was during the exercise, offering a step change in the management of highways incidents. Having spoken to colleagues since the exercise I noted that the capability met their needs, and they are keen to progress the roll-out of the programme."

Stormchain is currently being used by a range of LHAs in England where they are developing the 'muscle memory' that will be needed to use it on their 'worst day' (i.e., during a major emergency), by using it on a daily basis to record Out-of-Hours damage repair.

Even though the system has been designed as robustly as possible (e.g., data recording in the field can still be achieved in signal blackspots), as a technical system, there is always a risk that the IT could fail during a major incident. Accordingly, all training for the system's commercial clients (e.g., councils, council contractors) includes information on the mandatory data that must be collected at scene, in order to be fed into the system as and when connection/IT is reestablished.

4.3.3. Latin America and the Caribbean

Two countries returned questionnaires from this region, one high-income the other upper middle-income. Hazard damage records are relatively short, i.e. less than 10 years, though both have hazard susceptibility maps, particularly in relation to flood hazard. One uses drones for photographic and video records, the other does not. Both have standardised approaches to RIA, with one using electronic methods of field data collection using a web app and RIA software using the MAXIMO program.

4.3.4. Middle East and North Africa

Only one reply was received from this region, from a high-income country. Landslides and rainfall-induced floods were the main hazards recorded. The highway authority has set procedures for responding to emergences and has an RIA procedure in place. It has access to hazard susceptibility maps and a 10-year damage dataset. It shares its information with other agencies and the public. It uses electronic methods of field data collection supported by drones, though it does not use these for photograph or video purposes. Intelligent Transportation Systems are used to monitor and regulate traffic.

4.3.5. North America

Questionnaires were returned by six United States DoTs, together with two Canadian state transport authorities and the Ministry of Transport and Sustainable Mobility, Quebec. Both the United States and Canada are high-income countries. In terms of preparedness, almost all respondents stated that they have access to hazard susceptibility maps and historical records, though surprisingly some of these are quite short. Real-time data on earthquakes, meteorology, coastal flooding and tsunami surges can be obtained from the various state and federal statutory information providers. Most respondents confirmed they have set procedures for collecting RIA or similar data. Set procedures include the need to submit damage data to FHWA and FEMA (see Literature Review) using a specific coding and format for consideration of financial support. Most respondents share their damage data with other agencies for emergency response purposes, ordinarily through the state Emergency Operations Center or Agency.

Most use electronic systems for uploading damage data from the field in real-time, but some (the minority) use manual methods. In some cases, uploaded road damage data is transmitted to road users via VMS. Drones are used in most cases, including for the capture of photographic, video and LiDAR data. In at least one case, LiDAR data is used in a mapping and monitoring capacity using change detection (11 mm accuracy) and 3D visualisation. One respondent stated that LiDAR data was used for quantity estimation. Intelligent Transportation Systems are used widely, including CCTV monitoring, pavement sensors, VMS and AVL (Automatic Vehicle Location) systems. RIA software, or similar for processing damage data, is used by three of the respondents. One respondent uses Orion Futurity, another Survey 123, and the third an in-house system, though this might be an asset management system. One respondent indicated that crowd- and media-sourced data accounted for up to 45% of impact data during emergencies, with others quoting between 20% and 35%.

Hazard and risk assessments are carried out in a number of cases using factors such as the anticipated time to reinstate safe access, criticality of the infrastructure for emergency access, traffic volumes and public safety. One respondent referred to the need to take community impact into account, including whether communities would be isolated if access is not reinstated.

4.3.6. South Asia

Only one return was received from this region, from a low-income country. This highway authority has road closure data since 2000. It has no hazard susceptibility maps and does not use satellite imagery or GIS. There is no set RIA procedure and damage data is collected manually. Drones are used for photographic and video records.

4.3.7. Sub-Saharan Africa

Three replies were received for this region: one upper middle-income; one lower middle income; and one low-income country. Rainfall-induced floods were the most significant hazards to all three. Set RIA procedures are in place in one of the countries, though none use RIA software or equivalent. The highway authority with the set RIA procedure is intending to introduce mobile phone apps to collect damage data, where currently it is collected manually. This authority has 20 years of damage record and a damage hot-spot map within a GIS facility.

4.4. Concluding Remarks

The returned questionnaires are dominated by replies from high-income countries (12 out of 17), plus the late arrival from England. This may reflect a more advanced level of RIA practice in these countries and a possible reluctance among low- and middle-income countries to complete a questionnaire that they consider is not reflective of their practice and that might reflect badly if they did.

The response from highway authorities in Europe was disappointing, with only five questionnaires received (including the one from England). With the exception of the return from England, RIA procedures were surprisingly less than advanced in the European returns. Most other highway authorities operating in high-income countries, however, demonstrated a reasonably high level of RIA capability with access to supporting data and well-established impact assessment procedures in place, often using electronic field data collection and close to real-time analysis for decision-making and prioritisation. There were exceptions, however.

Almost all respondents appeared to appreciate the importance of collaboration with the emergency services and other providers of critical services and infrastructure. However, impact data sharing seemed to be less important. Safe access and communications were raised as important constraints by many. Procedures for real-time data sharing and effective collaboration during the initial vital hours and days of impact assessment and emergency response are considered to be critical and in need of strengthening. Lack of experienced personnel to assess the scale and severity of damage, and its implications for rapid reinstatement, also appears to be high on the agenda for more effective RIA.

Finally, the fact that most highway authorities undertook emergency response training exercises and drills, and had systems in place for stockpiling resources and plant at strategic locations on the road network, suggests that they fully appreciate the need to be adequately prepared for anticipated eventualities. This requires a knowledge of asset susceptibility and vulnerability that most respondents appeared to appreciate.

5. FOLLOW-UP DISCUSSIONS

Follow-up video and telephone calls were held with some of the respondents who had indicated on their questionnaires their willingness to elaborate and where it was felt that they might be able to provide further information of value to this review. Discussions were also held with highway authorities who did not return a completed questionnaire but with whom contact was made by other means. The main points of interest arising from these discussions are bullet-pointed below, according to highway authority.

5.1. New Zealand Transport Agency (NZTA)

- NZTA has GIS-based hazard maps showing seismic hazard (1:2500-year return period) and flood and hurricane hazard (1:100-year return period) and colour coding of the highway network to show sections potentially at risk from each.
- A National Resilience Assessment Toolkit (NRAT) is used by NZTA. NRAT is a digital tool that provides a nationally consistent overview of the hazards on the transport network. The tool makes it easier to assess, prioritise, monitor, and report on state highway damage/disruptions and network resilience more efficiently and effectively and allows funding to be targeted to the most critical sites.
- In the event of an emergency NZTA relies on contractors to carry out the required rapid impact assessments, according to quality-controlled response plans. These contractors have the NRAT app on their mobile phones and they upload damage data. Because their prime responsibility is to repair/reinstate the damaged section of road or structural asset, the NZTA does not receive this information in real-time. Often information on social media informs NZTA about the location, extent and severity of an event before they are notified through their contractors. Artificial Intelligence (AI) might be used to establish crowdsourced data. Gathering damage data quickly and consistently is the goal for the future.
- NZTA have identified the need for an RIA toolkit. The Police are using Survey 123 to collect incident data on the road network. One common operating system will be required. The most important information required by NZTA is the nature of the incident, its location and whether the road at the impact point is fully closed.
- Because of mobile network coverage, NZTA is considering increasing its use of satellite communications.
- NZTA operates a Road Asset Maintenance and Management Plan that is not yet interfaced with NRAT, but the plan is to facilitate this.
- The Government of New Zealand operates the National Crisis Management Centre (NCMC). As a provider of critical infrastructure NZTA provides data to the NCMC and uses the NZTA National Emergency Response Team (NERT) GIS mapping dashboard that displays live emergency data, including floods, landslides, sections and locations of blocked and damaged roads and weather forecasts.
- The use of drones is not standard due to flying regulations in the vicinity of active highways. Drones are more relevant to the response phase of emergency management.

5.2. Transport Scotland

- In particular, TS has been implementing emergency management in relation to debris flows on the road network. Trunk roads and local roads have been affected.
- TS operates Disruption Management Plans and Incident Response Plans.
- Landslide patrols are carried out. Impact and damage data was historically recorded in paper format, now uploaded via tablets.
- They have developed in-house software for all asset damage data management.

5.3. Roads Administration, Ministry of Public Works, Chile

- RA has teams in 16 regional and 52 provincial headquarters that record damage data using standard digital templates for each hazard record.
- Emergency response decision-making is carried out at regional level.
- Information is shared via GIS.
- RA is in the process of developing/importing hazard susceptibility maps into its GIS.
- RA uses historical average records of expenditure to provide an outline reinstatement cost for present/future damage repairs.

5.4. United States: California DoT

- Different skill sets are required to perform different damage assessment tasks and different data is required to address each impact category.
- Bridge damage data is collected manually in the field and sent by email to the DoT Bridge Emergency Response Center.
- The DoT is moving towards a Cloud-based share point system.
- Survey 123 is used but the DoT is considering how to maximise the data fields to accommodate the DoTs data requirements for different types of emergencies an asset damage.
- The DoT has opportunities to use Starlink communications (high-speed internet available globally) to upload data directly to the Cloud.
- All damage and condition data is managed using GIS, and other products in the ESRI suite of tools. Selected partner agencies have access to some of this data.
- An Integrated Maintenance Management System (IMMS) is an extensive asset condition database that can be used in the damage assessment though it is not linked via the GIS. As-built records help allow damaged assets to be defined.
- Drones are used extensively to collect damage data and GIS datasets allow damage to be quantified using infrastructure mapping and DEM.
- Collaboration with other agencies during emergencies is via the State Operations Center.
- The roles of different statutory agencies and emergency responders varies according to the nature of the emergency. The DoT usually takes the lead role on state roads, in collaboration with Law Enforcement.

- A State Emergency Plan defines agency responsibilities. There are 16 Emergency Support Functions (or teams), of which the DoT is one. NB this is not unique to California and is supported by all state DoTs.

5.5. United States: Utah DoT

- The DoT is in the process of setting up an emergency management division.
- For small events they rely on highway patrols to collect damage data and send texts and emails to HQ, including photographs. For larger events, structural and geotechnical engineers make site visits.
- Field damage data collection is undertaken using paper systems.
- The DoT is considering using truck-mounted, GPS-enabled video recording systems
- 88 maintenance stations are responsible for sub-sections of highway and specific structures.
- The US Geological Survey ShakeCast information system automatically sends alerts to maintenance stations in the event of an earthquake and Emergency -X identifies bridge structures most at risk in each case. Structural engineers then inspect each structure to identify any damage. Damage data is then relayed back to central HQ.
- The DoT's intention is to use Survey 123 for road damage data collection and collation.
- Drones are used to detect ground movements at landslide sites.
- Coordinating with Utah Department of Public Safety, Emergency Management, the DoT has identified critical infrastructure using GIS, including hospitals, emergency access and escape routes, FEMA emergency supply depots.
- Intelligent Transport Systems are used to monitor, advise and control traffic during times of emergency.
- The DoT uses Esri's ArcGIS Online to power UPLAN, an interactive mapping platform that includes information about the state's unified transportation plan, pavement management and traffic.

5.6. United States: Missouri DoT

- The DoT's Transportation Management System (TMS) has been established for about 30 years and during the last 15 years has collected reasonably robust data of road closures and road damage on the highway network.
- The DoT currently collects damage data in the field using a paper system whereby information is recorded, scanned and email to the head office emergency centre. However, they are also in the process of using an Orion-supplied system that allows information to be recorded on a smartphone and relayed automatically to head office. This system has a mapping dataset that shows the highway network, its assets, adjacent land use and utilities. Field engineers cannot mark up the map but can record location of damage, length of damage, type of damage and damage rating, e.g. light, heavy, road closure. There is also space for additional notes. The system can also receive voice messages and upload site photographs. Although the system is not GIS-based, important elements of the recorded data can be imported into GIS, when established.

- While outline repair works are identified in the field, cost estimates are prepared in head office.
- Information is collected in such a way that it is automatically consistent with the format required by FEMA and FHWA for reimbursement. It is acknowledged that this format is not necessarily consistent with the practical needs of damage data required for emergency response. The DoT is also in the process of fine-tuning this format.
- The DoT is generally able to relay information to emergency responders of road closures within a matter of hours, including high priority ingress and egress routes.
- The DoT is one of 13 members who automatically receive seismic data from the US Geological Survey through their ShakeCast procedure. However, information on the potential for liquefaction damage at the site scale is unavailable – most available liquefaction hazard maps are too small scale.
- Rainfall-induced flooding hazard maps are available and they can be combined with incoming meteorological data for early warning purposes. Flash flooding (i.e. localised in hills/mountains) is more difficult.
- Maintenance crews have the ability to make decisions on site during an emergency event, particularly in relation to emergency protection works.
- Vulnerability index maps are used to help prioritise reinstatement of access. These maps are available to all US DoTs. This information is combined with emergency access requirements and decisions are made not only on the basis of immediate-term priority but also in a way to facilitate longer-term recovery. Priority is also assigned based on anticipated period of road closure and traffic disruption.
- The DoT uses the TMS to inform drivers of road closures.
- An issue that can cause significant problems is communications outage. This can relate to lack of cell phone network and damage to fibre optic communication systems.
- Drones are used to inspect specific structures, especially if access is unsafe. LiDAR data is collected from drones to create DEMs for quantity estimation. Drones are especially used to assess liquefaction damage (if any) in specific locations. Federal Aviation Authority requirements prevent the use of drones beyond line of sight, so their use is effectively reduced to a maximum of 1 mile.
- The use of helicopters and perhaps fixed wing aircraft is likely to be more effective when impact assessment is required over large areas.
- Satellite imagery in near real-time can be obtained through the National Guard but this is not something the DoT uses.
- The DoT works alongside the State Emergency Management Centre, rather than being controlled by it. All road closures are undertaken alongside Highway Patrol/Law Enforcement.

5.7. CANADA: BRITISH COLUMBIA MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

- MoTI uses a combination of internal engineering/operations resources and private sector consultants and contractors for emergency response and reinstatement work

- Electronic field data collection systems are used with data uploaded to the Cloud via mobile phone apps using Survey 123 software. Information can be viewed on a dashboard in real-time.
- Situational Awareness is critically important and requires liaison with partner agencies and emergency responders.
- The MoTI uses drones, including 3D modelling facility, but not as standard practice yet.
- The Canadian Space Agency is able to provide near-real-time satellite imagery, though resolution and scale vary.
- The MoTI operates an asset management system, with as-built records, to allow damaged assets to be defined.
- GIS-based network criticality mapping allows emergency routes to be identified and detours to be defined on a multi-hazard basis. The GIS layering includes critical infrastructure (e.g. fibre optic cabling and gas), socio-economic data, demographic and traffic data, allowing routes to be prioritised for different users during an emergency.
- The Ministry of Forests takes control during wildfires. They have forest fire vulnerability maps using 25-30 years of data and use thermal imaging updated every 2hrs.

5.8. Indonesia: Ministry of Public Works (Kemen PUPR)

- The Rapid Reaction Team (TRC) at the regional office in responding to disaster events and impacts on PUPR infrastructure uses digital mobile form technology, which is verified and stored in the Ministry of PUPR's disaster information system.
- Damage identification is carried out by the TRC Team of the balai public infrastructure affected by the disaster. Damage is classified according to whether it is: light damage (<30% and still usable), moderate damage (30-45% and unusable), heavy (45-65% and unusable) or destroyed (>65%, requires reconstruction). Handling of light and moderate damaged infrastructure can be implemented immediately. Heavily damage infrastructure is subject to a technical damage survey to be able to measure the estimated cost of recovery.
- The submission of rapid reporting by the TRC Team with a digital mobile form is verified by the PUPR Office in the province (implementing unit) according to its authority, the information is verified and stored in the disaster information system at the organizational unit level (Supporting Post). Information is relayed to the public with the disaster information system of the Ministry of PUPR (PUPR Disaster Response Information System) https://sitaba.pu.go.id
- Drone technology in PUPR disasters is used, including:
- a. Emergency response phase, assisting the TRC Team in digital visualization related to the extent of the disaster impact and damage type classification data through aerial surveys.
- b. Recovery phase, the results of the survey with drones are carried out for spatial analysis of affected infrastructure/land areas.
- c. Rehabilitation and Reconstruction phase, carried out for monitoring and evaluation of post-disaster work and as monitoring of the progress of construction work implementation.

- The Ministry of PUPR's GIS information system technology (SIGI-PUPR) in supporting the disaster information system is used for spatial analysis of potential disasters, identifying disaster-affected areas, spatial disaster dashboards, and monitoring PUPR infrastructure that is vulnerable to disasters.
- The Ministry of PUPR's Disaster Data and Information (SITABA-PUPR) is a disaster data and information sharing platform that has been used for disaster data and information management between organizational units (internal) and also other Ministries and Institutions (external) by utilizing Application User Interface (API) technology.
- In the future, policies need to be further strengthened, especially in the master regulations related to disasters in PUPR, sharpening of the Standard Operating Procedure (SOP) of the implementing team (pre-disaster, emergency response and post-disaster), and commitment to response time of leaders at head office and regional offices.

5.9. Nepal: Department of Roads

- The Department of Roads has established Emergency Action Plans (EAPs) for each divisional office, which include specific budgets for emergency response and protocols for managing both minor and major disasters.
- Data on road closures due to disasters has been systematically collected since 2000; however, this data is not publicly accessible and is mainly shared with key disaster response stakeholders.
- While drones are used for assessing disaster impacts, the department lacks standardized Rapid Impact Assessment (RIA) procedures and relies on manual data recording.
- There is limited use of advanced tools like satellite imagery, GIS, and Intelligent Transportation Systems (ITS) for monitoring and response.
- For minor hazards such as small landslides, the Divisional Offices of DoR are equipped with heavy machinery, and manage road blockages in coordination with the Nepal Police for emergency response.
- In the case of major disasters like earthquakes or large-scale landslides, the Ministry of Home Affairs oversees the response, mobilizing the armed police, DoR, Red Cross, and other agencies to ensure a coordinated and comprehensive approach.
- The Department of Roads faces several challenges in disaster management. The shortage of qualified inspectors significantly impacts the speed and accuracy of damage assessments. Technological limitations and insufficient resources further constrain the department's ability to respond effectively.
- Traffic control during emergencies poses additional difficulties, with safety concerns and a lack of specialized personnel complicating efforts to manage and facilitate emergency vehicle access.
- To enhance its disaster response capabilities, the Department of Roads plans to integrate modern technologies such as hazard susceptibility maps, GIS, and satellite imagery into its RIA practices.

- There is a proposed shift towards web-based systems for rapid information sharing and the use of crowdsourced data.
- The department also aims to improve the use of drones equipped with video and LiDAR technologies, subject to regulatory constraints, and to develop standardized RIA procedures and software for more efficient data collection and analysis.
- The department's emergency resource deployment plans include coordination with petrol stations for fuel supplies and contacting nearby offices for vehicle mobilization. Bailey bridge stocks are maintained at strategic locations for rapid deployment in case of significant infrastructure damage.

In addition to the above notes, a question-and-answer session allowed specific issues to be examined further in relation to RIA and related procedures applied by the DoR in Nepal. These questions and answers are summarised below.

Question 1: How can RIA improve response?

Answer: The Department of Roads (DoR) has not fully utilized RIA due to a lack of knowledge, motivation among users, and inadequate monitoring by oversight agencies and superiors. Implementing a web-based system that provides authorized engineers with access to report incidents, and allows them to request financial support, equipment, and logistics through a centralized platform would mandate immediate response from all stakeholders.

Question 2: What RIA is the DoR currently applying to resolve these problems?

Answer: The DoR partially relies on telephone calls with regional offices and data exchange via social media to gather the information it requires. There is no mandatory or formal system in place for conducting RIAs.

Question 3: Would the DoR benefit from more rapid information sharing? If divisional engineers had access to web-enabled tablets to record and upload information for decision-making, would that help? What about crowdsourced data (e.g., Twitter)?

Answer: Yes, having web-enabled tablets for divisional engineers would significantly enhance the RIA system within the DoR by enabling rapid information recording and sharing. Crowdsourced data, such as tweets, would be particularly critical in remote areas. However, this improvement would require extensive training for DoR staff, and their efficiency should be evaluated based on their performance in RIA activities.

Question 4: Would drones, including those that combine video and LiDAR, be beneficial for RIA? Are there any constraints on using drones within the DoR?

Answer: Drones would be highly beneficial in improving the RIA system within the DoR. However, the department would need to develop a robust system and shift away from its conventional manual approach to data-gathering. There are constraints on using drones, such as restrictions in sensitive areas like airports and their approaches. Additionally, permission from the Home Ministry is required to fly drones above 30 feet.

Question 5: How could the DoR benefit from rapid, consistent data recording, transmission, and sharing/coordination in relation to hazard-prone road corridors?

Answer: Consistent data recording and sharing would be invaluable for preparing Emergency Action Plans to address various disasters, using past records as a basis. It would also enhance the DoR’s ability to respond to disasters more effectively, guided by this data.

Question 6: In the DoR’s case, traffic control during an emergency is a significant issue due to safety concerns and the need to provide access to the site by emergency vehicles. Could improved early warning and communication systems resolve or reduce these issues?

Answer: Traffic control during emergencies is indeed a major challenge for the DoR, especially when it comes to ensuring safety and facilitating access for emergency vehicles. Improved early warning systems and better communication could help mitigate these issues.

Question 7: What about the availability of specialists for RIA in landslide and flood hazard contexts?

Answer: There is a significant problem with the lack of specialists in the DoR for conducting RIAs, particularly in the context of landslides and floods. This deficiency leads to sub-engineers, engineers, SDEs, and Regional Directors making slow and impractical decisions during emergencies. To address this, authorities need to have a clear understanding of the scale of the problem, be able to develop immediate action plans, and be knowledgeable about the effectiveness of various tools and equipment, as well as other human and financial resources, to execute responses instantly.

Supplementary information provided:

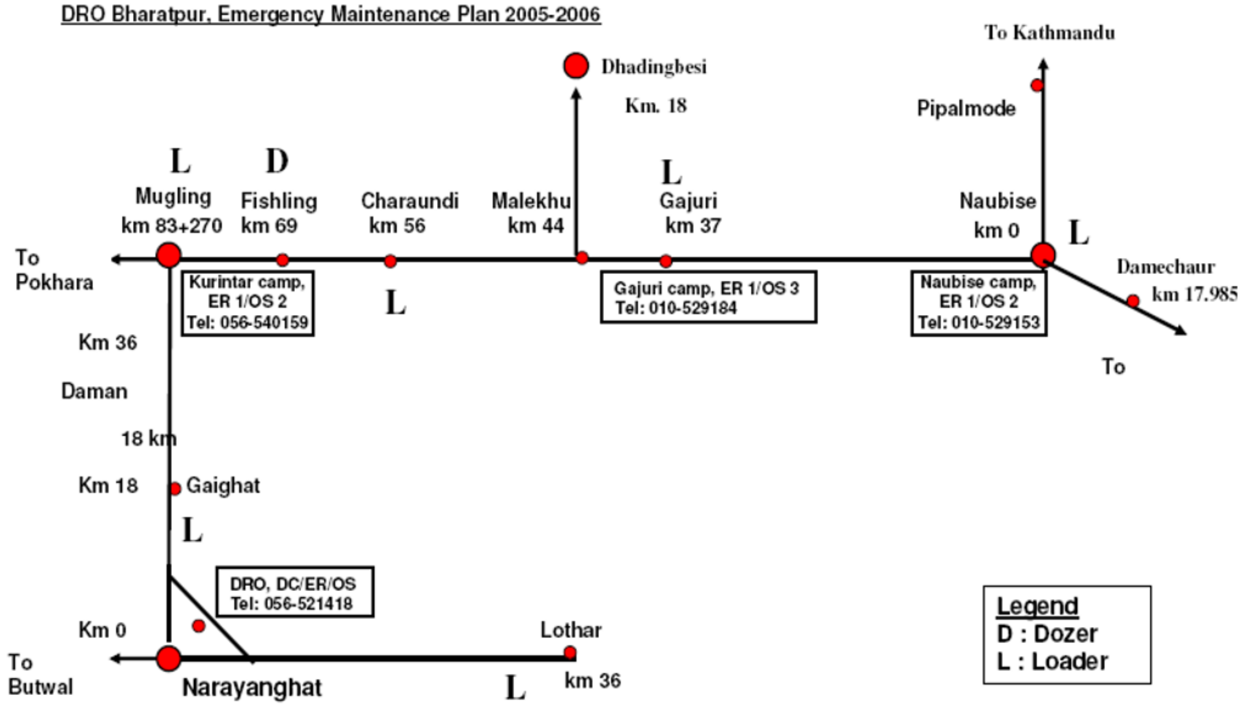
Every division office of the Maintenance Branch under the Department of Roads, Nepal, prepares an Emergency Maintenance Action Plan annually. The line diagram below illustrates a resource deployment chart used to address emergencies, highlighting the facilities available at different chainages. A red dot represents key points where department offices are located, with the size of the dot reflecting the number of staff—larger dots for main offices and smaller dots for smaller offices. 'L' stands for loader, and 'D' stands for dozer. 'ER 1/OS 2' indicates that the office has one engineer and two overseers. The chart also includes the telephone numbers for each office.

In the event of a disaster, the two nearest offices are contacted for support. For example, if an issue arises around the 24 km chainage on the Prithvi Highway, the Gajuri and Naubise offices are contacted for vehicle mobilization. Fuel storage is then arranged at each office by coordinating with petrol stations to ensure the road can be cleared. If the road is blocked, alternative emergency measures are implemented according to this plan. The same procedure is applied by the Department of Roads for other hazards like floods, wildfires, and earthquakes.

Additionally, the Department of Roads keeps 2–3 Bailey bridges at major nearby offices, such as the Mugling office, for use in the event of an earthquake or flood. In the future, this kind of plan could be made web-based, providing details like mobile phone numbers, vehicle capacities, and more.

13 Emergency Maintenance Action Plan :

DRO Bharatpur, Emergency Maintenance Plan 2005-2006



5.10. SUMMARY AND CONCLUDING REMARKS

Seven of the videocalls/telecons/face-to-face meetings were with members of highway authorities working in high-income countries. All of these authorities have access to hazard susceptibility maps, some of which depict seismic, landslide and flood hazards. In some cases, these maps are contained in GIS mapping layers, or the highway authority is in the process of organising the import of this information. Certain assets or sections of highway can be colour coded according to their vulnerability to different hazards, as is facilitated by the National Resilience Assessment Toolkit in New Zealand. Furthermore, statutory bodies provide real-time alerts on seismic events, for example, and weather forecast that are used as trigger warnings for highways authorities.

In at least two cases, the highway authority relies, to varying degrees, on contractors to collect damage data during and after a hazard event. In the case of the New Zealand Transport Agency (NZTA) and the British Columbia Ministry of Transportation and Infrastructure (MoTI), this data is collected electronically, in standard format and relayed, either immediately or with a time-lag to the highway's emergency management office. The time lag occurs in the NZTA case because the contractor's first priority is to make the situation safe on site in accordance with quality-controlled response plans. Perhaps, surprisingly, several highway authorities are using paper-based damage data recording systems, though most are in the process of transitioning to electronic systems using commercial software. The key information being recorded includes: date; location; extent (road length(s) affected); type of damage; extent or severity of damage (e.g. partial or complete) and length of time required for reinstatement, i.e. traffic disruption period.

Both electronic and manual systems are prone to failure when internet connections are down: a situation not uncommon during emergencies. Most of the highway agencies were considering using Starlink, where data is uploaded to the Cloud using high speed, globally-available internet or via satellite communication systems. Drones are used quite extensively, though there are issues as to where and to what elevation drones can be flown, plus the need to maintain line of site in most cases. This means that drones are probably best-placed to collect visual and LiDAR data at specific asset locations where access on foot would be unsafe. In a number of the United States DoTs they are also used to collect change data. Real-time or near-real time satellite imagery is only used by one of the highway authorities (British Columbia MoTI). Practicalities and cost have so far inhibited its wider use.

Nearly all highway authorities emphasised the need for consistent data recording across a range of hazard and impact types. Nevertheless, data fields need to be designed specifically to record critical information in each case and it is important that the field engineer is capable of observing and interpreting what they observe. A crack across a road, for example, could have several potential explanations, and each one will have different implications for serviceability and reinstatement. In the United States, the damage data needed specifically for FEMA and FHWA emergency funding is not necessarily the same as that required for on-the-spot prioritisation and design of access restoration and the highway authority will need to satisfy itself that it collects sufficient data to facilitate this as well.

Situational awareness and coordination with other partners are critically important. Some highway authorities do this via shared GIS platforms and files, others using more conventional forms of communication. In New Zealand, the National Emergency Response Team has a GIS mapping dashboard that the NZTA is able to use to view real-time hazard information and incoming weather systems.

California DoT described how GIS datasets allow damage to be quantified using infrastructure mapping and DEM. A record of as-built details allows the DoT to assess the design of the infrastructure that needs to be replaced. Other DoTs also have this facility. They also operate asset management systems that have the potential to be interfaced with the GIS to assist in the determination of damage and scope of reinstatement required. Some highway authorities said that that they use historical damage and repair data to assess current and future needs.

As described in the Literature Review, the assessment of impact extends beyond the location of damage to encompass all the downstream effects that loss of service may have. This requires network analysis and a knowledge of critical infrastructure including hospitals, emergency access, escape routes, emergency supply depots and communication systems. British Columbia MoTI has this mapping operating in GIS. Not only does it allow prioritisation of emergency works, but it also allows an assessment to be made of the wider impact of actions taken or not taken. Furthermore, it can be used to inform how traffic should best be regulated through Intelligent Transportation Systems (ITS). ITS is used by most highway authorities to control traffic during emergency events, in coordination with the Police/Law Enforcement.

Crowd-sourced data from social media platforms offers significant opportunities for all highway authorities if the data can be reliably collected, processed and verified (see Literature Review). With large networks extending over significant areas, most authorities agreed that this would be a useful source of data, but that perhaps it should be procured centrally, i.e. at national, regional or state level.

Nepal is the only low-income country with whom detailed ‘face-to-face’ discussions were held. Nepal is home to arguably the most extreme terrain in the world and experiences far more than its fair share of natural hazards, including rain-induced floods, glacial lake outburst floods, earthquakes and landslides. While most countries do not face this level of hazard, it is probably true to say that the operational problems faced by the Department of Roads (DoR) would not be unfamiliar to many highway authorities in other low- and middle-income countries, and perhaps some high-income countries as well. It might not be unreasonable to speculate that many highway authorities find themselves in similar positions to the Nepal DoR, i.e. in dire need of formalised and effective RIA.

The Nepal DoR is constrained by difficulties of access during emergency events and a lack of engineering and technical resources. Due to lack of geo-specialism among its staff, decision-making is often slow and impractical. It relies on its Divisional Offices to implement Emergency Action Plans and send data back to central headquarters. Data is collected in the field manually and sent via telephone messages and social media. The DoR does not have a standard procedure for RIA. In fact it has no mandatory or formal system for damage data collection and its analysis. It would like to have GIS-based hazard susceptibility maps, but it does not. It would like to use electronic methods of field data collection and enhanced telecommunications, but it doesn’t have the resources to do so. It suffers serious traffic control problems during road closures that pose significant issues for road safety and access for emergency vehicles. There is no ITS facility at DoR’s disposal.

The DoR does, however, store essential plant and other resources, including bailey bridges at strategic locations based on the network interconnectivity and known trouble spots.

Information was obtained from the Ministry of Public Work in Indonesia via email communication only. The information provided suggests that the Ministry is at an advanced stage of RIA. Damage data is collected electronically and relayed to a disaster information system that is analysed centrally for impact analysis.

6. CASE STUDIES

6.1. INTRODUCTION

The Terms of Reference for this assignment included the need to prepare case studies of RIA practice. The proposal was to develop 6 case studies in total: four from Low- and Middle-Income Countries (LMICs) and two from High-Income Countries (HICs). This was based on the expectation that case studies might be drawn from Uganda, Laos, Nepal and Mozambique (LMICs) and the USA and UK (HICs). Unfortunately, it was not possible to obtain a case study from Laos, but two were received from both Uganda and Nepal. In addition, the Roads Administration, Ministry of Public Works of Chile, the Ministry of Transportation and Infrastructure in British Columbia (Canada), the New Zealand Transport Agency and Transport Scotland confirmed their willingness to provide a case study. The final list is therefore as follows:

LMICs: Nepal (x2); Uganda (x2); Mozambique

HICs: Chile; British Columbia (Canada); New Zealand; Scotland (UK).

The information contained in these case studies has been provided by the highway authorities concerned in approximately the same format. Each is provided below with additional commentary, as required.

6.2. DEPARTMENT OF ROADS, NEPAL

Case Study 1 of 2: Nepal Earthquake 2015

Date of the Event: April 25, 2015

Location of the Event: The earthquake's epicentre was located in Gorkha District, approximately 80 km northwest of Kathmandu.

Source: Pradhan P.M. (2016)

Event Type: The event was a major earthquake with a magnitude of 7.8, followed by several aftershocks, the most significant of which was a magnitude 7.3 quake on May 12, 2015.

Event Impact (for the road authority and other affected parties): The earthquake caused widespread destruction, resulting in the loss of nearly 9,000 lives, injuring over 22,000 people, and leaving hundreds of thousands homeless. The road network suffered severe damage, with landslides triggered by the earthquake blocking major highways, particularly the Arniko Highway connecting Kathmandu to the Chinese border. Key bridges collapsed, and road surfaces cracked, hindering emergency response and relief efforts. The impact extended to isolated communities, which became inaccessible due to road damage.

Was the Event Predictable?

While the possibility of an earthquake was known, the exact timing and magnitude were unpredictable. Nepal is located in a seismically active zone, making such events likely, but the scale of the 2015 earthquake was unforeseen.

Was the Location Predictable, from Existing Information or Previous Events in the Same Location?

Yes, the location was partially predictable. Historical data and seismic studies had indicated that the region was at risk of a major earthquake. However, the specific epicentre and extent of the damage were not predicted.

Had the Road Authority Made Provision in Advance for Dealing with the Event?

The road authority had basic emergency response procedures in place, but the scale of the disaster overwhelmed these preparations. Limited resources, lack of detailed hazard maps, and insufficient infrastructure resilience contributed to the challenges faced.

How Did the Road Authority Collect Impact/Damage Data and Other Information Required to Respond to the Event, and How Was This Information Conveyed to Response Managers?

The Department of Roads primarily relied on field observations and reports collected manually. Information was gathered through physical inspections conducted by field officers and regional directors. This data was then manually updated on the Department’s website and shared with central authorities. The data collection was hampered by blocked access and communication challenges.

What Were the Emergency Measures Implemented (in General Terms)?

- Opening single lanes on blocked roads to restore partial connectivity.
- Collaborating with the Nepal Army and Nepal Police to clear debris and conduct rescue operations.
- Diverting water and addressing landslides to prevent further damage.
- Mobilizing resources from central and regional offices to expedite response.

Did the Road Authority Coordinate with Other Relief Agencies?

Yes, the Department of Roads coordinated closely with the Nepal Army, Nepal Police, the Ministry of Home Affairs, and various disaster management units. This collaboration was essential for effective emergency response and recovery efforts.

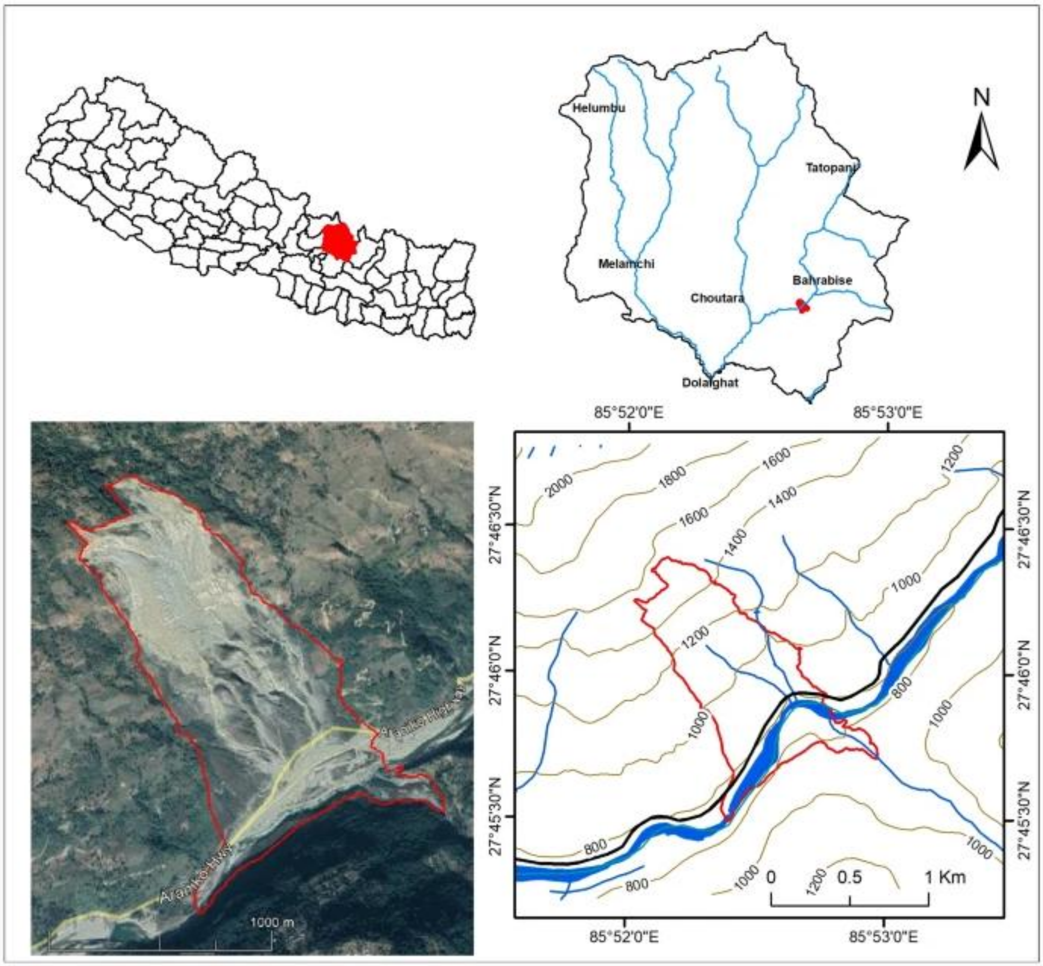
Has There Been Any Emergency Response Performance Assessment to Inform Future Practice?

Following the earthquake, there was an evaluation of the emergency response, which highlighted the need for better preparedness, improved communication channels, and the adoption of advanced technologies like GIS and satellite imagery for real-time data collection and analysis. However, specific standardized procedures for rapid impact assessments and advanced planning tools were not fully developed at the time.

Case Study 2 of 2: Jure Landslide 2014

Date of the Event: August 2, 2014

Location of the Event: Jure, Sindhupalchowk District, about 60 km northeast of Kathmandu, along the Arniko Highway.



Source: Panthee et.al (2023)

Event Type: A massive landslide triggered by heavy rainfall. The landslide dammed the Sunkoshi River, creating a large lake and blocking the Arniko Highway, a critical route connecting Nepal to China.

Event Impact (for the road authority and other affected parties): The landslide caused significant casualties, with 156 people reported dead or missing. The blocked river posed a severe flood risk downstream, and the Arniko Highway was completely blocked, disrupting transportation, trade, and communication between Nepal and China. The landslide also threatened nearby hydropower projects and local communities.

Was the Event Predictable?

The landslide was partially predictable due to the region's known susceptibility to landslides, particularly during the monsoon season. However, the exact timing and magnitude of the event were not predicted.

Was the Location Predictable, from Existing Information or Previous Events in the Same Location?

Yes, the location was somewhat predictable. The area had a history of landslides, and its geological instability was well-documented. However, there was no specific early warning system in place for this event.

Had the Road Authority Made Provision in Advance for Dealing with the Event?

The road authority had not made specific provisions for such a large-scale landslide. While general emergency response plans existed, there were no detailed hazard maps or pre-placed resources to handle the immediate aftermath effectively.

How Did the Road Authority Collect Impact/Damage Data and Other Information Required to Respond to the Event, and How Was This Information Conveyed to Response Managers?

Impact data was collected manually through field inspections by regional directors and engineers. The information was then communicated to the central office and other relevant authorities. The manual collection process was slow, and communication with the disaster management units was challenging due to the scale of the disaster.

What Were the Emergency Measures Implemented (in General Terms)?

- Coordinating with the Nepal Army and Nepal Police to manage the immediate threat of flooding and evacuate affected communities.
- Attempting to breach the landslide dam to prevent catastrophic flooding.
- Clearing debris from the Arniko Highway to restore connectivity.
- Mobilizing resources from nearby regions to support the response effort.

Did the Road Authority Coordinate with Other Relief Agencies?

Yes, there was significant coordination between the road authority, the Nepal Army, Nepal Police, and other disaster management agencies. This collaboration was crucial in managing the risk posed by the landslide dam and in the eventual restoration of the road network.

Has There Been Any Emergency Response Performance Assessment to Inform Future Practice?

The response to the Jure landslide highlighted several critical areas for improvement, including the need for better landslide monitoring, pre-positioning of emergency resources, and the adoption of real-time data collection technologies. The incident underscored the importance of developing standardized rapid impact assessment procedures and enhancing coordination with other agencies for a more effective response in future disasters.

6.3. Uganda National Roads Authority (UNRA), Uganda

Case Study 1 of 2: Karuma Bridge closure

Date of the event: 6th May 2024

Location of the event: Karuma Bridge, River Nile

Event type: Bridge closure resulting from fatigue failure due to traffic impact and increased traffic loads. Defects such as concrete spalling, longitudinal and transverse cracks, corrosion of reinforcement resulting from water seepage through the cracks, and crushed bridge bearings were observed on assessment of the bridge. The effect was observed to be more severe on the outbound lane with heavier traffic.

Event impact: As a result of the bridge closure, there has been an increased cost to transportation of people and goods which has also increased the cost of goods. There are also limits to travel hours as the alternative route traverses a national park. Consequently, cases of fresh produce such as fruit and vegetables going bad have been reported within the area. In addition, people whose livelihoods relied on providing goods and services to the heavy trucks' resting stations of Karuma and Kamdini have been adversely affected. Wildlife such as baboons that relied on people using the route to feed them are starving and were required to look for alternative food sources including people's gardens.

Was the event predictable?

The event was foreseen given the observed defects. Designs for a new bridge downstream were underway with a funding organisation secured.

Was the location predictable, from existing information or previous events in the same location? Yes, routine visual tests are done on the bridge quarterly (every three months) or after heavy rains.

Had the road authority made provision in advance for dealing with the event?

The road authority had no structured response in place. However, since this occurrence one is being worked on to deal with similar events.

How did the road authority collect impact/damage data and other information required to respond to the event and how was this information conveyed to response managers?

Engineers were sent out in vehicles to conduct a visual assessment of the bridge. Also, non-destructive strength tests such as Schmidt Hammer test and cores were taken from the bridge for further assessment. Drones or GIS web-enabled applications are currently not in use by the Authority.

Typically, a report of the findings is written within two to three working days after data collection and then shared with responsible parties. In this instance, information about the closure of the bridge was shared over the radio, on platforms such as X (formerly Twitter), WhatsApp and newspapers. Alternative routes were also communicated across these platforms.

What were the emergency measures implemented (in general terms)?

The bridge was closed off to heavy traffic and access controlled by the traffic police such that only one lane was being used. An effort has been made by the road authority to reduce traffic loading on the bridge. Information and warning traffic signs have been placed at junctions to alternative routes and at approaches to the bridge. The authority is also in the process of securing a contractor to undertake the emergency repair works. An emergency procurement was undertaken to ensure that the work is completed quickly. Mobilization of machinery and importation of replacement parts is also underway. At the time of repair works, it is planned that the bridge will be closed to all users.

Did the road authority co-ordinate with other relief agencies?

Response activities were handled by the road authority station managers responsible for the region where the bridge is located; local governments who provided information in terms of flood levels and suggestions for alternative routes; the traffic police and army for traffic control and enforcing the directive on bridge closure; and the Uganda Wildlife Authority (UWA), given the proximity of the bridge to a national park. UWA was also responsible for authorizing free access to vehicles because the alternative route traverses a national park and requires a toll to access.

Has there been any emergency response performance assessment to inform future practice?

The road authority recommends conducting regular bridge structural health monitoring including monitoring for movement at joints and settlement, in addition to the visual condition assessments. Furthermore, stations should be provided with bridge engineers to conduct the assessments regularly and consequently be able to plan timely for such incidents. The need for archiving of bridge design reports and as-built drawings was also identified.

Case Study 2 of 2: Fort Portal-Bundibugyo Road, Rift Valley margin

Date of the event: Several events occurring along the road

Location of the event: Fort Portal-Bundibugyo Road, Rift Valley margin

Event type: Shallow mudslides and deep landslides occurring at different sections of the road caused by poor farming practices such as terraces running perpendicular to the contours with the farm boundary bordering the crest of the cut, heavy rainfall within the project road, existence of steep mountainous terrain with volcanic soils/black cotton soils.

Event impact: Closure of the road for 1 – 3 days which impedes movement since there is no alternative access road. As such businesses and people can’t get around.

Was the event predictable

In some cases, large cracks and bent trees/plants are visible signaling the likelihood of a slide happening while the shallow mudslides are unpredictable but expected after a heavy rainfall event.

Was the location predictable, from existing information or previous events in the same location
Sections of the road prone to landslides have been identified based on experience. However, real time data is used to address events i.e. events are handled when they occur.

Had the road authority made provision in advance for dealing with the event

No structured response for dealing with landslides is available and the event is not included in the road budget. However, equipment to clear mudslides/landslides is always stationed within the vicinity (less than 30km) of locations prone to landslides. Drainage channels to redirect water into culverts have also been constructed. Dumping sites for the cleared debris have also been identified.

How did the road authority collect impact/damage data and other information required to respond to the event and how was this information conveyed to response managers

Information about the occurrence of a slide is obtained from UNRA's local contractor's staff by the station manager who communicates with upper management about the event and requests for approval of budgetary requirements to respond to the event. Station Engineers drive out to the scene to clear the debris. The section is repaired once the budget is approved. Information is shared with the public over the radio, on platforms such as X (formerly Twitter), WhatsApp and newspapers.

What were the emergency measures implemented (in general terms)

The damaged area is cordoned off with warning tape and warning signs placed at approaches to the section. The police are engaged for traffic control. Fallen debris is then cleared using wheel loaders and transported to designated dumping sites. Depending on the magnitude of the slide and mobilization of equipment, this could take up to 3 days before the road is opened up to traffic. To repair damaged parts of the pavements, fill is usually required for sections on the embankment and natural gravel used for the pavement. Maintenance works such as patching are usually done at sections of the road damaged by boulders.

Did the road authority co-ordinate with other relief agencies?

Response activities were handled by the road authority station managers responsible for the region; local governments usually help with coordinating with the community and providing extra equipment for clearing debris, the Uganda police organise traffic control. In cases where people have been displaced and property and lives lost, the Redcross has helped in supporting the community.

Has there been any emergency response performance assessment to inform future practice

There is a need to include a budget item to cater for such emergencies that happen often to address financial constraints, facilitation with the appropriate equipment, need for early warning systems to be better prepared to deal with such events, training of farmers on good farming practices, teamwork and coordination with the community and other agencies. The need for clear cut procedures on how to deal with such events and training of station personnel on knowledge about landslides was also identified.

6.4. NATIONAL ROADS ADMINISTRATION, MOZAMBIQUE

Date of the event: 13th March 2024

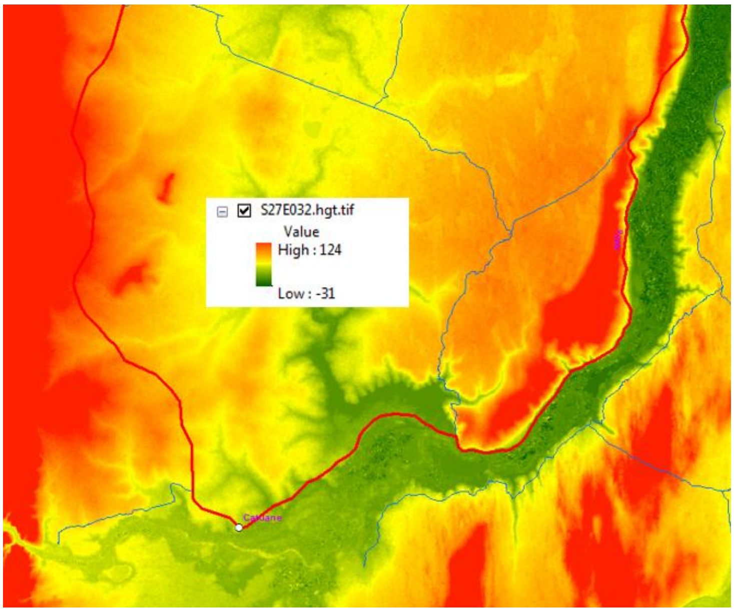
Location of the event: Several locations along the R406 Salamanga-Catuane Road, Maputo Province.

Event type: Rainfall-induced flooding.

Event impact: Flooding to the road, damage to structures, isolation of the agricultural hinterland of Catuane town, i.e. area cut-off.

Was the event predictable?

Yes, there are flood hazard maps available as illustrated below. The red line is the road.



Was the location predictable, from existing information or previous events in the same location?

Yes, from the above map, and every year in the rainy season the road has been cut due to the presence of a river (Maputo River) that runs parallel to the road in the lowland.

Had the road authority made provision in advance for dealing with the event?

There has been some work related to the increase of drainage structures.

How did the road authority collect impact/damage data and other information required to respond to the event and how was this information conveyed to response managers?

Impact data collection is performed by provincial technicians in a standard format. This is done manually (in paper form) and the information typed into Excel before it is sent to the Emergency Department.

What were the emergency measures implemented (in general terms)?

Providing information to road users concerning road closures. Clearing drainage structures. The prioritization of this road is related to population density and the agricultural produce that needs to be transported to the Maputo market.

Did the road authority co-ordinate with other relief agencies?

Yes, through combined access to the Excel files and GIS maps.

Has there been any emergency response performance assessment to inform future practice?

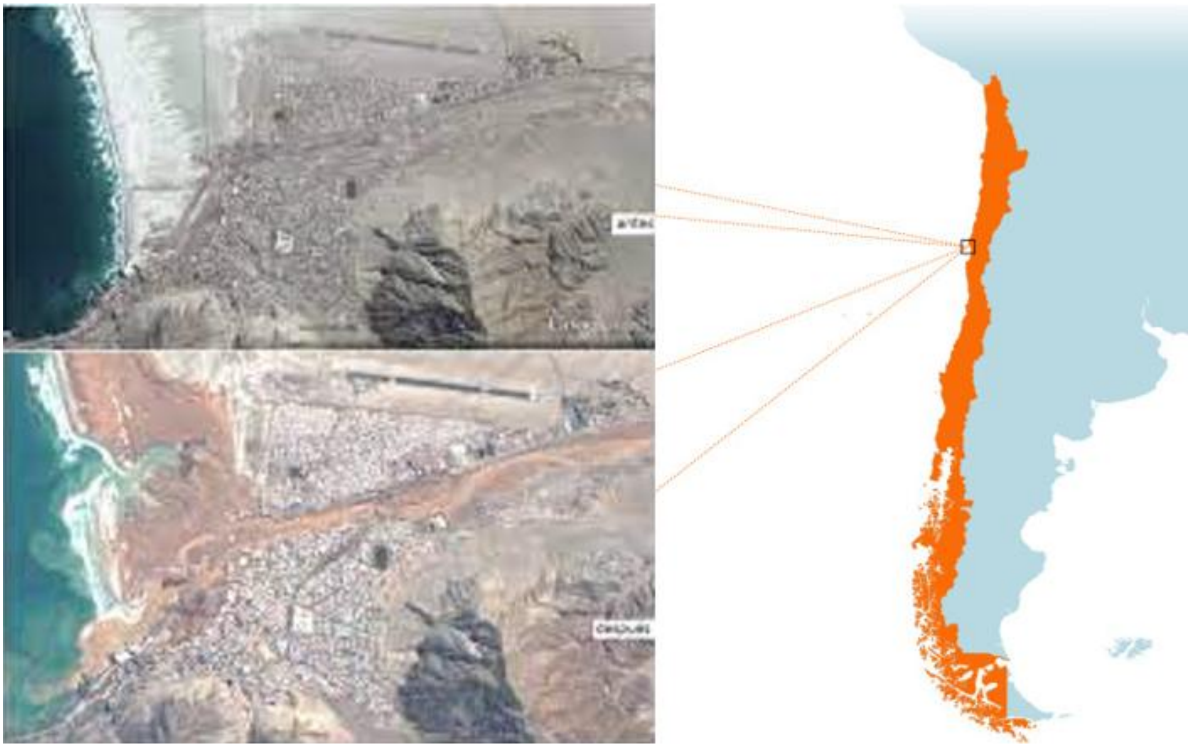
Yes, through a review of horizontal and vertical alignments, perhaps examining different corridors on higher ground and improvement to the capacity of drainage structures.

6.5. ROADS ADMINISTRATION, CHILE

Case Study 1 of 2: Atacama Desert mudflow

Date of the Event;: March 28, 2015

Location of the Event: Atacama Region, Chañaral city, about 960 km northern Santiago, Atacama Desert.



Event Type: A massive mudflow triggered by heavy rainfall in the Andes Mountains.

Event Impact (for the road authority and other affected parties): The mudflow caused significant damage in Chañaral city and closer towns, with 31 people reported dead or missing and the destruction of houses and buildings, the formation of a fan of material at the mouth of the El Salado River gorge. The mudflow also destroyed part of Route N°5 and blocked/damaged 2.7 km of other roads.

Was the Event Predictable?

Heavy rainfall over the mountains during summer is a phenomenon that occurs every year, however the magnitude of the rain falling onto frozen ground at high elevation resulted in high rates of runoff. The magnitude of the event was not predicted.

Was the Location Predictable, from Existing Information or Previous Events in the Same Location?

In the first event (2015) the location was somehow predictable. The area had a history of mudflows, but 2 years after (2017) a second event occurred in the same area. SIEMOP (Emergency Information System of the Ministry of Public Works - Annex 2) was commenced in 2015, the points where damage occurred were registered, so the second event was predicted more accurately.

Had the Road Authority Made Provision in Advance for Dealing with the Event?

The road authority had not made specific provisions for such a large-scale mudflow, just regular reminder of Emergency Plans and coordination, but there were no detailed hazard maps to help authorities to make better decisions.

How Did the Road Authority Collect Impact/Damage Data and Other Information Required to Respond to the Event, and How Was This Information Conveyed to Response Managers?

Impact data was collected through field inspections by provincial and regional teams. The information was registered in SIEMOP (Emergency Information System) and communicated to the relevant authorities. The collection of information was slow, due to disruption to surface transport and problems of cell phone network signal.

What Were the Emergency Measures Implemented (in General Terms)?

- Coordination with the road maintenance contracts and teams, as well as mining companies in the area to help clear the roads
- Coordination with municipalities of the affected provinces, to remove debris and mud in Chañaral city and other affected towns and to reinstate sewer system.
- Restore connectivity on Route N°5.

- Mobilization of resources from nearby regions to support the response effort.

Did the Road Authority Coordinate with Other Relief Agencies?

Yes, there was coordination between the road authority and the national disaster management agency called SENAPRED, which is in charge of national emergency coordination, to help the affected people. Operational coordination was generated between the road authority and the municipalities to make the sewage system operational again.

Has There Been Any Emergency Response Performance Assessment to Inform Future Practice?

Specifically, a performance evaluation of the response was not conducted. However, in the second event that occurred in 2017, the recorded information was key to preparation and response. The event underlined the importance of having systematized information for a more effective response in future disasters.

6.6. Ministry of Transportation and Infrastructure, British Columbia, Canada

Date of the event: November 15, 2021

Location of the event: Southwestern British Columbia

Event type: Category 5 Atmospheric River

Event impact (for the road authority and other affected parties): Extensive and significant damage to the Provincial highway network, National Rail network and ports

Was the event predictable?

Atmospheric Rivers (AR) are common in southwestern BC with typically 30 per year. What made this event significant was the short duration, volume of precipitation and the AR impacted areas further inland than normal.

Was the location predictable, from existing information or previous events in the same location?

Yes, as per above, ARs are common in this area however this particular AR hit areas further inland which don't historically get the full impact (precipitation) of ARs that hit the coastal area.

Had the road authority made provision in advance for dealing with the event?

No, as ARs are typical in this area at that time of year, the Provincial Road Authority was operating under normal operational readiness for this event with no special provisions or actions taken.

How did the road authority collect impact/damage data and other information required to respond to the event and how was this information conveyed to response managers?

This is described in detail below. Survey 123 is used to collect information for situational awareness which is distributed internally to the Emergency Operation Centers for analysis and prioritization of response actions.

What were the emergency measures implemented (in general terms)?

Yes, a provincial state of emergency was declared as well as essential travel only orders were put in place to limit/manage the use of the Highway network

Did the road authority co-ordinate with other relief agencies?

Yes, through the Provincial Emergency Operations Center which includes all Provincial Ministries, local governments, emergency responders, Federal Government (Canada) and relief agencies (Canadian Red Cross, etc). The Ministry of Transportation coordinated information sharing, assisting other agencies as requested/needed and operational response updates.

Has there been any emergency response performance assessment to inform future practice?

No formal review of the Provincial response has been completed. Overall, the response was considered a success. The use of the Incident Command Systems (ICS) and Emergency Operation Centers (EOC) during the event demonstrated that those systems worked efficiently and effectively.

6.7. New Zealand Transport Agency

North Island Severe Weather Events (NISWE) 2023

Dates of the events

- Heavy rainfall between 26 January and 3 February 2023
- Cyclone Gabrielle between 12 and 16 February 2023

Location of the Events

The following regions of the North Island of New Zealand were impacted:

- Northland
- Auckland
- Waikato
- Bay of Plenty
- Tairawhiti
- Hawkes Bay
- Manawatu

Event Type: Severe weather in the form of heavy rainfall followed by a cyclone.

Event Impact: The North Island severe weather events in January and February 2023 were of a scale and severity unprecedented in New Zealand. It is only the third time in New Zealand's history in which a State of National Emergency has been declared.

These events led to 15 deaths and widespread, significant damage including property loss, road closures, collapsed bridges, damaged power and communication infrastructure and loss of livelihoods.

Was the Event Predictable?

New Zealand was impacted by two severe weather events: heavy rainfall that commenced 26 January and ended on 3 February 2023 across the Northland, Auckland, Waikato and Bay of Plenty regions, followed by cyclone Gabrielle, which crossed the North Island during the period 12 to 16 February 2023.

These events presented very different challenges. The first heavy rainfall occurred with very little advance warning of the potential consequences and the response required was very reactive. The cyclone arrived following advanced warning and a more pro-active response was possible.

For the first weather event, the Auckland Transport Operations Centre (ATOC) issued a situation alert on 26 January 2023 advising of significant rainfall expected in Northland, Coromandel and the western Bay of Plenty. The alert also identified the red trigger level for wind on the Auckland Harbour Bridge.

For cyclone Gabrielle a risk assessment was started on 8 February following initial warnings from Metservice. Planning for a coordinated response commenced on 9 February with a NERT activated on 11 February 2023, one day prior to the cyclone making landfall.

Was the Location Predictable from existing information or previous events in the same location?

No, given the uncertain nature of severe weather impacting New Zealand - many of the areas impacted were not predicted ahead of the weather events.

Had the Road Authority made provision in advance for dealing with the event?

Not for the first weather event between 26 January and 3 February, as it did not have sufficient warning of the event.

Yes, for the cyclone during the 12 to 16 February period. Please see the above section on predictability for further information.

How Did the Road Authority Collect Impact/Damage Data and Other Information Required to Respond to the Event, and How Was This Information Conveyed to Response Managers?

This was provided manually by our roading contractors and provided to our Transport Operations Centres in Auckland (ATOC) and Wellington WTOC). There was very often delays in receiving information in this way.

What Were the Emergency Measures Implemented (in General Terms)?

At 20:20 hours on 27 January 2023, ATOC Manager called the Lead Advisor Emergency Management about the evolving weather situation across Northland, Auckland and Coromandel. At 20:45 the Executive Assessment Team (EAT) were called to discuss the situation and accepted the recommendation to stand up a National Emergency Response Team (NERT) immediately. The first sitrep was issued at 21:30 that night.

The NERT was activated from 27 January through to 7 February 2023 for the first weather event.

On 8 February 2023 information was received from Metservice regarding the potential impacts from cyclone Gabrielle. A risk assessment identified the need to plan for a significant response to a severe risk. A NERT was planned from 9 February and was fully activated on 11 February 2023.

Regional Emergency Response Teams (RERTs) were activated in affected regions to better coordinate the response at the regional level once the cyclone had cleared. The RERTs were valuable to respond to the different stages of response and recovery at the regional level.

The NERT and RERT responses transitioned to recovery at the end of March 2023.

This was the first time that a full activation of the emergency response processes (NERT and a number of RERTs) had been utilised due to the severity and duration of the event.

Did the Road Authority Coordinate with Other Relief Agencies?

Yes, there was considerable coordination that occurred over the duration of both events at national, regional and local levels through the established processes used for Emergency Management in New Zealand. NZTA provided people to act as liaison officers with other key agencies and organisations.

Has There Been Any Emergency Response Performance Assessment to Inform Future Practice?

Yes – a Lessons Management Report has been produced. The recommendations for improvement in this report have been accepted by senior management and actions are underway to address the recommendations through an Emergency Management Improvement Programme. Recommendation 5 in this report has significant RIA implications, and is copied below.

To develop a Common Operating Picture and Processes (COP).

- Develop a COP tool that allows users to display relevant information for accurate and informed decision making. Operational level information for the National Emergency Response Team (NERT) and the National Incident Management Team (NIMT) and strategic level information for Governance.
- Develop a tool to better capture as near, real-time situational awareness as possible to feed into the COP tool.
- The tools will need to be on platforms that all parties that need access can utilise.
- The COP to provide a single source of truth.
- Where possible to include local road information to provide full information on the roading network for alternative solutions.

6.8. TRANSPORT SCOTLAND

Date of the event: 7th October 2023.

Location of the event: Multiple hillside channels along 5km length of Glen Kinglas, areas at Rest and Be Thankful (RABT) as well as wider trunk road and local road network.

Event type: Multiple debris flow events following 160mm of rainfall over 36 hours.

Event impact (for the road authority and other affected parties): Closure of A83 trunk road for 5 days. The impact was compounded by local road closures caused by the same weather event.

Was the event predictable?

Weather forecasts were being monitored. The forecast rainfall was considered to be sufficient to be on heightened risk of landslides. The Old Military Road (OMR) diversion at RABT was put into operation in anticipation of the weather event. The actual rainfall at event locations was recorded to be significantly higher than forecast.

Was the location predictable, from existing information or previous events in the same location?

There is a history of small landslide events at Glen Kinglas but these have been much less frequent than RABT. Studies have been undertaken to understand the risk to the trunk road and mitigation has been installed at key channels. This mitigation has proved successful in containing debris flow events prior to October 2023. The mitigation in place was not impacted during the October 2023 event. The rain that was forecast was of a level that landslide events could be expected to occur however the location and impact of any event is difficult to predict.

Had the road authority made provision in advance for dealing with the event?

In response to the forecast rainfall and heavy rainfall warning landslide patrols were initiated, the local diversion at RABT was put into operation.

How did the road authority collect impact/damage data and other information required to respond to the event and how was this information conveyed to response managers?

Emergency response procedures were implemented which were followed by specialist inspection by geotechnical experts. Regular (several per day) meetings were held, coordinating the response team and information being shared to Transport Scotland, stakeholders and media.

What were the emergency measures implemented (in general terms)?

Police Scotland advised the A83 was to be closed. BEAR Scotland (an alliance of UK road organisations) put the standard incident diversion route in place. Inspect and clean up then commenced when considered safe to do so. The A83 was re-opened after 5 days.

Did the road authority co-ordinate with other relief agencies?

Regular interface with Argyll & Bute Council and Police Scotland through meetings of local resilience partnership.

Has there been any emergency response performance assessment to inform future practice?

Hot and Cold de briefs were undertaken. Enhanced monitoring was implemented at Glen Kinglas. Physical mitigation was later constructed at one channel in the form of a concrete barrier system. A detailed topographical/LiDAR survey has been carried out and a Natural Terrain Hazard Assessment is currently underway to provide an understanding of the hillside risk to the trunk road.

6.9. Summary and concluding remarks

6.9.1. Overview

The two Nepal case studies relate to essentially catastrophic geohazards: a 7.8 magnitude earthquake and a 'huge' landslide. The Gorkha earthquake in 2015 caused significant fatality, widespread disruption, destruction to roads and other infrastructure. It was an international as well as a national emergency. Routine emergency response provision was in place, and a large earthquake somewhere in the vicinity of Kathmandu was overdue, but the timing, location and severity of this event was unexpected. The landslide occurred at a location where, for several years (Hearn 2021) there had been evidence for a progressive increase in slope failure, as shown in Fig 6.1. As described above, it also caused significant fatality, closure of the Arniko Highway for over a month (without any viable detour) and the creation of a lake with the threat of outburst flooding and flooding of an adjacent hydropower facility.

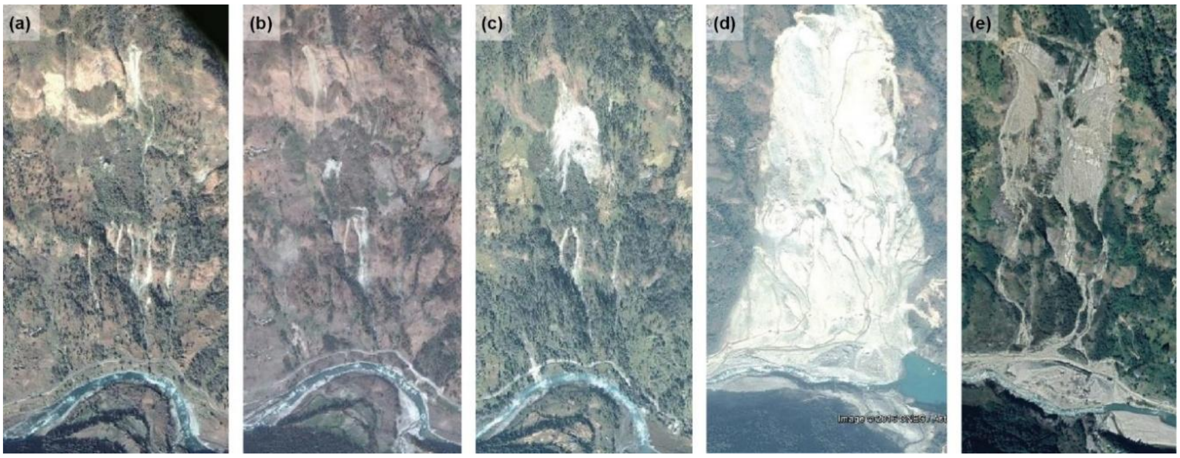


Fig 6.1 Progressive development of the Jure landslide on the Arniko Highway, Nepal. (a) Nov 2000; (b) Aug 2004; (c) Oct 2012; (d) Dec 2014; (e) Nov 2020. From Hearn 2021, reproduced with permission of the Geological Society, London

During these events the collection of damage data by the Nepal DoR was hampered by blocked access, safety to personnel and communication problems. The DoR assisted the Nepal Army and Nepal Police as best it could but it had no robust plans in place and very limited resources. The lessons learnt from these case studies were the need to have strengthened preparedness, more clearly-defined RIA procedures in place, significantly better (real-time) communications facilities and perhaps improved coordination with other agencies. Whether slope movement monitoring might have helped is conjectural, but remote sensing data such as InSAR might be considered once a potentially unstable situation is identified.

The two Uganda case studies are far less catastrophic than those from Nepal, but they also reflect a reactive rather than a proactive and prepared response. The Karuma Bridge case study appears to reflect a lack of procedure for routine structural inspection and decision-making over repairs and retrofitting. The lessons learnt seem to relate to a need for more robust and regular structural inspection and an asset management system that allows timely intervention.

The landslides and related hazards affecting the Fort Portal to Bundibugyo Road occur on a fairly regular basis with known trouble spots. The highway authority (UNRA) makes provision by having plant and resources in place at strategic locations. Information on road damage and blockage, when it occurs, is relayed to the UNRA station manager by site-based maintenance contractors. The lessons learnt from this case study include the need for more substantial emergency budgets, clearer procedures during emergency events and training of UNRA personnel in landslide management.

The Mozambique case study has similarities to the problems affecting the Fort Portal – Bundibugyo Road in Uganda, albeit in relation to different hazard types. Flooding seems to repeatedly affect a specific area in Maputo Province where rural communities are cut off and their agricultural produce is unable to get to market. Flood hazard mapping developed by the highway authority (ANE) clearly shows the distribution of flood hazard. Damage data is collected in paper form, typed into excel and sent (presumably by email or social media) to the Emergency Department. Damage to highway assets is repaired and improvements made to cross drainage but the lesson in this particular case appears to relate to the horizontal and vertical alignment of the highway, with the possible consideration of its realignment.

Mudflows and debris flows are often associated with unstable catchments and therefore their locations can be predicted. This appears to be the case with the Atacama Desert mudflows in Chile in 2015 and 2017. However, the timing and magnitude of these events are controlled by rainfall patterns, especially where heavy rain falls on frozen ground in mountainous source areas. The Roads Administration collects damage data manually but, as in Nepal, this is hampered by difficulties of access during emergency events and communications outages. To assist in disaster management the Ministry of Public Works developed its SIEMOP Emergency Asset Management (EAM) system, described in Annex 2 of this report. The system allows the identification of the effects of emergencies on the road network, and is able to generate emergency maps linked to a damage database.

Gillett et al (2022) describe Atmospheric Rivers (ARs) as long, narrow, shallow filaments of concentrated water vapour transport, typically found ahead of cold fronts in extratropical cyclones. These authors described the AR event of November 2021 that brought two days of intense precipitation to southwestern British Columbia in Canada. According to the authors, floodwaters, landslides, washouts and bridge collapses caused by the event closed all the highways, pipelines and rail lines connecting Vancouver and southwestern British Columbia with the rest of Canada for several days, with some highways closed for weeks after the event.

The Ministry of Transportation and Infrastructure (MoTI) of British Columbia used this event as their case study. They noted that these events are common but not on the scale of the 2021 event which involved much greater precipitation that extended further inland than is normally the case. No special provisions were in place before the event, other than usual preparedness for ‘ordinary’ events. Damage and impact data was collected using ARCGIS Survey 123 software and used to raise situational awareness. The data was shared with the Emergency Operations Center for analysis and emergency response prioritisation. The case study illustrates the importance of close cooperation between critical infrastructure agencies, Incident Command System and Emergency Operation Centres and the need for real-time information sharing. The event was managed efficiently and effectively.

The North Island Severe Weather Events of 2023 in New Zealand resulted in the declaration of a State of National Emergency in the country for the first time. Two consecutive events took place. The first involved heavy rain, was unpredicted and the emergency response was entirely reactive. The second was the landfall of Cyclone Gabrielle when early warning was provided and a pre-landfall risk assessment facilitated anticipation and emergency preparedness. Contractors provided damage data to the Transport Operations Centres in Auckland and Wellington, though there was some delay in receiving the data as the first priority was to deal with the damage as it occurred. A National Emergency Response Team was put into operation, with Regional Emergency Response Teams providing local knowledge and disaster management. A Lessons Management Report identified ways in which the procedures could be strengthened to deal more robustly with future events of this kind. It was recommended that a Common Operating Picture and Processes system is established that, inter alia, provides a common data platform that all parties can access, using tools to capture data in as near to real-time as possible and providing a ‘single source of truth’, I.e. so that conflicting reports on damage can be avoided. Information on the condition of the highway network will enable priority decision-making.

The debris flows that impacted the A83 in 2023 in Scotland were anticipated from weather alerts. Landslide patrols were implemented accordingly. While debris flows had occurred previously, the locations, severity and impacts of those that occurred in 2023 were largely unpredictable. Emergency response procedures were followed to assess the actual damage incurred, and information was shared with other emergency management stakeholders and the public. This was followed by specialist inspections and the implementation of monitoring schemes.

Finally, a highway authority not referred to above provided a case study that has not been used here. The case study involves multi-agency response to an event that damaged multiple assets and caused significant traffic disruption with the closure of bridges and highways for several hours in a built-up area. The highway authority had its hands tied to a considerable extent by poor leadership among the multi-agency response team. The case study illustrates the need to have hand-picked specialists who are sufficiently qualified and experienced to be placed in positions of authority and leadership and for there to be robust response planning and clear lines of communication.

6.9.2. Key points to take forward for RIA

Based on the information and discussion presented thus far in this report, the key elements that need to be taken forward for RIA preparedness and response are listed below:

Preparedness

1. Have prior knowledge (preferably in a GIS data layer) of the vulnerability of the network and its assets to different hazard types. This is based on past damage records supplemented by verified hazard susceptibility mapping, previously produced by specialists. Satellite imagery may also assist.
2. Automatically access real-time early-warning of incoming hazard triggers, including earthquakes and weather systems.
3. Establish geohazard monitoring at vulnerable and high risk sites to provide a means of early warning. This can be facilitated using satellite imagery for progressive deterioration of ground conditions.
4. Stockpile emergency provisions at strategic points on the highway network to deal with events when they occur. Strategic points are decided on the basis of network connectivity and hazard vulnerability from records, susceptibility maps and knowledge.
5. Ensure staff are fully trained in the diagnosis of hazard types in the field. Also, have direct-line access to specialists who may need to be consulted for specific events.
6. Regularly undertake emergency response and data collection drills to ensure that the response procedure works efficiently and effectively and the right data is being collected.
7. Develop an integrated, multi-agency emergency response team, with clear lines of authority and responsibility, headed and staffed by experienced personnel.

Damage data collection

8. Use crowd- and media-sourced data, together with that from regional offices and emergency response agencies to gain a rapid and verified overview of the extent and severity of damage.

9. Carry out rapid field damage data collection.
10. Ensure safe access for all field staff through liaison with emergency services, including police and fire departments. This requires declaration of go and no-go areas from the emergency service personnel as well as geohazard specialists where required. Always maintain line of site between field staff and secured communications.
11. Damage data should be systematically recorded, either on paper or (preferably) electronically, but it is wise to have the two systems available in case the former fails.
12. Damage data should be relayed in as close to real-time to the headquarter emergency department as is possible. This may require permanent access to satellite telephones or systems such as Starlink.
13. Ensure that the field inspection teams collect only and all of the data required for damage assessment and priority decision making, including numerical, textual and supporting photographic data.
14. Field teams should be sufficiently qualified and experienced to make a first-stage assessment of the works required to establish temporary and permanent access and the length of time it may take to implement the former.
15. Use drones to collect damage data if practical, necessary and safe to do so. Don't use drones for the sake of it. Know in advance what data to collect and how it will be used to inform the RIA.
16. Consider using vehicle-mounted, GPS-enabled video surveillance systems capable of relaying information directly to the headquarter emergency department.
17. Consider using proprietary or in-house developed software to aid electronic damage data collection and processing.
18. Impact and risk assessment for emergency works prioritisation
19. The headquarter emergency department should be drill-ready to receive incoming data from multiple field teams.
20. Ideally, information should be registered in GIS with the ability to view its impact on the network as a whole, including critical infrastructure and supply and escape routes in each case. This requires spatial visual analysis. Decision-making should be peer-reviewed, and not reliant on artificial intelligence.
21. The highway authority should be able to automatically determine the class and code of road links and assets affected, the traffic volumes disrupted and the wider socio-economic and livelihood impact of road closure and loss of access to other critical infrastructure. Ultimately, this can be facilitated using GIS. The field inspection teams should not be relied upon to provide this information because they may not have sufficient knowledge and may make under-informed and subjective judgement.
22. Damage data should be pooled and shared between emergency response and critical infrastructure providers.
23. Determine priority based on consideration of the wider impact of the recorded damage to each asset and road link. Theoretically, this could be made an automated procedure, but practically it will be based on informed heuristic and peer-reviewed decision-making.
24. Consider developing software to assist in this process.

Quantity-cost estimation

25. Use field team assessments of required temporary works as the first stage.
26. Use the quantities of as-built temporary and permanent reinstatement works from past events.
27. Use infrastructure mapping and DEM (where available), together with as-built details and asset management data where they exist to determine approximate quantities. Combine with contractors' emergency call-up rates for cost estimates.
28. Consider developing software to assist in this process.

Public awareness

29. Use social media and news outlets to inform the public of road closures and traffic control requirements and, if possible, use ITS to regulate and monitor traffic movements.

7. GUIDANCE ON RAPID IMPACT ASSESSMENT: PRACTICES, BENEFITS, CHALLENGES AND OPPORTUNITIES

From the literature review, the questionnaire returns, the one-to-one discussions, the case studies and the summaries provided above, the following RIA provisions and procedures are recommended. They are summarised in the flow chart in Figure 7.1. Figure 7.2 outlines the software applications that could potentially be used in support of these activities. Volume 2 of this Guidance provides further discussion on software considerations.

PRE-EMERGENCY: BEFORE THE HAZARD STRIKES

7.1. Preparedness

7.1.1. In any emergency response scenario, information is the key commodity. The ability of a highway authority to respond to the emergency effectively depends to a considerable degree on the extent to which this information comes as a surprise, without any forewarning and opportunity for anticipation and preparation. A highway authority cannot work in isolation and ignorance of information that others may have on geohazard, environmental and societal conditions that might directly and negatively impact the highway authority and its ability to respond during emergency conditions. At the very least this can lead to reputational damage; at the very most it can result in loss of life, major damage to infrastructure and societal and economic disruption and hardship.

7.1.2. There are several important components of preparedness that, combined, allow the highway authority to be 'one step ahead' when an emergency begins to unfold. These components include:

7.1.2.1. The establishment of a network emergency management centre (NEMC) in the highway authority's regional or head office. This emergency management centre should be interfaced with the central 'unified command' government/state emergency centre (CGEC).

7.1.2.2. Field and head office staffing with the necessary skills and experience. Ensuring that staff are fully-trained in hazard recognition, damage diagnosis, risk prognosis, data collection, impact assessment, interpretation and emergency works prioritisation is essential. Suitably-qualified engineers can usually fulfil these tasks with the appropriate training. Complex problems, such as large deep-seated landslides and structural failure of bridges and tunnels, will require specialist assessment. These assessments may be required during the early hours of an emergency. Many highway authorities have these staff resources but others do not. It is recommended, therefore that each highway authority reviews its staff resources and their competencies with a view to strengthening it to respond to the hazards that are most-commonly faced. If these specialists are not retained in-house then rapid call-out arrangements should be put in place with external experts **in advance** of the next emergency.

7.1.2.3 Several highway authorities rely on regional, sub-regional and district headquarters to implement the RIA. The benefits of this approach lie in the local knowledge that these offices have. Local staff are familiar with the network and its assets in their area of responsibility and understand how they have performed in the past. However, these offices need to have staff equipped with the necessary skillsets, trained and provided with the field resources required for RIA. There also needs to be a proven system of recording damage data systematically in the format required by the head office

NEMC and there also needs to be a proven and trusted method for communicating this information to the NEMC for immediate situational awareness.

Standardised inspection sheets should be developed in advance for major structures, such as bridges and retaining walls. Completed sheets can supplement the damage record and help support decisions on asset functionality. These sheets should not be developed for all assets, such as culverts, and continuous assets such as side drains, earthworks and the carriageway, as their completion would be too time-consuming and cost-ineffective.

7.1.2.4 There has been a growing trend for highway authorities to rely on contractors in times of emergency. These contractors might be responsible for the maintenance of particular road links or a combination of road links under performance-based contracts. The highway authority may have special call-up arrangements with contractors for emergency situations. These contractual arrangements need to be in place **in advance** of emergencies, for obvious reasons, with quality-controlled procedural and operational plans in place for assessing and managing damage. It is also important that lines of communication are established whereby damage and network functionality information is relayed in as near real time as possible to the NEMC. This is most-effectively achieved when the contractors responsible record this information electronically in a system that is automatically shared with the NEMC (see below) and amongst themselves.

7.1.2.5. Emergency budgets that can be drawn down in time of emergency. Most highway authorities have these budgets, provided by central government, but others do not. It is recommended, therefore, that each highway authority reviews its operational capability and makes arrangements accordingly. The cost of responding to past impacts can help inform these annual budgets.

7.1.2.6. Records of past hazards on the road network and their wider impact. These records allow the highway authority to know which locations, sections and areas of the network are most vulnerable to different hazards, mostly landslide and flood hazards. Recording these repeated impact locations supports risk mitigation/adaptation/resilience planning because affected areas will probably only get worse with climate change effects.

7.1.2.7 Highway asset inventories. Some highway authorities maintain asset management systems that include the condition of the pavement, bridges, roadside drainage structures, retaining walls and earthworks. These asset management systems provide the following important sources of information that inform preparedness for RIA:

a. The location of assets according to asset type, code and inventory number. These assets will include, *inter alia*: bridges according to construction type and span; elevated sections; tunnels; retaining walls; rock fall canopies; culverts; off-road drainage protection works; slope stabilisation works etc.
b. The network criticality of each asset, perhaps assigned a value of 1 to 5, that represents the importance of the asset in maintaining the operation of the network as a whole and access to critical infrastructure (see below). This allows the wider impact of asset or road link failure/closure to be determined **in advance** of its possible damage during an emergency event.
c. The condition of each asset.
d. The vulnerability of each asset, based on damage records and field inspections.

e. The design of each asset should it need to be repaired or replaced as a result of hazard impact.
f. The locations of traffic cameras, traffic information and control signage.

7.1.2.8. Baseline datasets and maps that depict the spatial susceptibility of the road network to different hazards. The most common of these products are seismic hazard, flood risk and landslide susceptibility or vulnerability maps. These maps are almost always prepared by specialists working in universities or government agencies. Those prepared for research purposes usually require verification; those developed by government agencies are normally peer-reviewed, verified and can be considered to be fit-for purpose. Other baseline mapping should include critical infrastructure (hospitals, fire stations etc), the location of villages, towns and other population centres served by the network and communities whose livelihoods and well-being are particularly reliant on vulnerable links.

Satellite imagery can also form a useful means of spatial awareness in relation to the terrain occupied by the highway network. Satellite imagery can be used in conjunction with the hazard and susceptibility maps to visualise the exposure of different parts of the highway network to landslide and flood hazards, for example.

7.1.2.9. Based on 7.1.2.7 and 7.1.2.8 above, and together with a knowledge of the critical links within the network (7.1.2.7 b) above), the highway authority can take action in advance of an emergency situation to:

a. Protect or strengthen vulnerable infrastructure to prevent serious damage to it in the event of a hazard
b. Position emergency plant and resources (including excavators, loaders, bailey bridges, construction materials and fuel) at depots located at critical supply points on the network. Critical links and structures within the highway network will be pre-determined by the highway authority and can be recorded within an asset management system, as a separate layer in a GIS or in a highway network shapefile. These critical links can be identified and ranked in order of criticality by applying a combined vulnerability and value assessment to each. Vulnerability would reflect the link's vulnerability to hazard; value would reflect the traffic volumes using the link and the infrastructure and facilities (hospitals, fire stations, power stations and electricity sub-stations for example) that are reliant on its operation, including those for whom there are no other viable access alternatives. This process can be aided by 'what-if' scenario analysis of link closures on the network.

7.1.2.10 Third-party assets within or adjacent to the road right of way that could be affected by defects, failures, road closures and repair or reinstatement works. Usually, highway authorities maintain a record of third-party infrastructure utilising bridges as they are visible and special provision needs to be made. Pylons located alongside and above the road in sloping ground are easily recognised but may be without record. Quite often, highway authorities are unaware of buried utilities, such as fibre-optic cables, in fill slopes or aligned through culverts from one side of the road to another. Even where permission to use the right of way has been granted, these records may not exist. Without this information, the full impact of road failure in the event of a flood or landslide, for example, cannot be gauged and utilities can easily become damaged or destroyed inadvertently by emergency reinstatement works.

7.1.2.11. A quality-controlled system for processing and filtering damage information intercepted on social media. It is preferable if this information is gathered and disseminated by whichever central government department or agency is responsible for emergency preparedness and response, e.g. the CGEC.

7.1.2.12. An established procedure for obtaining real-time hazard warning data from statutory providers. The most common type of information is rainfall forecasts and typhoon and cyclone warnings (wind and rain) from the meteorological department. Other information might include warnings of an incoming rapid rise in temperature in snow covered areas, with the potential to trigger snow melt floods and avalanches, and seismic activity in advance of earthquakes, tsunamis and volcanic eruptions. The forestry and fire departments will be able to provide near real-time information on wild fires.

Ordinarily, the most effective way of deriving this information is through the CGEC responsible for collecting and disseminating the data to those that need to use it. However, the United States Geological Survey (USGS), for example, provides a facility whereby earthquake alerts are sent to mobile phone apps. Several Departments of Transportation in the USA have an arrangement in place referred to as ShakeCast, with the USGS.

7.1.2.13. Geohazard monitoring schemes can be implemented to provide early warning of developing hazards. These schemes relate mostly to the monitoring of landslides and high-risk slopes, but also river scour to the foundations of bridge abutments and piers and structural deformation and fatigue to bridges and other structures. In the case of landslides, there is often an acceleration of movement that precipitates total failure. In some circumstances InSAR satellite data can provide indications of ground movement, but for more robust monitoring field-based displacement monitoring, using extensometers and inclinometers, for example can provide real-time information. LiDAR-derived three-dimensional DEMs can also provide a means of monitoring ground movements for early warning purposes through structure from motion.

These systems are expensive and the highway authority first needs to know where to install them. For these reasons they are usually only used where the failure of a slope would pose a significant risk to facilities above or below. The highway authority will need to seek geological and geotechnical advice before deciding where and how to implement these systems. Another geohazard that can be monitored in advance of catastrophic failure is a Glacial Lake Outburst Flood. Usually, there are tell-tale signs of dam degradation prior to failure and these signs can be monitored by satellite remote sensing and other means. The highway authority will be reliant on specialist organisations to provide this information, either directly or through a central emergency centre.

7.1.2.14. An agreed and formalised structure and framework within which the highway authority collaborates with emergency services, the military/civil defence forces if they are involved in emergency response and reinstatement, and other critical infrastructure providers during times of emergency. Ordinarily, this is within the framework of the CGEC. This is critical for several reasons:

a) It automatically shares incoming hazard information among all agencies that require it, thus enabling combined and consistent situational awareness.

b) It ensures that those responsible for coordination and decision-making in the first few hours after a disaster has struck are fully experienced, capable and empowered to manage the situation without the burden of bureaucracy, minimising delay and avoiding mistakes.

c) It allows each partner agency, including the highway authority, to understand the chain-of-command and fully appreciate their own role, responsibilities and lines of communication.

d) It provides the framework within which Standard Operating Procedures can be developed and applied. These assist with planning and operational decision-making, help clarify inter-agency roles and responsibilities, establish protocols and streamline decision-making **in advance** of an emergency.

e) It provides the facility for establishing a central pool of verified damage and impact data that all parties can draw upon in near real-time. The benefit of a fully-functioning verified data pool to which all parties contribute and access is that the *whole is greater than the sum of its parts*. This is referred to by some highway authorities as a 'common operating picture'

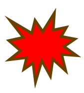
7.1.2.15. Regular emergency simulation exercises (drills), both singularly by the highway authority and combined within the multi-agency emergency response framework of the CGEC, ensures readiness and helps iron out any practical and logistical difficulties **in advance** in relation to roles and responsibilities, methods of damage data collection, transmission of damage data to head office, its analysis and use in the prioritisation of emergency access reinstatement works. Exercises should be designed to test pre-trained skills, competencies (individual and team) and structures.

Implementing a 'dummy run' exercise will help ensure that there is no delay or redundancy in the RIA procedure. The damage data collection templates (see below) should be tested by processing the data gathered at the NEMC to ensure that it enables prioritisation over emergency reinstatement and associated decision-making.

7.1.2.16. An established means by which the public are informed of road closures and dangerous situations.

7.1.2.17. Procedures for monitoring, informing and controlling traffic in the event of an emergency situation, referred to as Intelligent Transportation Systems.

EMERGENCY: THE HAZARD STRIKES



In the immediate aftermath, the highway authority will inevitably rely on telephone calls and radio communications, supported by text messages and electronic messaging from its regional offices and other trusted sources. This can be supplemented by social-media information, preferably filtered and quality-controlled via the CGEC. Where large areas of network are affected, it will be imperative to gain a rapid overview and this is usually best done from the air, via remote sensing.

7.2. REMOTE SENSING

7.2.1. There is usually a lag between the timing of an emergency situation and the availability of satellite imagery that records it. For this reason, most highway authorities do not rely on satellite imagery to inform them of damage and wider impact. The exceptions are those highway authorities (or overarching emergency centres) that have special arrangements with their national satellite data providers who are able to control where and when satellite data is collected. This is rare and costly and may only be relied upon when a national state of emergency is declared. Another consideration is that the skies might take some time to clear if the sources of hazard are rainfall-induced landslides and floods, thus obscuring visual imagery from space.

7.2.2. Ordinarily, where hazards impact large areas the most effective way of recording their areal extent is via helicopter or fixed wing aircraft. This assessment is carried out visually and by GPS-enabled photographic and video record. Organising this form of remote sensing will be beyond the financial means of the highway authority and special clearance will be required to fly in any case. It is more likely that these flights will be organised by the CGEC with the output disseminated to the highway authority and other critical service providers.

7.2.3. UAV (drones) are being increasingly used as a means of collecting vital remote sensing data, though they are effectively a means of field data collection. GPS-enabled photographs and video footage are the main forms of damage and impact data acquisition, though LiDAR is also collected by some authorities. LiDAR data provides three-dimensional DEM. This is not essential for immediate impact assessment. Most countries have legal limits as to where, how far and at what heights drones can be flown, and this can constrain their use by the highway authority unless special arrangements are in place. It may prove most effective to use drones to inspect those locations and structures that are inaccessible and unsafe for field staff during damage assessment. For example, some highway authorities use drones to carry out remote bridge inspections, including structural damage, fatigue and deflections. Another example, would be the case where a section of road, perhaps 100 m in length, has been removed entirely by flood plain scour. Access on foot may not be possible and drone survey can provide a rapid source of information.

7.3. FIELD DATA COLLECTION

7.3.1. In virtually every case where a natural or man-made hazard impacts infrastructure, the community or the environment, the damage caused and wider impact is assessed in multiple stages, with increasing levels of detail from one stage to the next. In the context of this RIA guideline, the following stages are recommended, though requirements will vary according to specific circumstances and institutional setups. They will also vary according to the areal extent of damage/inundation. For example, if only one bridge or section of highway is affected, then the various stages effectively roll into one continuous process.

a) An initial 'Fast Reconnaissance' (FR) stage during the first 8 hours or so, depending on the scale of the event and its duration, to assess the wide-area impact of the hazard[2]. This FR stage involves an

[2] The deluge and powerful winds that accompany a hurricane or typhoon, for example, can cause catastrophic damage to multiple layers of infrastructure (roads/bridges, communications, utilities) and services (fuel, food, lodging, medical facilities) that will significantly delay the ability to conduct assessments. In all cases the initial effort, even for a road authority, is to support the rescue, reprovisioning, and/or

overview of the areal extent and scale of damage to the community and critical infrastructure, including transportation, and identifies areas for priority second stage assessment. This assessment would ordinarily be undertaken by agencies acting on behalf of the national, regional or state government and would involve the highway authority as part of the CGEC recommended above. This is a stage when situational awareness is of the utmost importance.

b) A second stage, undertaken as quickly as possible and within a maximum of 48 hours, that forms a Preliminary Damage Assessment (PDA) of each highway asset and road link within the affected area. As far as the highway authority is concerned, this PDA records the location and extent of damage, degree of loss and the ongoing level of hazard to the travelling public and wider community so that emergency measures can be put in place to reinstate access and safeguard infrastructure, the public and the environment from further damage.

c) A third stage that forms a Detailed Damage Assessment carried out by structural engineers and geotechnical engineers, for example, in relation to the stability of specific structures, especially bridges, and slopes, including major landslides. Traffic restrictions will be in place, including bridge and carriageway closures, until these surveys are undertaken. These traffic restrictions will remain in place if these surveys declare the situation to be unsafe, requiring geotechnical investigation, structural analysis and remedial and replacement measures prior to the opening of the road to traffic.

7.3.2. Before any field inspections are undertaken, the safety of field personnel must be ensured. This requires liaison with the emergency services, including the police and fire departments, and military/civil defence forces if they are engaged in the emergency response strategy. If a length of road has been impacted by a succession of major landslides, for example, none of these authorities will be able to determine residual levels of hazard and a landslide expert will need to assess the situation in advance of anybody else. The same would apply to a condition where a succession of bridges along a highway may have been damaged. Provision to consult with these specialists in the immediate aftermath of an emergency will have been made as part of the emergency preparedness (see above).

7.3.3. It is imperative that line of sight is maintained between all personnel in the field. Site inspections should be co-ordinated by a team leader with continuous mobile, radio or satellite phone connection to the local office and the NEMC, recommended above.

7.3.4. At the PDA stage, damage data should be systematically recorded, either on paper or (preferably) electronically, but it is wise to have the two systems available in case the former fails. Those highway authorities using electronic systems of data collection do so using personal mobile assistants and tablets or tough books with the required software uploaded onto them. In all the

recovery of victims. Finding and accessing those victims is often a significant challenge in the immediate aftermath without the infrastructure and services damaged or destroyed and, in some cases, flood waters needing time to recede. Sending engineers/inspectors into a large-scale event without well thought out plans for access to communications, power, fuel, food/water/lodging, medical attention, etc. just adds to the burden of the response. For large-scale events, it can take days to define the limits of the damage/destruction and for PDA/RIA to occur, and generally only after significant and continuous coordination with first responders, emergency managers, and other supporting agencies.

examples that have come to light, the software has been proprietary, i.e. off-the-shelf, requiring different levels of modification to suite the highway authority's specific needs.

7.3.5. The following is a checklist of the type of information that, in one way or another, will need to be recorded. In designing the damage record template, it is preferable to base as much of it as possible on tick-box answers. Some data fields will require written answers, perhaps to elaborate. The highway authority will decide what other data to collect in order, for example, to conform with emergency funding data formats and the specific condition parameters of each asset type that control its functionality.

i. Time and date
ii. Field engineer name
iii. Road link number in the network
iv. Chainage location
v. GPS co-ordinates
vi. Asset type
vii. Asset number as per the inventory in the asset management system
viii. Source of hazard (e.g. landslide from above, landslide from below, river flooding, river scour, debris flow etc)
ix. Extent of damage (depends on the asset and the hazard type). For example:
    a. Wall foundations exposed by erosion or slope instability
    b. Culvert destroyed by debris flow
    c. Carriageway partially block by cut slope failure
    d. Carriageway totally blocked by landslide from above
    e. Carriageway partially eroded by river scour
x. Functionality of damaged asset. For example:
    a. Single lane traffic permissible with traffic control
    b. Asset requires reconstruction before traffic can safely resume

c) Asset must remain out of operation, with road closure, until structural inspection is carried out

xi. Length of road affected in the case of damage to carriageway
xii. Estimated length or time required to implement temporary works to allow controlled trafficability. Note that xi) affects xii) because it might take a proportionately (10x) longer period of time to reinstate a road damaged over a 100m length than a 10m length
xiii. Estimated length of time to implement permanent works
xiv. Works items and estimated quantities for xii) and xiii)
xv. Other non-highway assets damaged/destroyed/at risk, for example electricity pylons, fibre-optic cables, gas and water supply pipelines, communication towers etc
xvi. Specific safety/stability concerns, for example adjacent occupied building at risk, precarious blocks of rock
xvii. Location-specific information that affects impact rating (see below) that can only be ascertained on the ground.

7.3.6. Damage data should be relayed in as close to real-time to the NEMC as is possible. This may require permanent access to satellite telephones or mobile communications systems such as Starlink. Currently, many highway authorities complete damage data forms in hard copy and scan and email/WhatsApp them to the NEMC. Under such circumstances, the highway authority must strive to find ways of securely and rapidly transmitting information.

7.3.7. Take photographs from various angles of all assets inspected and relay these to the NEMC as quickly as possible.

7.3.8. Use drones to collect damage data if legal, practical and safe to do so. Don't use drones for the sake of it. Know in advance what data to collect and how it will be used to inform the RIA.

7.3.9. Consider using vehicle-mounted, GPS-enabled video recording systems capable of relaying information directly to the NEMC.

7.3.10. Consider using proprietary or in-house developed software to aid electronic damage data collection and processing (see below).

7.3.11. In the event that specialist assessment is required to determine the stability and safe-functionality of a critical asset or high-risk location, a Detailed Damage Assessment (DDA) is required. This assessment is undertaken immediately after or contemporaneously with the PDA by geotechnical engineers, structural engineers and other specialists, either using in-house resources or from external sources. The affected section of road must remain closed until these assessments have been undertaken and the area declared safe. DDA will continue beyond the RIA period to inform the design of reconstruction and reinstatement works.

7.4. QUANTITY AND COST ESTIMATION

7.4.1. Prior to the development of an emergency works strategy an estimate of the required: i) works items, ii) quantities and iii) costs of asset repair and reinstatement is required. Estimates i) and ii) are required from the RIA field teams to the extent that this is possible within the boundaries of their observational and technical skills. Where the field teams are unable to provide this information with the required level of confidence, specialist advice will need to be sought as part of the DDA. Estimate iii), i.e. costs, should be compiled by staff at the NEMC. The following sources of data can be used to assist:

a) Historical information concerning the quantities (and cost if recent) of repair and reinstatement works undertaken to resolve similar problems on the same network.
b) As-built drawings, where available, that describe the constructed design of each damaged asset. These will provide further details of reinstatement requirements.
c) In some circumstances, LiDAR DEM data can be used to assist in the quantification of mass earthworks, for example, required to reinstate or reconstruct access. However, where the topography has changed significantly as a result of the hazard, this DEM data will be out of date. Its update, in the immediate-term at least, may prove impractical, and reliance will have to be placed on field estimates.
d) Works item rates should already be established, either using the highway authority's own engineering resources or those provided by emergency call-up contractors or contractors already engaged under performance-based contracts for the affected parts of the network.

7.5. IMPACT AND RISK ASSESSMENT FOR EMERGENCY WORKS PRIORITISATION

7.5.1. The NEMC will need to establish a verified damage dataset as quickly as possible. This dataset will be multi-sourced. It will initially include information from social media and news releases, filtered through the CGEC for multi-agency consistency and verification. Other initial data sources will include telecommunications and emails received from regional and district offices. The most important objective of the highway authority at this initial point in the RIA will be to verify incoming data and gain a rapid overview of the extent and severity of damage. This will be achieved through the participation of the highway authority in the Stage 1 Fast Reconnaissance (see above) within the framework of the CGEC. All damage data should be pooled and verified within a central database, hosted by the CGEC, but accessed securely by agency partners including the highway authority NEMC.

7.5.2. If the provisions under Preparedness (see above) have been implemented, the highway authority will be able to receive incoming damage data from its RIA field teams or contractors during the PDA and be in a position to examine its implications in relation to the spatial functionality of its network and the critical utilities and facilities that rely on it. Preferably, this should be undertaken in a GIS environment. Several authorities use ArcGIS to fulfil this task, but other options also exist, including QGIS and graphical interfaces (see below). The spatial datasets available to the highway authority NEMC should include the following:

a) The road network as a shape file or, preferably, a graph file, with each link classified according to status, e.g. national; interstate; trunk; expressway; regional; local; feeder etc, depending on the established system.
b) Traffic volumes (AADT) and class per link.
c) Classification of highway assets according to their individual and network criticality. These assets include bridges and elevated sections, tunnels, retaining walls, rockfall canopies, culverts, off-road drainage structures such as check dams and cascades etc.
d) The location on the network, within or adjacent to the right of way where third party utilities are located, either above or below ground. These might include, for example electricity pylons, fibre-optic cables, gas and water supply pipelines, communication towers etc.
e) The location of critical facilities and infrastructure, including hospitals and other medical facilities, power stations and sub-stations, fuel stations, fire stations, emergency supply depots etc.

If the CGEC is fully-functioning then these datasets can be hosted centrally and the highway authority can utilise a central GIS facility. Otherwise, the highway agency will need to develop its own system.

7.5.3. The NEMC should aim to have a formalised, peer-reviewed procedure in place for combining damage data with the total consequence of the damage to yield impact, or risk, for prioritisation purposes. This procedure combines the ability of the asset to function safely during the emergency period with the wider consequence if it is unable to do so. The total consequence of a loss of function would be the sum of the effects based on the criticality of the asset, the traffic volumes disrupted, loss of access to hospitals and other critical infrastructure, closure or unsafe access for emergency responders and communities that are cut-off as a result of road closure. It is recommended that the highway authority reviews the Highway RIA document prepared by Deeming (2021) to determine the extent to which its contents might be applicable to its own hazard scenarios and operating system.

There are several other factors that will control the impact of link or asset closure on the wider network and the facilities and communities dependent upon it. These factors include, *inter alia*:

a) The availability, suitability and safety of detours, i.e. other links in the network that allow the damaged asset(s) to be bypassed.
b) Options for constructing temporary access, for example across river terraces, that allow the damaged asset(s) to be bypassed.
c) The use of bailey bridges (if available and applicable) to provide temporary access.
d) The criticality of any particular asset in providing wider network access will depend on the status of other assets within the same link. In some circumstances, the damage may be the total collapse of a single bridge. In that case, the wider impact of its loss of function can be easily determined, and access reinstatement in relation to the bridge is the only priority. In other circumstances, there may be multiple road closures due to landslides and river scour along a 100 km long road link. There will be no ease of impact if only one location is cleared without the others being cleared simultaneously. Work will need to start first on those closure locations that will require the longest time to reopen, hence the need for field teams to estimate reinstatement times. Access to these locations to commence this work will depend on neighbouring closures and so decision-making will require real-time liaison between field teams and the NEMC so that the most appropriate course of action is taken.

7.5.4. Damage might be gauged on a scale of 0 to 1, such as *slight* (0.25), *moderate* (0.5), *major* (0.75) or *total* (1.0) with the following definitions:

- Slight (0.25) - the structure or location is considered to remain usable, but perhaps with some mitigation or traffic management;
- Moderate (0.5) – the structure or location remains functional, though single lane or controlled access will be required until full functionality is restored;
- Major (0.75) – the structure or location should be closed to traffic until its functionality is restored;
- Total (1.0) – the structure or location should be closed to traffic and will require reconstruction.

As described above, it is important to estimate the time required for safe temporary functionality and traffic access to be restored for all but *slight* damage cases, as this is critical to the wider impact assessment. Assigning consequence scores to arrive at an overall value of damage impact on the wider network, for prioritisation purposes, is the preferred approach to emergency response decision-making. However, it may prove difficult to objectively assign these scores and it is recommended that decision-making is undertaken collectively by NEMC managers, drawing on support from these semi-quantitative approaches and visual analysis of the network and its link criticality, in liaison with the field teams concerned.

Bespoke RIA software can be used to facilitate these semi-quantitative approaches to impact assessment using network analysis, spatial datasets and asset/infrastructure criticality (see below).

7.5.5. The cost estimate and the estimated time taken to facilitate repairs and reinstatement are important considerations that reflect on the final emergency response action plan. Unfortunately, many highway authorities are resource-limited and some have inadequate draw-down emergency funds. The time required to secure additional funding is time lost in an emergency situation and therefore important questions need to be answered concerning financial allocation and the readiness of external sources.

7.5.6. The highway authority will need to monitor, regulate and control traffic during the emergency situation in collaboration with the Police. Effective traffic signs and public information systems will be of the utmost importance during this period. In some circumstances, traffic will need to be controlled perhaps at 100 km or more from the scene or area of emergency and the highway authority should invest in ITS that facilitate this.

7.6. SOFTWARE CONSIDERATIONS

7.6.1 RIA software can be acquired off the shelf, varying from a generic solution like ArcGIS with Survey123, to bespoke RIA-specific solutions and modules such as StormChain and IBM. However, the cost of these products can be prohibitive. It is important that a solution be web-based, so it can be accessed (securely) through the web from any device and from any location. ArcGIS, for instance, is desktop based, though elements of it can be made available in the browser.

Field data collection

7.6.2. Collection of information at the location of a disaster can be done through a tablet-based survey system. ArcGIS, for example, offers Survey123, while StormChain has a tablet application. Data collection can also be through survey systems available at low or no cost, which can be configured to be just as powerful. KoboCollect, Open Data Kit and CSPro are examples of such systems. Data collected is synchronized with a cloud-based server.

Development considerations

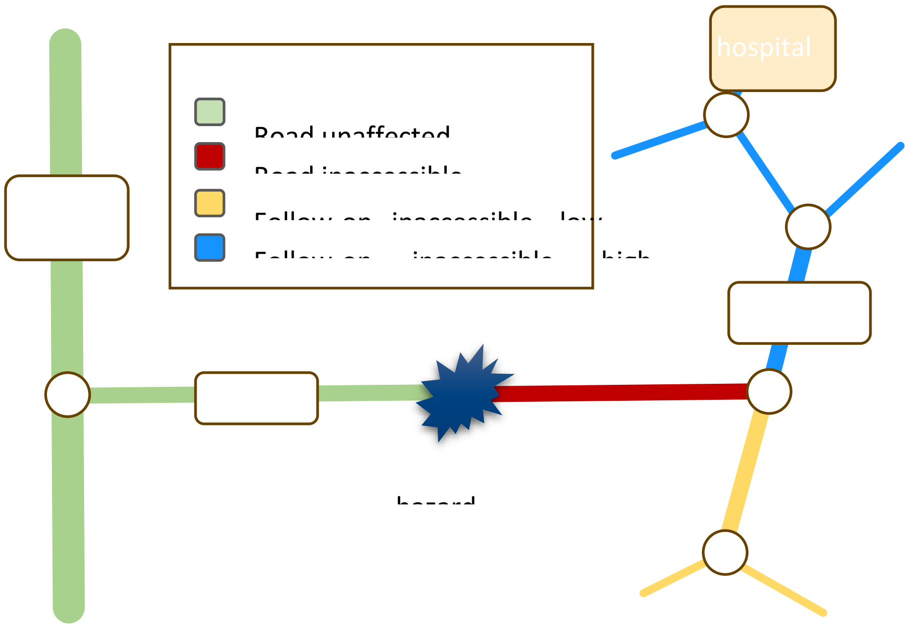
7.6.3. At its core, RIA software should consist of a data collection platform (populated with forms designed by experts), and a GIS web application. The web application must associate damage locations with road polylines and visualize these on a map. This map can be enriched with relief through a digital elevation model. Other static datasets, such as population centres, land use, and bodies of water can be added to the map through vector tiles. The collected data can then be filtered in different ways, e.g. by date, by disaster type or by damage. Once enough data has been collected (including historical data), susceptibility maps can be generated.

7.6.4. The usefulness of the data visualization is dependent on the availability of road network data. The web application must be able to retrieve road network polylines, with road name and class attributes, and calculate the intersection of roads and damaged infrastructure. The road network is not a static dataset, so that an integration strategy must be designed for the web application to always show the latest data. One approach to this is the regular (e.g. weekly) generation of vector tiles from a road network shapefile, to be used by the web application as a tile pyramid.

7.6.5. The RIA software does not stand on its own. While it may offer different visualizations of data and ways to analyse it, it cannot support all possible ways to view and manipulate the data. It is important that data can be exported (after filtering) to a variety of formats (e.g. CSV, Excel), and most importantly to GeoJSON or ESRI shapefiles, so that it can be further processed using ArcGIS or QGIS (a free GIS tool). The implementation of a Web Feature Service (WFS) would allow GIS tools to query data continuously from the RIA software's back end, without the need for export.

7.6.6. Software can be devised to combine damage data with critical infrastructure. By assigning weights to the importance of infrastructure like bridges and tunnels, as well as buildings such as hospitals or power plants, maps can be coloured to show which areas would suffer most from the interruption of access due to a road closure or bridge collapse, thus producing an impact map. In combination with auxiliary datasets of population centres, the number of people affected by a road closure can be calculated instantly.

7.6.7. A criticality map can determine which other connected roads and critical facilities and infrastructure would be made inaccessible as well. To do this, the RIA software must analyse the road network and compute a connection graph, as illustrated below.



7.6.8. In this simple example, a hazard of some sort closes the road. Through a connection graph, the software determines which connected roads also become inaccessible. The impact from the original closure is calculated through analysing how many roads are impacted, in combination with the critical infrastructure affected (e.g. a hospital).

7.6.9. RIA software should benefit from other inputs that help it determine a course of action that goes beyond calculating damage impact. If connected to datasets with information on the availability of mobile resources (emergency services) and static resources (stock, such as emergency bridges, food, equipment, and plant), it can be used to activate resources as necessary.

7.7. Conclusions

The purpose of a pre-defined and structured approach to RIA is to ensure that critical damage and impact data is obtained rapidly, and in a quality-controlled manner that is able to inform collective decision-making over emergency response prioritisation and access reinstatement. In achieving this goal, the highway authority must work with other critical infrastructure partners under the general umbrella of a central command, and especially not in isolation.

All procedures of damage data collection, analysis, data sharing, data verification, situational awareness and response are reliant on proven systems being in place to begin with. 'Single truth' information is the vital commodity. It can only be derived when multiple agencies work together with an overarching framework to provide it. Advanced technology can assist in many ways, but ultimately effective RIA is based on:

- Commitment
- Preparedness
- Adequately trained staff (in-house or contracted)
- Adequate resources and budgets
- Collaboration
- Multi-agency situational awareness
- Robust damage data and impact assessment
- Informed, collective and peer-reviewed decision-making.

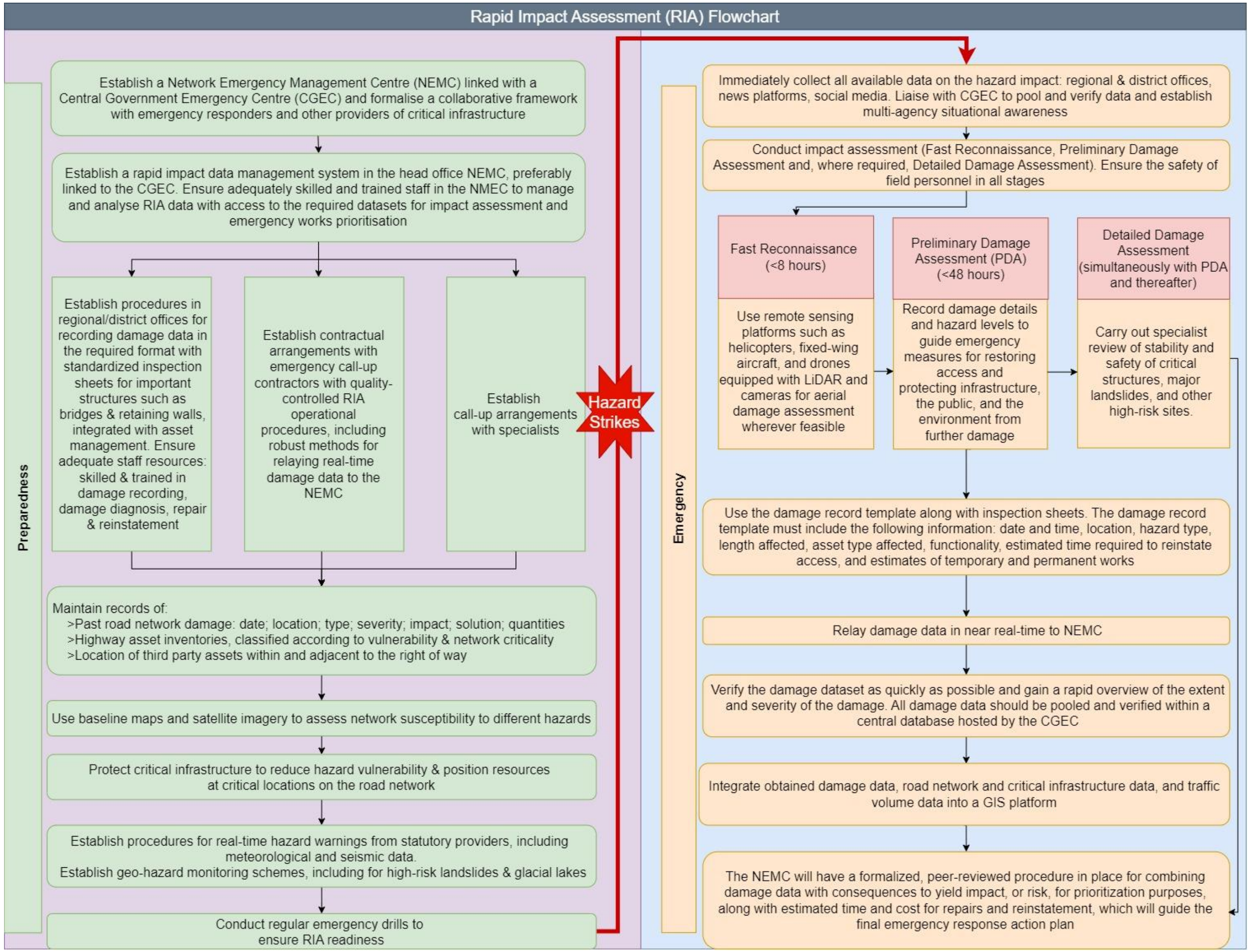


Figure 7.1 Flowchart for Rapid Impact Assessment in the Highway Sector

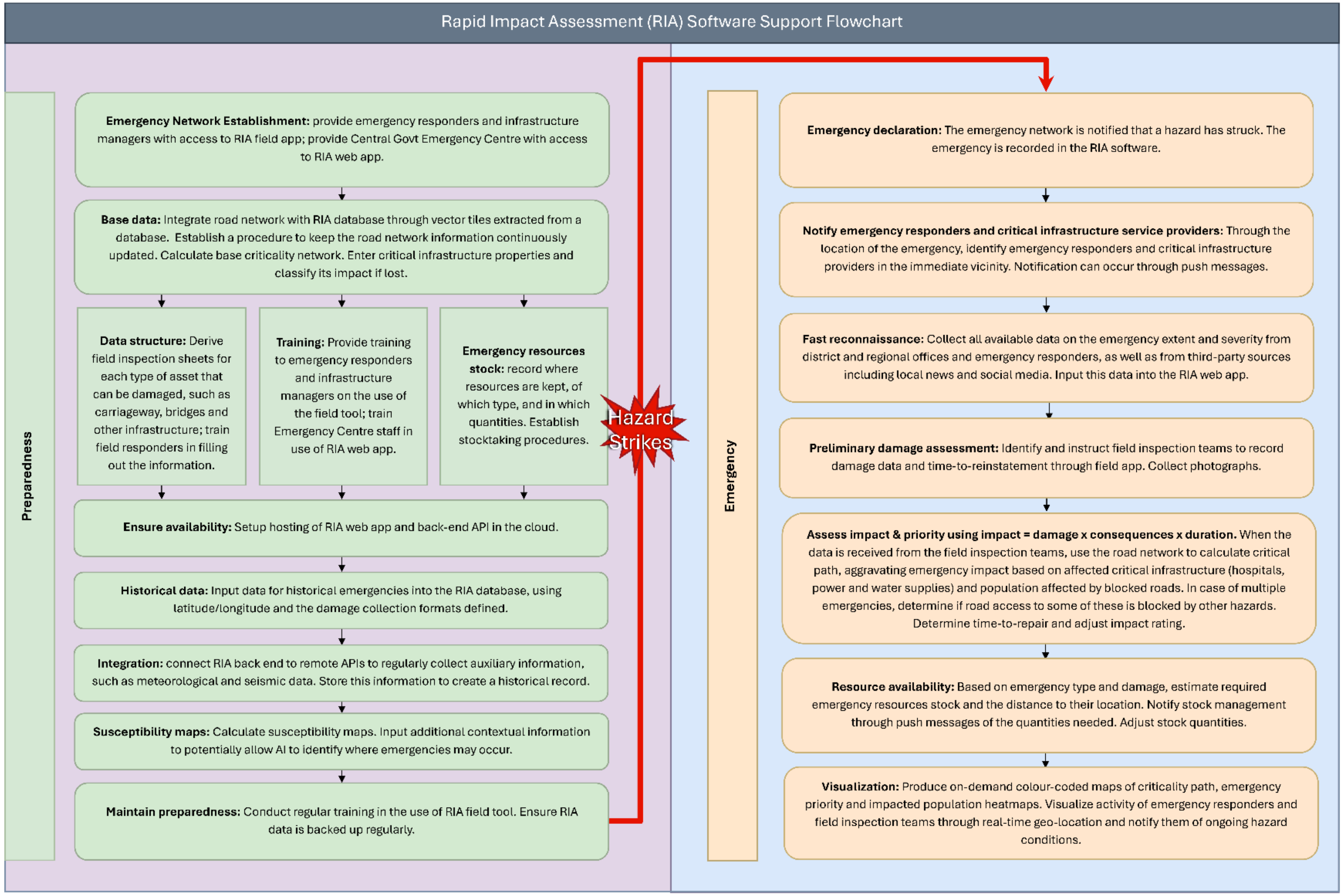


Figure 7.2 Flowchart for software support to Rapid Impact Assessment in the Highway Sector

8. RAPID IMPACT ASSESSMENT FOR LOW- AND MIDDLE-INCOME COUNTRIES (LMICS)

Administratively and procedurally, there is no reason why the approach to RIA should be any different between highway authorities according to whether they are located in high-income, middle-income or low-income countries. However, of the top ten disaster-prone countries in the world, eight are LMICs, of which slightly more than half are either Low Income or Lower Middle Income (Statista 2024). Generally, therefore, the level of hazard in many LMICs is significantly higher than it is in HICs, the exception being the USA that actually tops the list of disaster-prone countries. Size of territory must play an important part in this ranking, but Nepal, with a land area approximately the same size as England and Wales combined, for example, suffers frequent deadly and damaging impacts from earthquakes, landslides, floods and debris flows.

Although the majority of questionnaire respondents quoted a lack of trained and experienced staffing resources as being a significant constraint, this factor is probably most pertinent in LMICs and especially LICs. Financial resources are also a constraint, and it is probably the case that many LMICs have less access to the information and communication technology that most HICs have. Highway authorities in LMICs therefore probably have the most to gain from enhanced procedures and capability in RIA. Financial constraints might not reflect how a highway authority spends its money but may be more indicative of the resources made available to it from central government.

Despite these considerations, enhanced RIA need not be reliant on significant financial investment. As this report has demonstrated, good RIA is governed by preparedness, anticipation, co-ordination and pre-prepared systems of damage data collection, impact assessment and peer-reviewed, informed decision-making over emergency works prioritisation and programming. It is recommended, therefore, that highway agencies operating in LMICs carry out an audit of their existing procedures and, together with their emergency response and critical infrastructure partners, consider how best to optimise the following:

- Preparedness and response co-ordination within a multi-agency emergency management central command that defines responsibilities and roles, collects, validates and disseminates damage and impact information across a range of critical infrastructure sectors, including highways
- Compilation of all available information, including historical records, maps and maintenance crew experience to identify vulnerable locations, structures and sections of the road network. Use this information, together with an assessment of network criticality to optimise the location of emergency supply depots for plant, construction materials, fuel etc
- Establishment of standard operating procedures (SOPS) within district and regional offices for mobilising damage inspection teams, including the use of exercises or drills to ensure efficiency and safety. If contractors are relied upon in the case of emergency, make sure they work to quality-controlled SOPS and brief the highway authority on damage and road closure conditions in as close to real-time as possible

- Establishment of standard damage data recording systems (electronic or hardcopy) that record sufficient data to allow an immediate assessment of functionality before moving on to the next location. The purpose is to determine whether a location, section of road or structure remains serviceable. If it does not, outline what is required to reinstate serviceability, both temporarily and long-term (if different). Estimate the time required, approximate quantities and whether specialist assessment is required before reinstatement can proceed
- Recording of any third-party assets located within the right of way or adjacent to it that have been affected or might become affected
- Relay this information to the headquarters emergency centre as quickly as possible. If using electronic data recording, this can be in real-time if electronic communication systems allow. If paper-systems are used, then these should be scanned and sent electronically at the first available opportunity
- All field data collection will need to take place in full co-operation with the emergency services, and damage and road closure data should be relayed to the multi-agency central command to inform collective situational awareness
- The highway authority's emergency centre should be emergency-ready at all times. It should be able to receive and assimilate incoming damage data from multiple survey teams. It should be able to rapidly visualise the distribution of damage and road closure and assess its spatial impact. It can do this using the highway network shapefile, information on traffic volumes, network link criticality, the availability and condition of detour options, emergency supply depots and their sufficiency, the location of critical infrastructure, such as hospitals and fire stations, the location of vulnerable communities and the need to maintain and restore lifeline service routes. GIS and RIA software can be used to expedite this process. Otherwise, manual (heuristic) assessment should be used. Both methods require peer review, i.e. quality-controlled decision-making.
- The emergency centre should then prioritise emergency implementation works and develop an emergency action plan and programme accordingly.

To conclude, a fully-functioning and effective RIA does not need to be technology-driven. It can rely on established and proven procedures. These procedures include organisational preparedness, multi-agency cooperation and data sharing, staff training and staff preparedness, streamlined damage data collection carried out according to standard operating procedures and centralised assessment of impact, leading to informed decision-making over prioritisation and emergency action plans. However, as Figure 7.2 shows, communications technology and the ability to collate and visualise multiple spatial datasets means that data recording, transmission and impact analysis can be supported and made more time-effective using the ever-increasing functionality of hardware and software products.

Based on the guidelines contained in Section 7, Table 8.1 outlines a field data collection sheet that could be applied during the Preliminary Damage Assessment, and possibly the Fast Reconnaissance stage, depending on circumstances. It is more amenable for use in a paper-based system, and would need reformatting if applied electronically. There is a focus in the data collection sheet on landslide and flood hazards, and its content and design would need to be adjusted to reflect the highway assets, neighbouring infrastructure and hazard exposure of each particular highway authority. A similar sheet developed for local highway authorities in England, for example, is shown in Annex 3 provided by the UK Road Leadership Group Climate Adaptation Subboard.

Date:	**Time**:		**Inspector name**:		**Road name/ number**:				**Chainage**:		**GPS UTM Coordinates**:		
Cause of damage:	Landslide				Cross-road drainage hazards		Floodwater inundation	River scour	Coastal flooding	Earthquake	Wind	Other (pls specify)	Length of road affected
	From above		From below		Flooding	Debris flow							
	Cut slope	Hillside	Fill slope/ embankment	Hillside									

Asset type	**Asset inventory number**	**Construction type**	**Structural element**	**Extent of damage**				**Safety of use**		**If unsafe, can temporary measures be implemented to enable safe access?**			
				Slight	Moderate	Major	Total	Safe	Unsafe	Yes			No
										Type of measures	Approx quantities	Approx time to open road	Specialist input to DDA 1. Geotechnical 2. Structural 3. Hydrologist, 4. Other
Bridge			Piers										
	Waterway blocked		Abutments										
	Waterway partly blocked		Superstructure										
Culvert			Inlet										
	Waterway blocked		Outlet										
	Waterway partly blocked		Structure										
Retaining wall			Foundations										
	Above Rd	Below Rd	Structure										
River training			Structure										
Carriageway	Blocked	Partly blocked	Undermined/ failed	Partly undermined									
Traffic control and public safety measured required													
3rd-part (non-highway) assets damaged/at risk													
Other facilities and critical infrastructure affected by road closure													
Available detours and their feasibility													
Damage impact rating by inspector (1-5, 1 highest)			**Justification and further observations**										

Table 8.1 Indicative damage data collection sheet

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ANNEX 1 : SUMMARY OF QUESTIONNAIRE SURVEY REPLIES

This is a summary of the outcome of a questionnaire survey conducted as part of the PIARC – World Road Association Special Project on Rapid Impact Assessment for Hazard Management on National Road Networks from September to August 2024. All national or state road authorities who are members of PIARC or linked to the organisation through national coordinators were invited to complete the survey online. The Word version of the questionnaire is copied below and the summary of responses is provided in the remainder of the Annex. For obvious reasons, this summary only refers to those questions (requiring Yes/No and tick box answers) that are able to be summarised, and excludes those requiring written answers.

Permanent International Association of Road Congresses (PIARC) Special Project: Rapid Impact Assessment for Hazard Management on National Road Networks

i. Please note that all information provided will be collated as part of a combined database and will be use anonymously. If we choose to use your response as an example of good-practice we will contact you beforehand for permission to do so.

ii. Please note that, in this questionnaire a 'hazard' is a cause of damage and disruption. A disaster is the outcome of a hazard where the losses and disruption are very large.

iii. In the context of the road sector, a 'Rapid Impact Assessment' (RIA) is a systematic response methodology defined before a natural or man-made hazard occurs that severely impacts the functionality of the road network or parts of it. It is usually activated within the first 24 hours of an emergency occurring. An RIA obtains a rapid and broad picture of the extent of the damage suffered to help define and prioritise initial response activities. It includes an immediate assessment of the condition of the road network and the affected sections, the services that it can offer safely immediately post-disaster and the prioritized works and budgets needed for repairs and restoration. It also helps identify where and when more detailed forms of assessment may be needed, such as detailed structural assessments and recovery needs.

iv. This questionnaire is expected to take 15-20 minutes to complete. Please answer all questions as fully as you can.

1. Country:

2. Authority Name (if applicable):

3. Name of person completing this form:

4. Date:

5. Position of person completing this form:

6. Email address:

7. Please indicate the significance of the natural hazards listed below to the operation of your road network. Please add any additional hazards not listed, with their significance.

No	Hazard	None	Low	Moderate	High	V. High
1	Landslide	○	○	○	○	○
2	Rainfall-induced floods	○	○	○	○	○
3	River scour	○	○	○	○	○
4	Coastal floods/tsunamis	○	○	○	○	○
5	Coastal erosion	○	○	○	○	○
6	Glacial Lake Outburst Floods	○	○	○	○	○
7	Debris flow	○	○	○	○	○
8	Earthquake	○	○	○	○	○
9	Snow drift	○	○	○	○	○
10	Snow avalanche	○	○	○	○	○
11	Fire	○	○	○	○	○
12	Wind (i.e. tornado/hurricane)	○	○	○	○	○
13	Man-made: collision[1]	○	○	○	○	○
Other 1		○	○	○	○	○

No	Hazard	None	Low	Moderate	High	V. High
Other 2		○	○	○	○	○
Other 3		○	○	○	○	○
Other 4		○	○	○	○	○
Other 5		○	○	○	○	○

[1]This would include, for example, the bridge collapse due to shipping impact in Maryland, USA in March 2024

8. Do you maintain records of hazard impact on your road network?

◉ Yes

○ No

If yes, how long have you been collecting this data (please provide first year of collection and the type of data you collect)?

9. If your answer to 8 was yes:

9a. Is this data publicly-available?

○ Yes

○ No

9b. Do you share this data with other hazard/disaster response stakeholders? (e.g. Emergency Services, relief agencies, NGOs etc)

◉ Yes

○ No

10. Do you collaborate with emergency service providers and other disaster management stakeholders? (e.g. Emergency Services, relief agencies, NGOs etc):

10a. Before a disaster, i.e. as a means of preparedness?

(●) Yes
( ) No

10b. After a disaster, as part of an integrated response?

( ) Yes
( ) No

If you answered yes to 10a or 10b, how do you collaborate, e.g. financially, human and plant resource sharing, information-sharing?

11. Do you have hazard susceptibility maps or other documents and historical impact datasets that you rely on to indicate which parts of your network are most vulnerable so that you are more prepared when a hazard occurs?

( ) Yes
(●) No

If yes, please elaborate (e.g. scale, content, source etc):

If no, would you consider such documentation useful?

( ) Yes
( ) No

12. Do you use satellite imagery and GIS to help identify hazard-prone parts of your network? This might include areas subject to flood risk, landslides and snow drift, for example.

( ) Yes
( ) No

If yes, please elaborate:

If no, would you consider such a system useful?

Yes

No

13. Do you stockpile resources and plant in strategic locations for use in response to emergencies?

Yes

No

14. In the event of a hazard occurring, do you have set procedures for recording impact data? These will include inventories of the location, type and extent of damage and other forms in a pre-determined format.

Yes

No

If yes:

Are these forms filled in manually or electronically (in an app for example) by smartphone or tablet?

Manually

Electronically

How is this information transmitted and analyzed? For example, is impact data directly uploaded to regional or central HQ via a web-enabled system? Please elaborate on the system used.

Is this information shared automatically with other disaster management stakeholders, such as relief agencies, NGOs and the Emergency Services?

Yes

No

If yes, how is it shared?

15. Have you developed a standardized Rapid Impact Assessment procedure that you systematically use after each disaster to assess impacts and prepare service restoration and reconstruction works, as needed?

- ○ Yes
- ○ No

If yes, please describe the procedure:

16. Do you use Rapid Impact Assessment software?

- ○ Yes
- ○ No

If yes, has this software been developed in-house or is it purchased?

- ○ In-house
- ◉ Purchased

If purchased, which software do you use?

17. How do you monitor progress of RIA and emergency response and the performance of the emergency works?

18. Do you carry out regular disaster response exercises/drills?

- ○ Yes
- ◉ No

19. Please list your priority actions in the event of a disaster, placing the highest priority first:

1.

2.

3.

4.

5.

6.

20. Do you use satellite imagery to collect hazard impact data?

- ○ Yes
- ○ No

If yes, which imagery do you use?

21. Do you use drones (UAVs) to help in data collection during the Rapid Impact Assessment?

- ◉ Yes
- ○ No

If yes, do you collect the following from UAVs?

21a. Photographs

- ○ Yes
- ○ No

21a. Videos

- ○ Yes
- ○ No

21c. LiDAR or other

- ○ Yes
- ○ No

If you have answered Yes to 21a to 21c please describe how you analyze this information?

22. Do you employ sensors, cameras, GPS, automated signaling and other Intelligent Transportation Systems to monitor and regulate traffic flow during emergency conditions?

○ Yes

○ No

If yes, please elaborate:

23. Generally, when a disaster occurs, which of the following methods do you rely on for collecting Rapid Impact Assessment data? Please assign a percentage to each.

23a. Field observations and reports %

23b. Satellite information %

23c. Drone information %

23d. Media-shared information %

23e. Crowd-sourced information %

23f. Use the data compiled by Provincial and Local Government agencies %

The total percentage must equal 100%. Now it is %.

24. How do you determine the immediate emergency works (e.g. length of road to be constructed, volumes of cut and fill, length and height of retaining wall, number and length of temporary bridges) that need to be implemented to reinstate access and make the affected location(s) safe?

25. How do you prioritize these measures, i.e. link by link and/or location by location?

☐ link by link

☐ location by location

26. Do you carry out hazard and risk assessment as part of the prioritizations?

○ Yes

◉ No

If yes, how do you assess/calculate hazard and risk?

27. If your answer to 26 was yes, do you include traffic volumes, roadside communities and public safety in the assessment/calculation of risk?

Yes

No

If yes, please describe how you determine risk?

28. How do you determine the costs of the measures that need to be implemented as part of the emergency works?

29. What topographic data do you use to help determine quantities for emergency response costing purposes?

30. Would you be willing to engage in email correspondence or a zoom meeting so that we can collect further information from you?

Yes

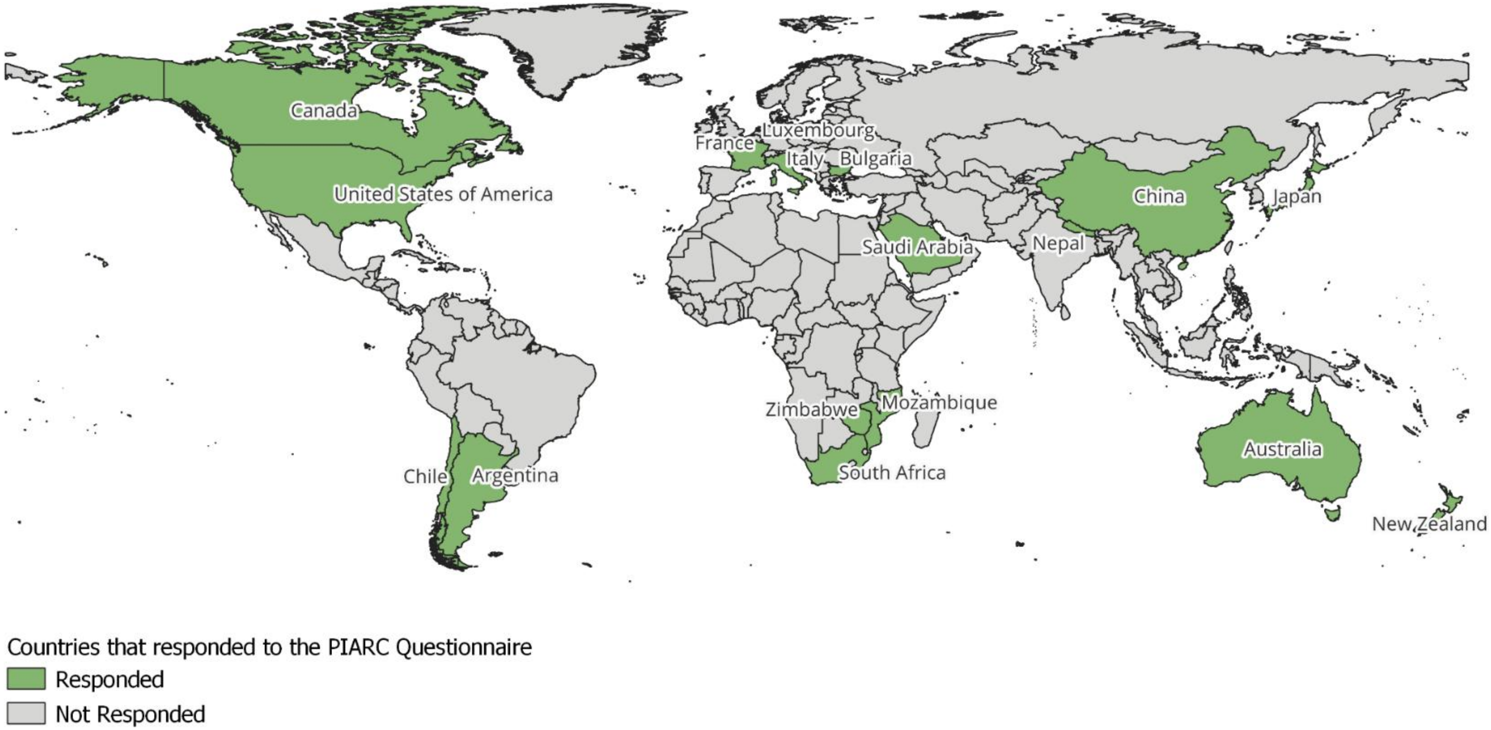
No

31. Finally, what are the main challenges your agency faces when assessing highway damage and response/ recovery needs during emergency situations? Please assign a rank against each challenge below, with a rank of 1 against the greatest challenge.

Response	Rank
Travel to the affected section of the road network	
Safe access to the damaged section or structure for inspection	
Insufficient number of qualified/trained inspectors	
Communications	
Limitations on technology for assessment	
Coordination with other agencies	
Lack of published procedures	
Insufficient resources	
Insufficient skills	
Other (please specify)	

☐ I confirm I have given correct information based on my knowledge and expertise.

In total, there were responses from 17 countries. The map and table below show the countries and organizations from which the responses were collected. Altogether there were 25 questionnaires completed. The reply received on behalf of Local Highway Authorities in England arrived too late to be included.



Country	Organization
Argentina	National Road Directorate
Australia	Department of Transport and Main Roads (DTMR)
Bulgaria	Road Infrastructure Agency
Canada	British Columbia Ministry of Transportation and Infrastructure
Canada	Transport Canada – Pacific Region
Canada-Quebec	Ministry of Transport and Sustainable Mobility
Chile	Roads Administration (DoR)
China	Southwest Jiaotong University (TC1.5_Working Group 3)
China	The Inner Mongolia Transportation Department
France	French Ministry for Transports
Italy	ANAS
Japan	Disaster Prevention Div., Safety, Disaster Prevention and Engineering Dept. Honshu-Shikoku Bridge Expressway Company Limited
Luxembourg	National Road Administration
Mozambique	National Roads Administration (ANE-IP)
Nepal	Department of Roads
New Zealand	New Zealand Transport Agency (NZTA)
Saudi Arabia	Unstated, possibly a consultant to road authority
South Africa	South African National Roads Agency Limited
United States	Missouri Department of Transportation
United States	Alaska DOT&PF
United States	Minnesota Department of Transportation
United States	ALDOT

United States	Arkansas Department of Transportation
United States	California Department of Transportation
Zimbabwe	Ministry of Transport and Infrastructural Development

7. Please indicate the significance of the natural hazards listed below to the operation of your road network. Please add any additional hazards not listed, with their significance.

Significance of Natural Hazards to Road Network Operations

Natural Hazards	V. High	High	Moderate	Low
Landslide	7	8	6	4
Rainfall-induced floods	8	12	3	1
River scour	1	8	9	5
Coastal floods/tsunamis	6	2	4	5
Coastal erosion	0	6	6	5
Glacial Lake Outburst Floods	2	2	4	2
Debris flow	9	3	5	3
Earthquake	6	6	1	8
Snow drift	3	3	4	9
Snow avalanche	3	3	4	6
Fire	2	8	7	6
Wind (i.e. tornado/hurricane)	4	4	10	6
Man-made: collision1	6	4	6	5
Collision With Elevated Bridges.	0	0	0	1
Collision With Guardrail On River Bridges.	0	0	0	1
Erosion	1	0	0	0
Extreme Heat	0	0	1	0
Extreme Heat Causing Pavement Buckling	0	0	1	0
Flow Overtopping	0	1	0	0
Forest Fire	0	0	1	0
Freshet (Seasonal Flooding Due To Winter Snow Melt)	0	1	0	0
Human-Caused Fires	0	1	0	0
Ice Accumulation	0	1	0	0
Ice Storms	1	1	0	0
Ice/Frost	0	1	0	0
Lightning Strikes	0	0	0	1
Muds	0	0	1	0
Rainstorm	0	1	0	0
Sand Storm	0	1	0	0
Severe Winter Conditions	1	0	0	0
Space Weather	0	0	0	1
Typhoon	0	1	0	1
Volcanic Activity	2	1	0	0
Water Puddles	0	1	0	0
Wildfires	0	0	1	0

Legend
0
1
2
3
4
5
6
7
8
9
10
11
12

The heat map visualizes the significance of various natural and man-made hazards to road network operations. Each row represents a different hazard, while the columns categorize their impact levels as “Very High,” “High,” “Moderate,” and “Low.” The colour intensity in each cell reflects the number of occurrences or importance of each hazard at that impact level.

If the ‘Very High’ hazards are summed from each questionnaire, the following order of significance is obtained: debris flows, rainfall-induced floods; earthquakes; landslides; coastal flooding and tsunamis; snow avalanches; snow drifts, wind and glacial outburst floods; and fire. However, one respondent’s opinion as to what constitutes ‘Very High’ may differ from the next, depending on circumstances. Consequently, those hazards identified as having the highest significance in each case were summed and the following order of significance was obtained: rainfall-induced floods; landslides; debris flows; wind; earthquakes and coastal flooding and tsunamis; fire; snow avalanches and snow drifts, followed by other hazards with only 1 or 2 cases. To conclude, rainfall-induced floods, landslides and debris flows are the most significant.

The heat map visualizes the significance of various natural and man-made hazards to road network operations. Each row represents a different hazard, while the columns categorize their impact levels as “Very High,” “High,” “Moderate,” and “Low.” The colour intensity in each cell reflects the number of occurrences or importance of each hazard at that impact level.

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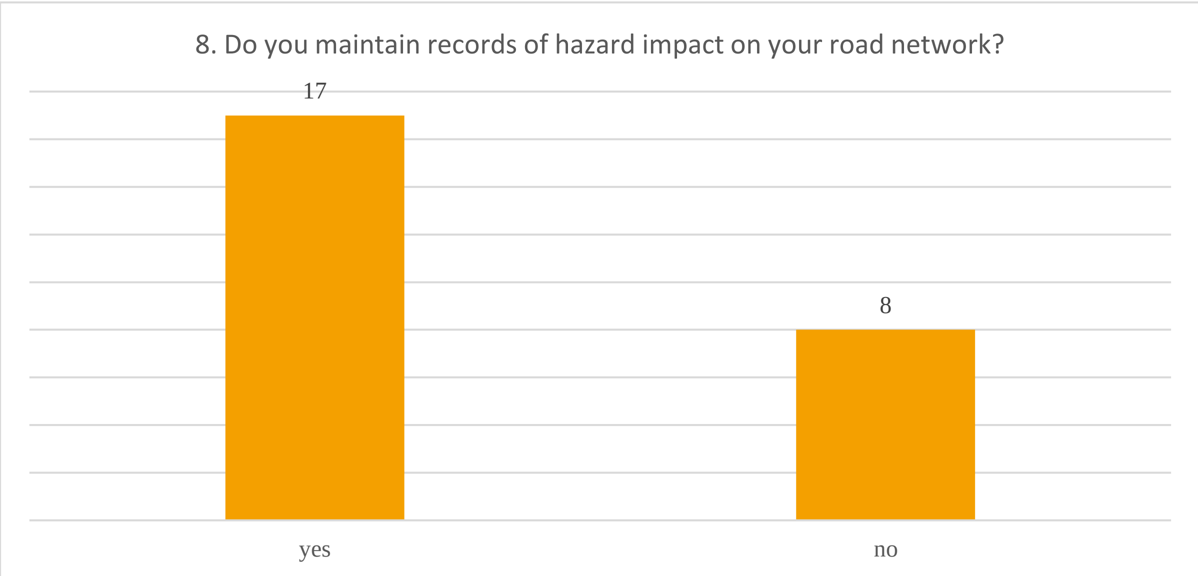
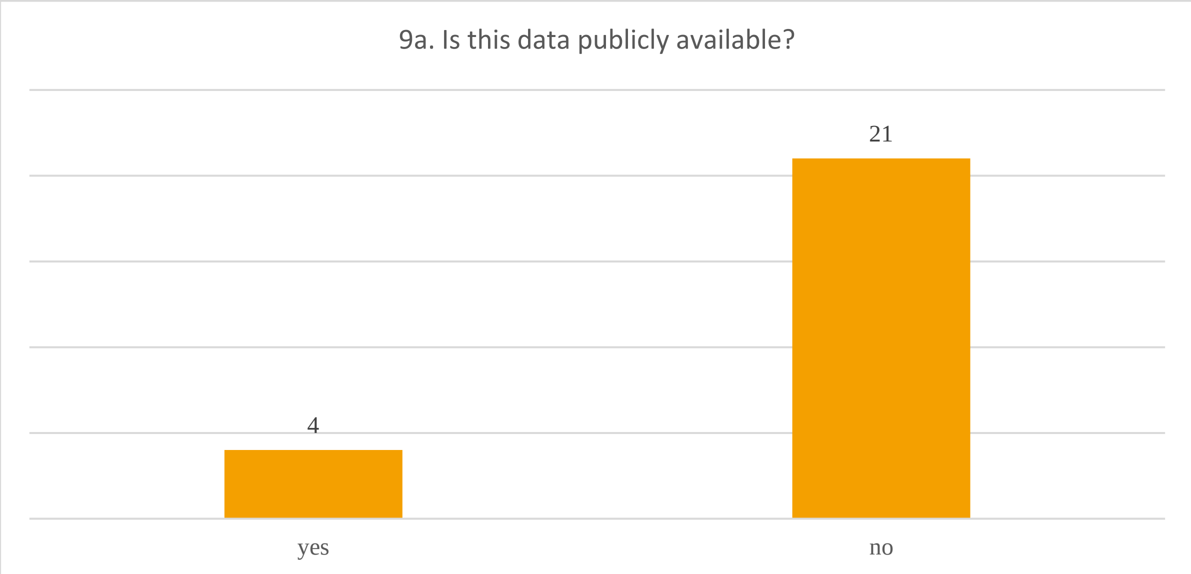
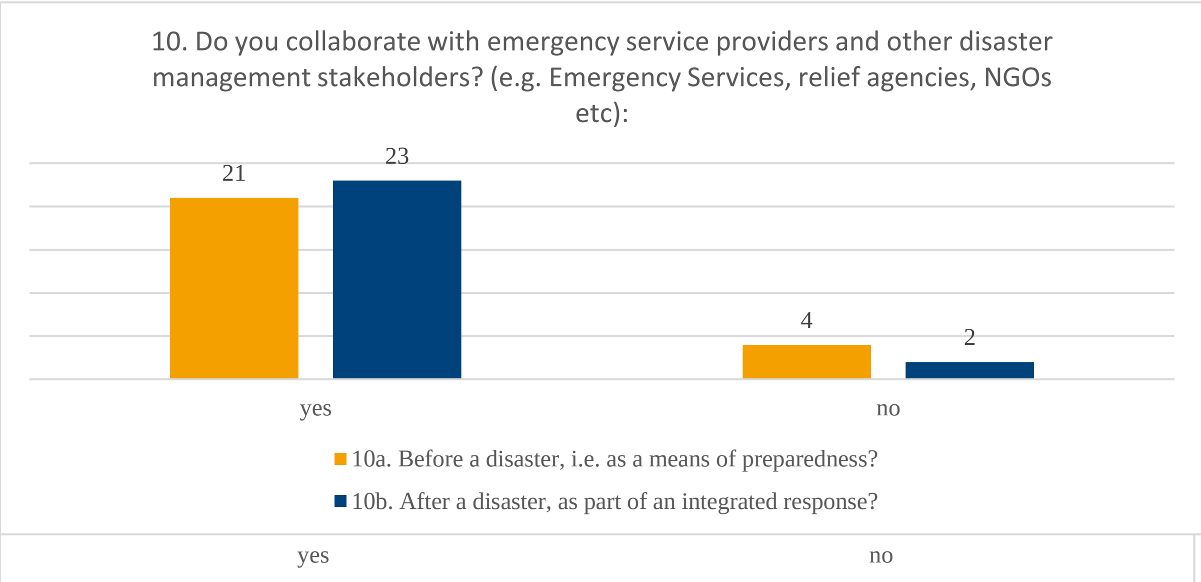
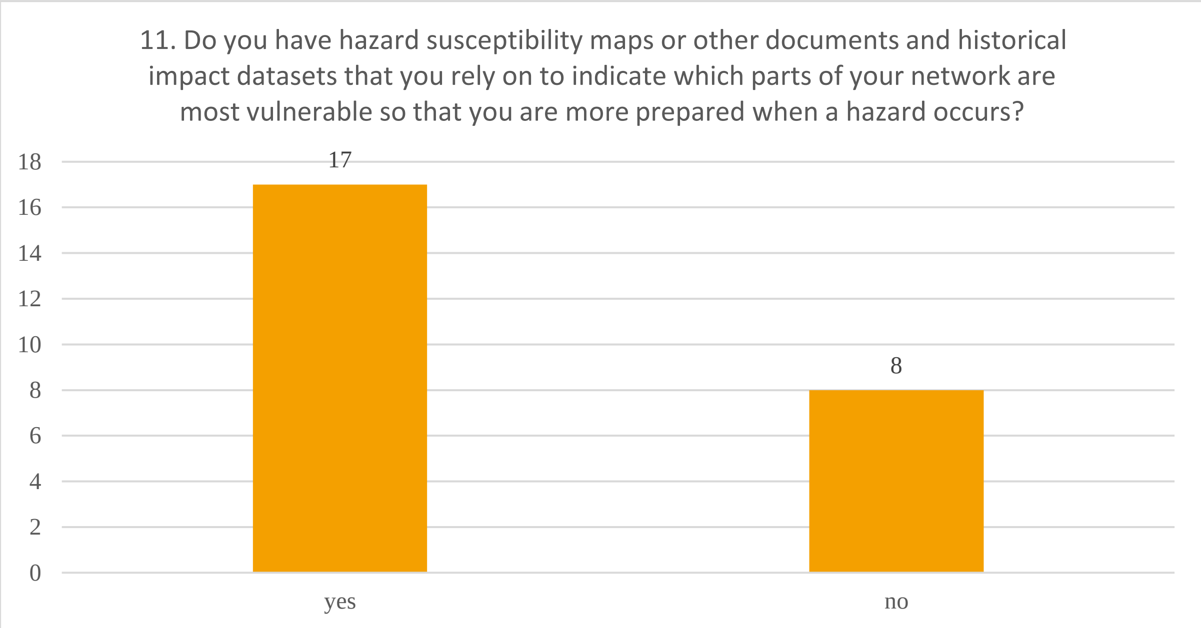
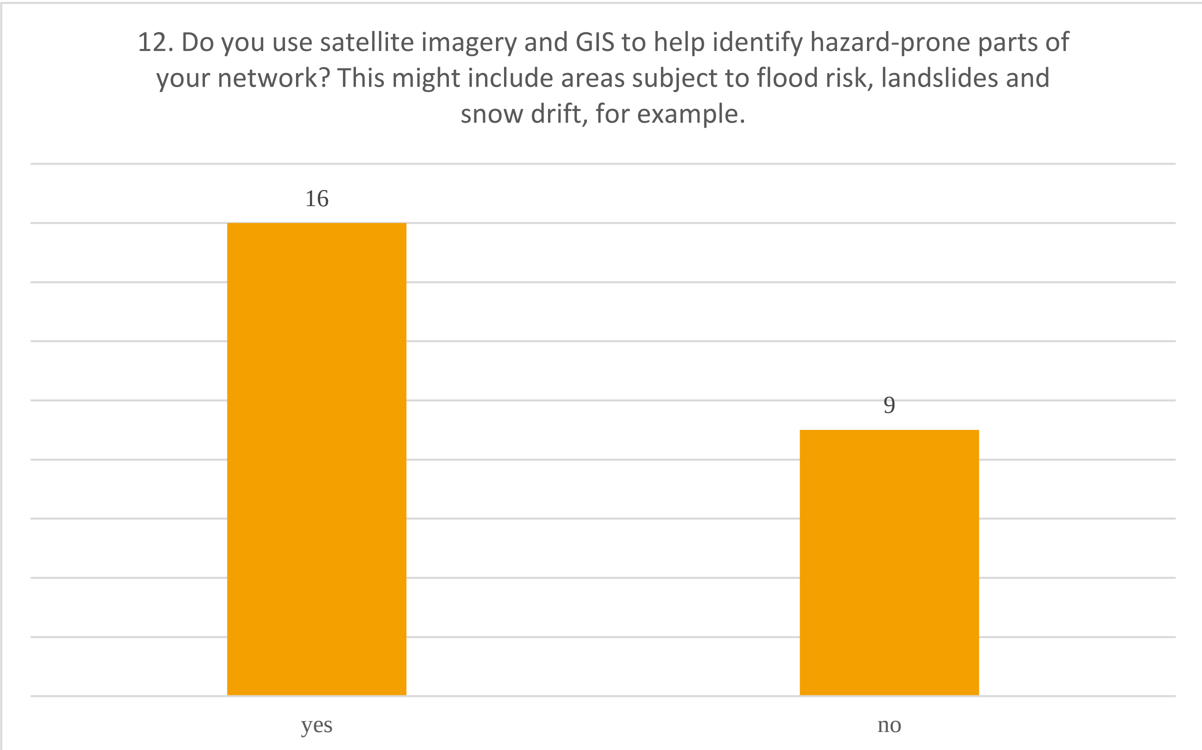
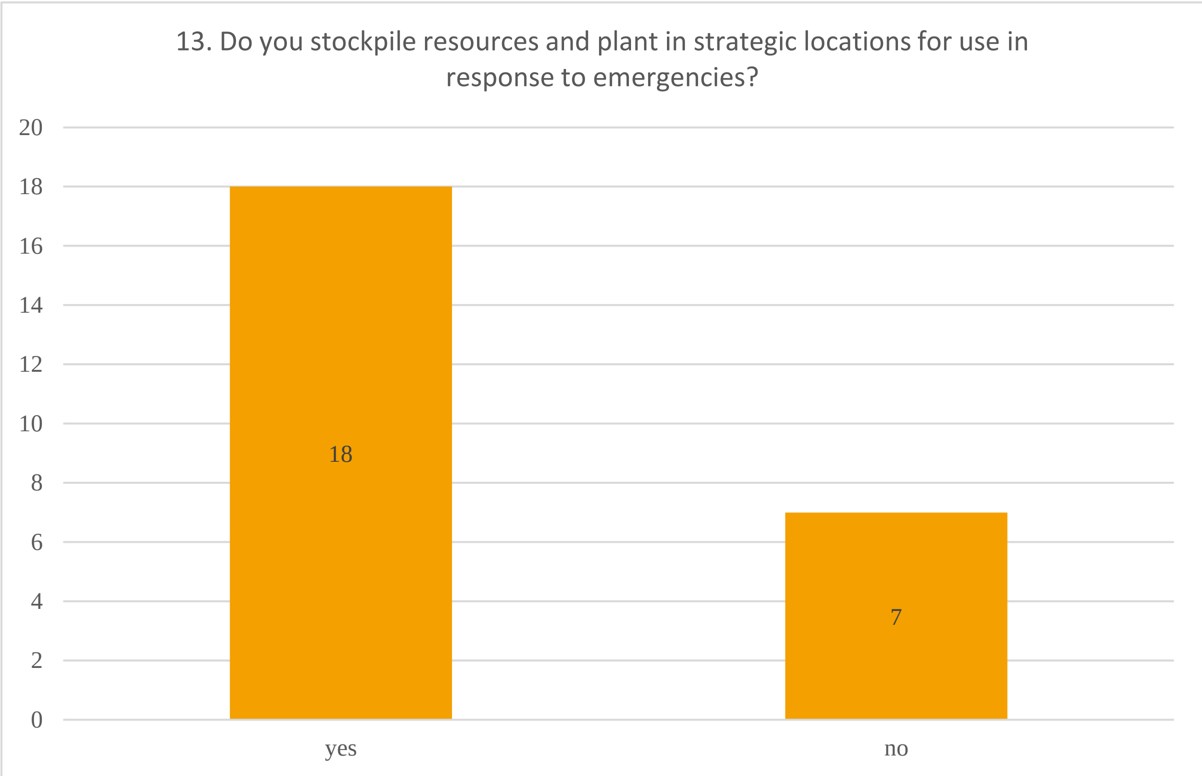


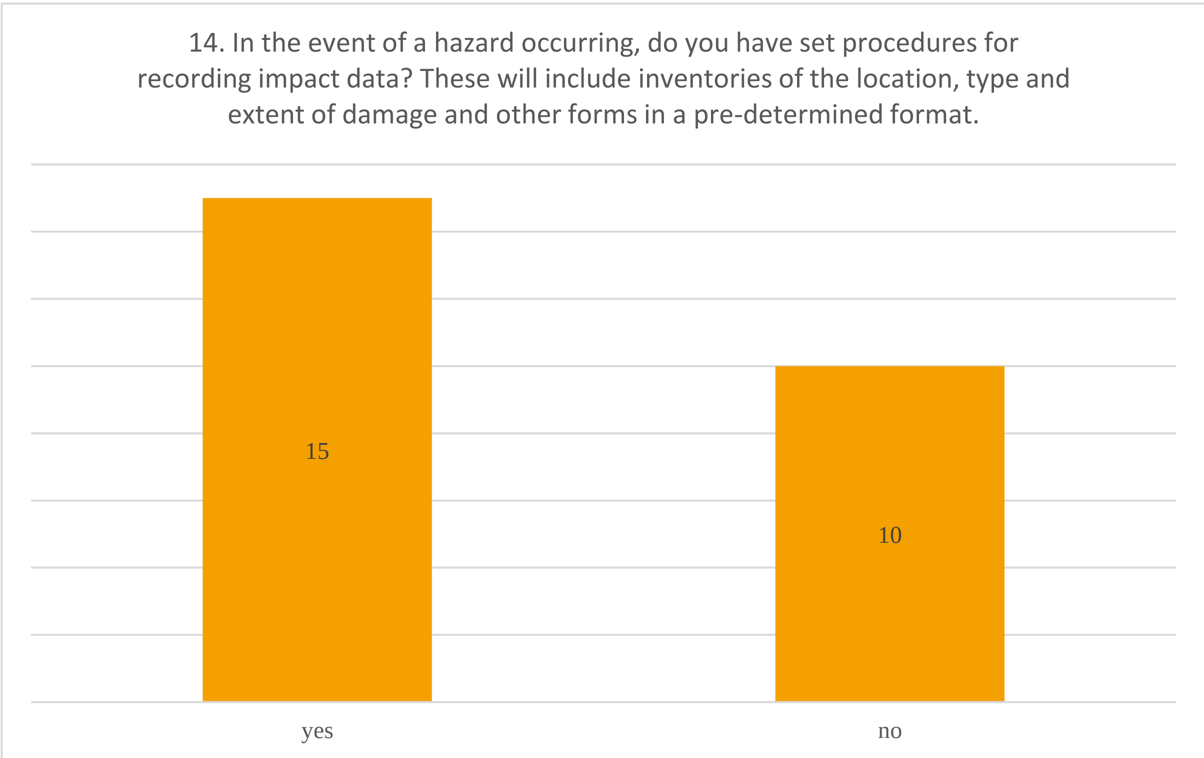

9a. Is this data publicly available?
4
21
yes
no


10. Do you collaborate with emergency service providers and other disaster management stakeholders? (e.g. Emergency Services, relief agencies, NGOs etc):
21
23
4
2
yes
no
10a. Before a disaster, i.e. as a means of preparedness?
10b. After a disaster, as part of an integrated response?
yes
no

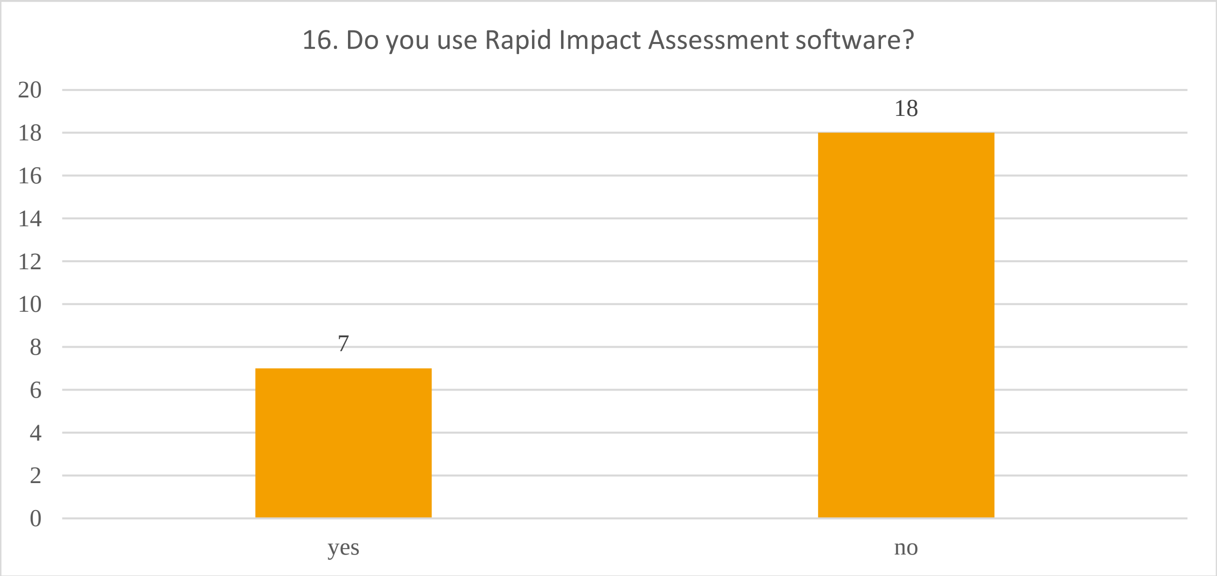

11. Do you have hazard susceptibility maps or other documents and historical impact datasets that you rely on to indicate which parts of your network are most vulnerable so that you are more prepared when a hazard occurs?
18
16
14
12
10
8
6
4
2
0
17
8
yes
no

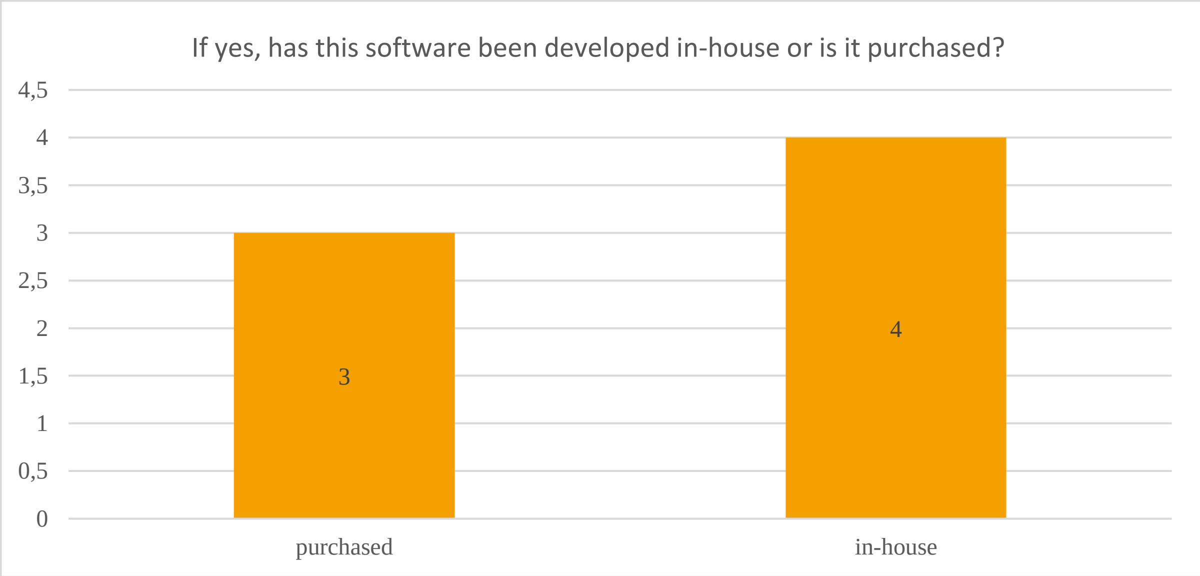

12. Do you use satellite imagery and GIS to help identify hazard-prone parts of your network? This might include areas subject to flood risk, landslides and snow drift, for example.
16
9
yes
no


13. Do you stockpile resources and plant in strategic locations for use in response to emergencies?
20
18
16
14
12
10
8
6
4
2
0
18
7
yes
no


14. In the event of a hazard occurring, do you have set procedures for recording impact data? These will include inventories of the location, type and extent of damage and other forms in a pre-determined format.
15
10
yes
no

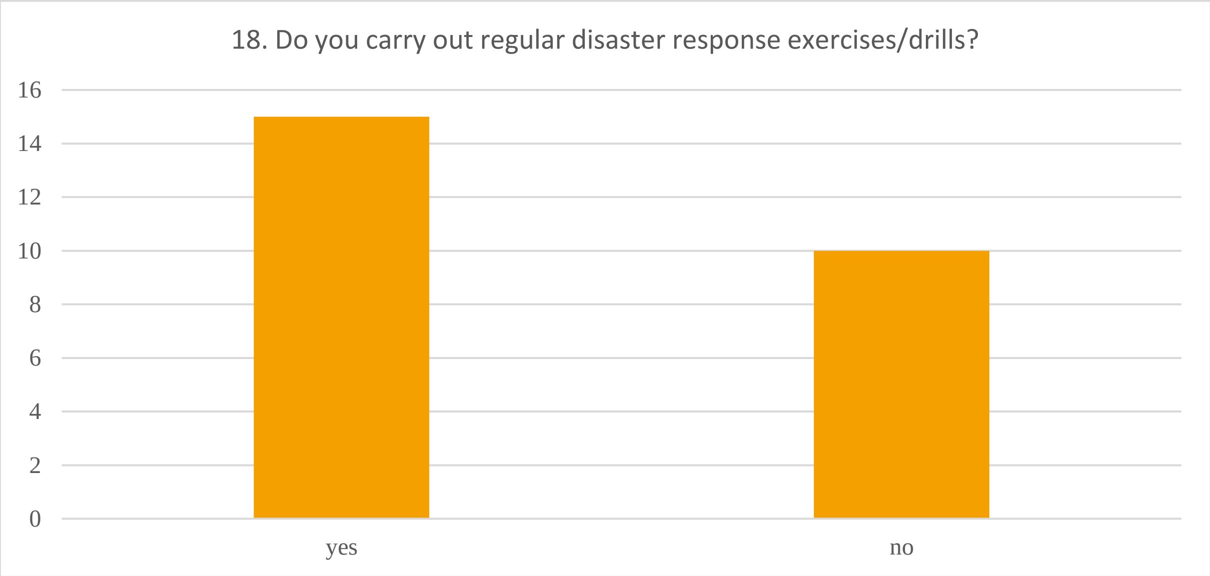

15. Have you developed a standardized Rapid Impact Assessment procedure that you systematically use after each disaster to assess impacts and prepare service restoration and reconstruction works, as needed?
18
16
14
12
10
8
6
4
2
0
8
17
yes
no

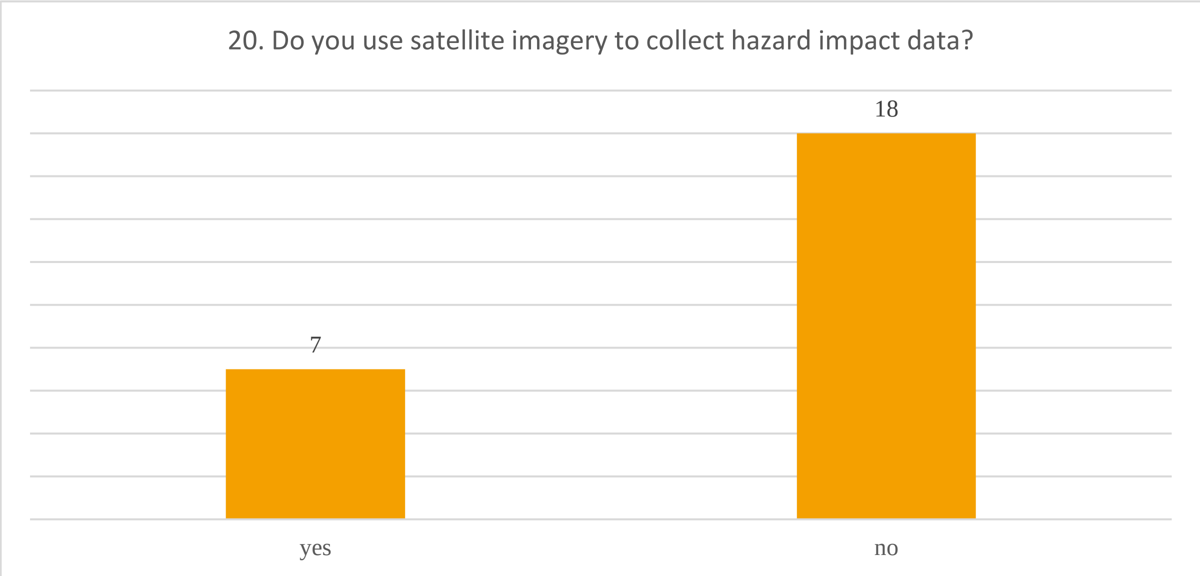

16. Do you use Rapid Impact Assessment software?
20
18
16
14
12
10
8
6
4
2
0
7
18
yes
no

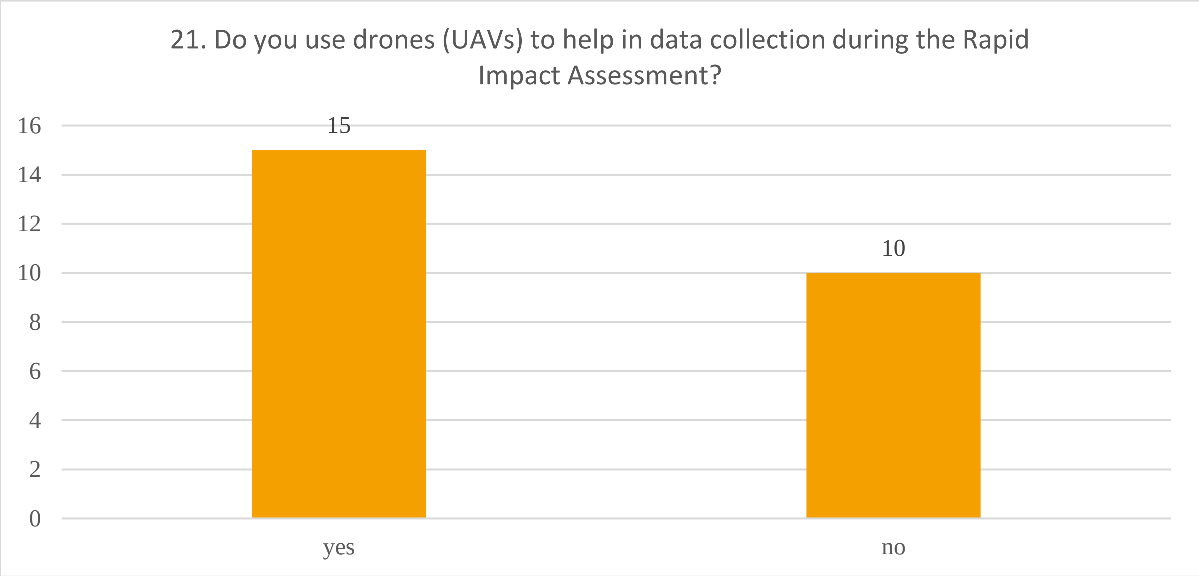


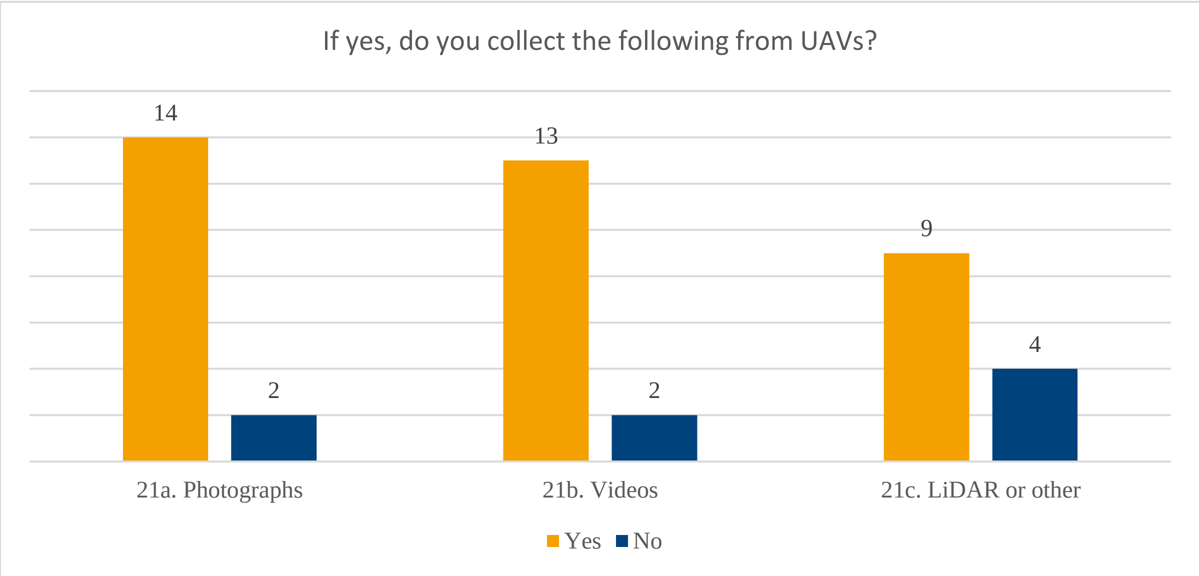
RIA Software currently in use

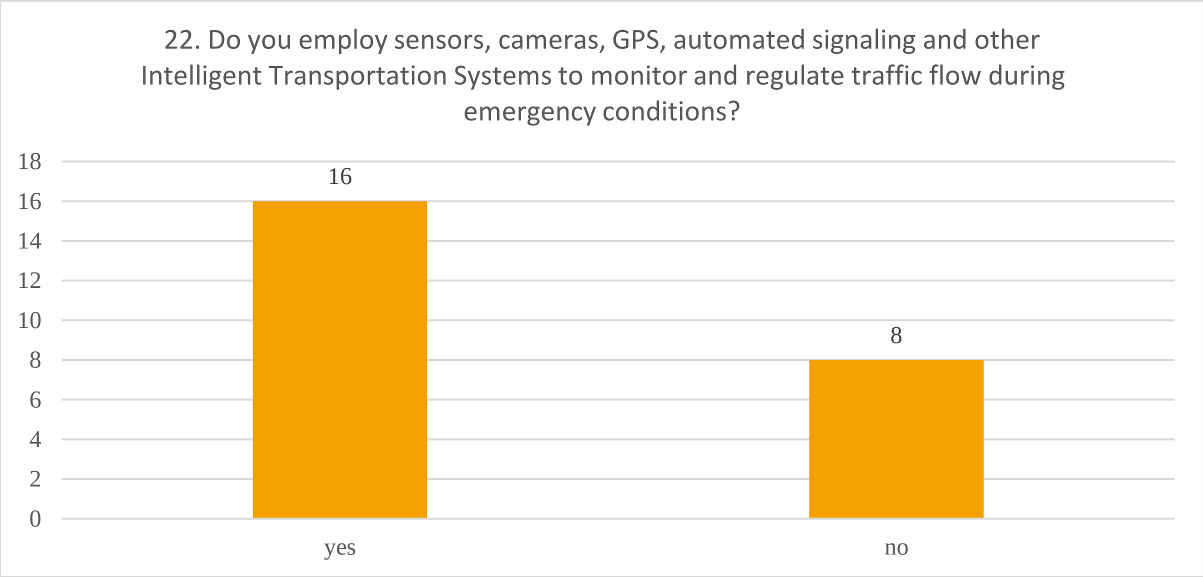
1. RADAR (Recording Asset Damage & Restoration) developed by Gruntify
2. MAXIMO – IBM (world-class EAM system)
3. Orion (Futurity)

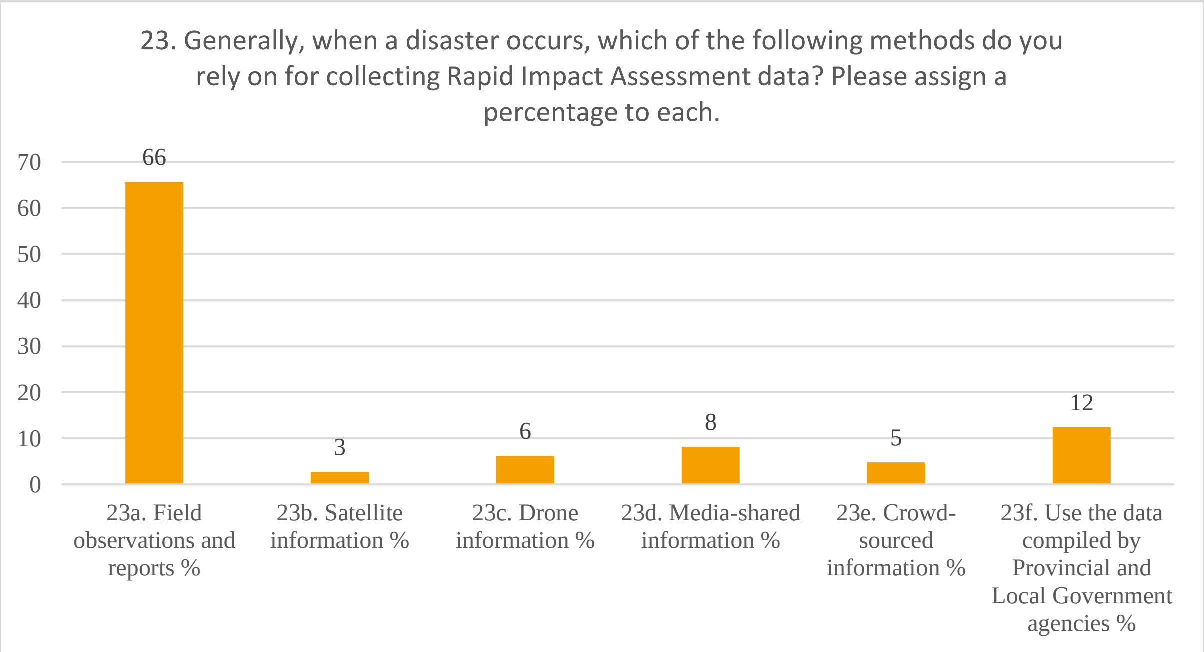

18. Do you carry out regular disaster response exercises/drills?
16
14
12
10
8
6
4
2
0
yes
no

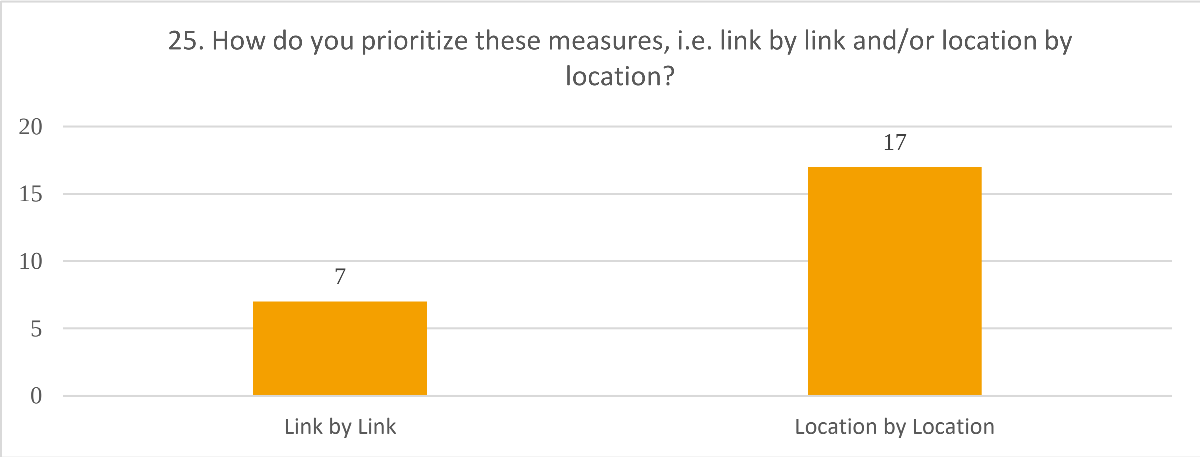

20. Do you use satellite imagery to collect hazard impact data?
18
7
yes
no

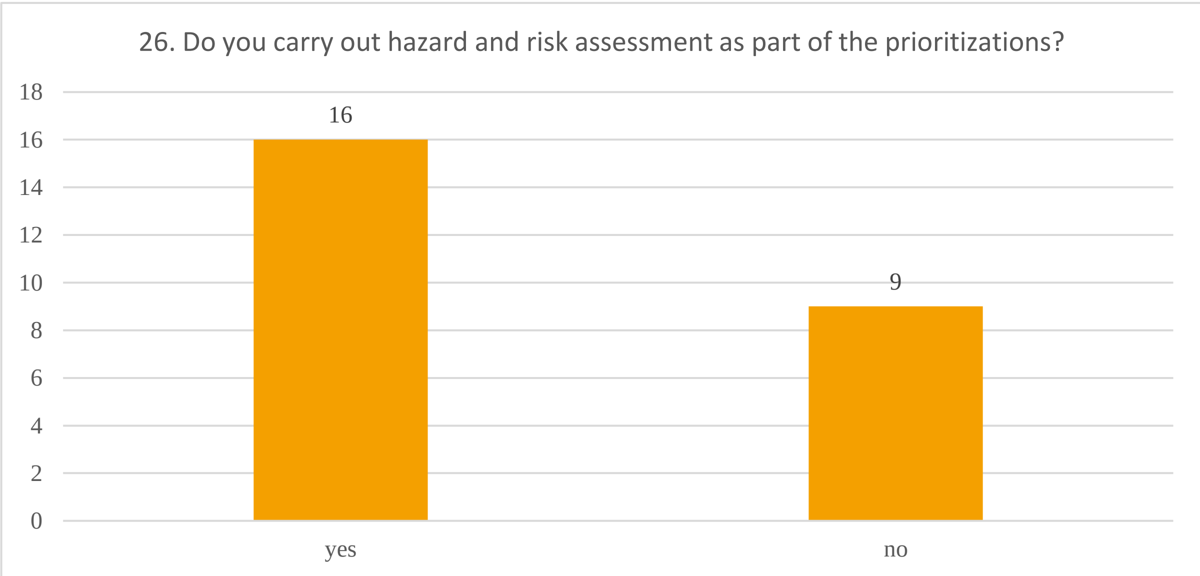

21. Do you use drones (UAVs) to help in data collection during the Rapid Impact Assessment?
16
14
12
10
8
6
4
2
0
15
10
yes
no

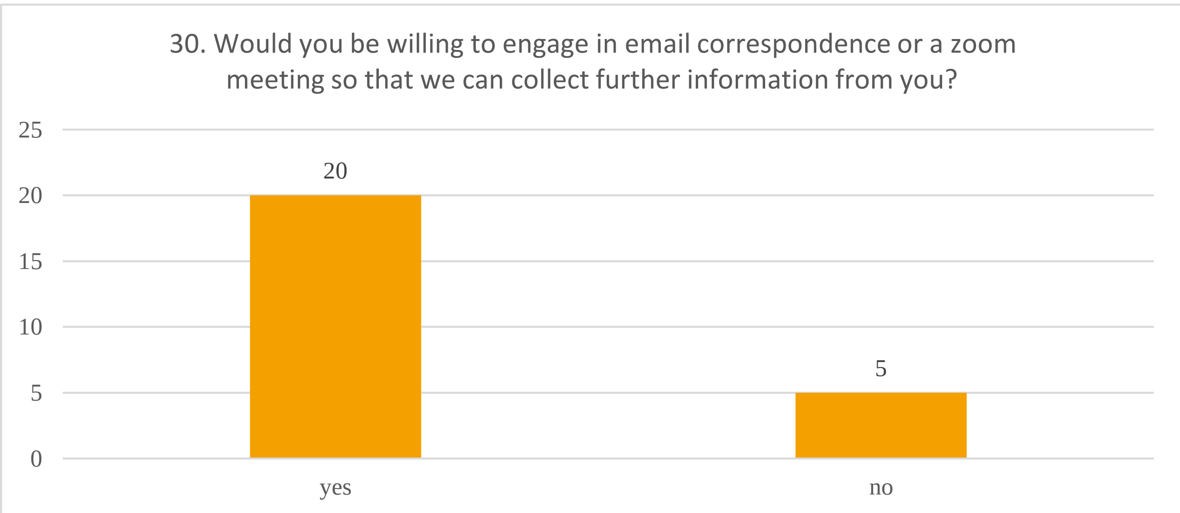

If yes, do you collect the following from UAVs?
14
2
13
2
9
4
21a. Photographs
21b. Videos
21c. LiDAR or other
Yes
No


22. Do you employ sensors, cameras, GPS, automated signaling and other Intelligent Transportation Systems to monitor and regulate traffic flow during emergency conditions?
18
16
14
12
10
8
6
4
2
0
16
8
yes
no

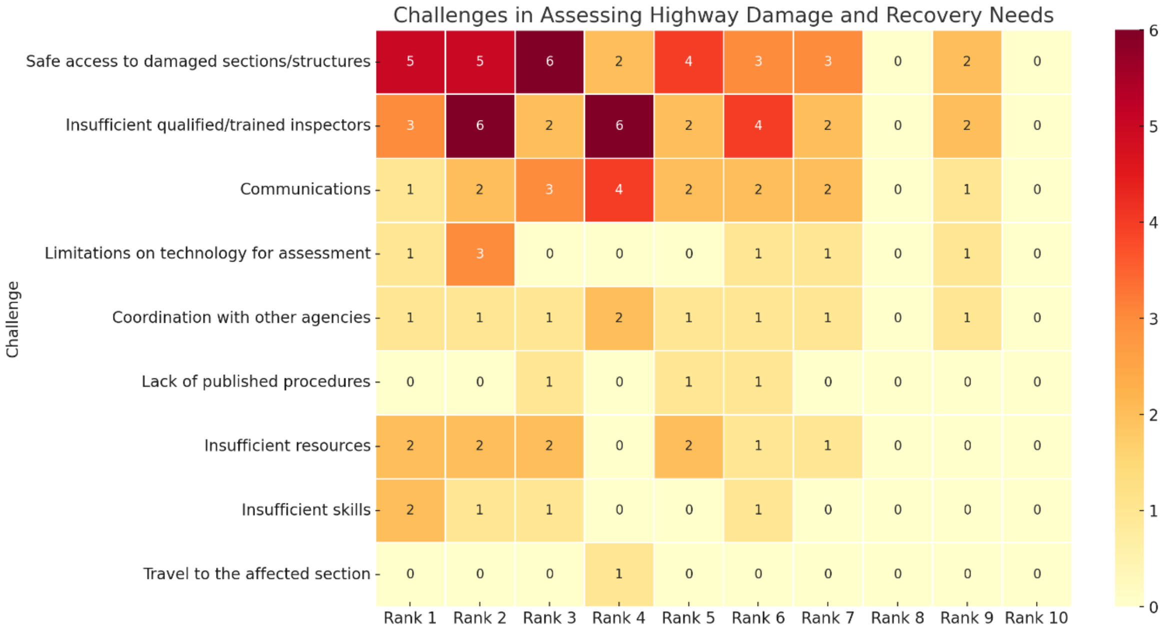

23. Generally, when a disaster occurs, which of the following methods do you rely on for collecting Rapid Impact Assessment data? Please assign a percentage to each.
70
60
50
40
30
20
10
0
66
3
6
8
5
12
23a. Field observations and reports %
23b. Satellite information %
23c. Drone information %
23d. Media-shared information %
23e. Crowd-sourced information %
23f. Use the data compiled by Provincial and Local Government agencies %


25. How do you prioritize these measures, i.e. link by link and/or location by location?
20
15
10
5
0
7
17
Link by Link
Location by Location


26. Do you carry out hazard and risk assessment as part of the prioritizations?
18
16
14
12
10
8
6
4
2
0
16
9
yes
no


30. Would you be willing to engage in email correspondence or a zoom meeting so that we can collect further information from you?
25
20
15
10
5
0
20
5
yes
no

This summary captures the critical challenges faced by agencies during emergency situations, as highlighted by the heatmap.



Challenge	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8	Rank 9	Rank 10
Safe access to damaged sections/structures	5	5	6	2	4	3	3	0	2	0
Insufficient qualified/trained inspectors	3	6	2	6	2	4	2	0	2	0
Communications	1	2	3	4	2	2	2	0	1	0
Limitations on technology for assessment	1	3	0	0	0	1	1	0	1	0
Coordination with other agencies	1	1	1	2	1	1	1	0	1	0
Lack of published procedures	0	0	1	0	1	1	0	0	0	0
Insufficient resources	2	2	2	0	2	1	1	0	0	0
Insufficient skills	2	1	1	0	0	1	0	0	0	0
Travel to the affected section	0	0	0	1	0	0	0	0	0	0

Top Concerns:

Safe Access to Damaged Sections/Structures:

High Priority: Frequently ranked as the most significant issue by multiple agencies, indicating widespread concern.

Overall Impact: Consistently appears across various ranks, showing its critical importance.

Insufficient Qualified/Trained Inspectors:

High Priority: A consistently high-priority issue, especially in the top ranks.

Overall Impact: The need for more qualified inspectors is a recurring concern across different levels.

Moderate Concerns:

Communications:

Moderate to High Priority: Identified as a significant issue, particularly in the middle ranks.

Overall Impact: Its presence across various ranks underscores its importance in emergency responses.

Limitations on Technology for Assessment:

Moderate Priority: Most significant in the second rank, with less impact in other ranks.

Overall Impact: A concern, but not as critical as issues like access and inspector availability.

Coordination with Other Agencies:

Moderate Priority: Identified across multiple ranks, though with less intensity.

Overall Impact: A notable challenge, but generally not the top priority for most agencies.

Insufficient Resources:

Moderate Priority: Particularly a concern in the top ranks.

Overall Impact: Availability of resources is essential for effective emergency responses.

Insufficient Skills:

Moderate Priority: Highlighted in the top ranks, showing the need for sufficient skills.

Overall Impact: Skill shortages impact the efficiency of response efforts.

Lesser Concerns:

Lack of Published Procedures:

Low Priority: Appears minimally, indicating it is not a major concern.

Overall Impact: Agencies may have established procedures or prioritize other challenges.

Travel to the Affected Section:

Low Priority: Least mentioned, indicating it is not a primary concern.

Overall Impact: Travel logistics are a minor challenge compared to other factors.

ANNEX 2: MINISTRY OF PUBLIC WORKS EMERGENCY INFORMATION IN CHILE

Locality: Chile

Status: National regulation

Owner: Ministry of Public Works

Participants: Road Administration

Author: Marcelo MEDINA

Contact: marcelo.medina@mop.gov.cl

Website/links: www.vialidad.mop.gob.cl

CONTEXT

Chilean territory is always affected by natural disasters, due to country location on the rings of fire that causes volcano activity, earthquakes and a geography that generate alluviums during summer time, as well as other types of natural disasters (wild forest fire, floods, mudflows, landslides, snow avalanches, tsunamis, earthquakes, volcano eruptions, tidal waves, waterspout, etc.). These natural disasters cause severe damage to road infrastructure therefore it is important to collect relevant information on the effects on the road network.

SIEMOP (Ministry of Public Works Emergency Information System)

Since 2015 the Chilean Road Administration has collected relevant information about damages and effects on the road network through a computational Close Source System (world class EAM – Enterprise Asset Management) aimed to manage Road Maintenance Information, and as addendum SIEMOP was implemented on the same platform as a dedicated module for emergencies.

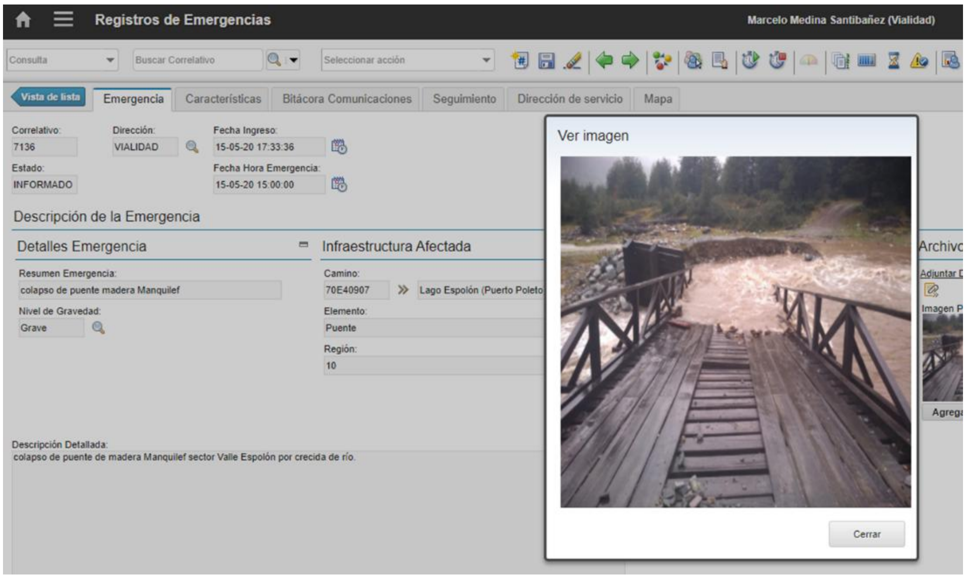


Fig. 1 – Emergency Record on SIEMOP

Closed Source of information allowed us to generate automatically Emergency Maps, with the Emergency Records information, that it is published on internet for road users.

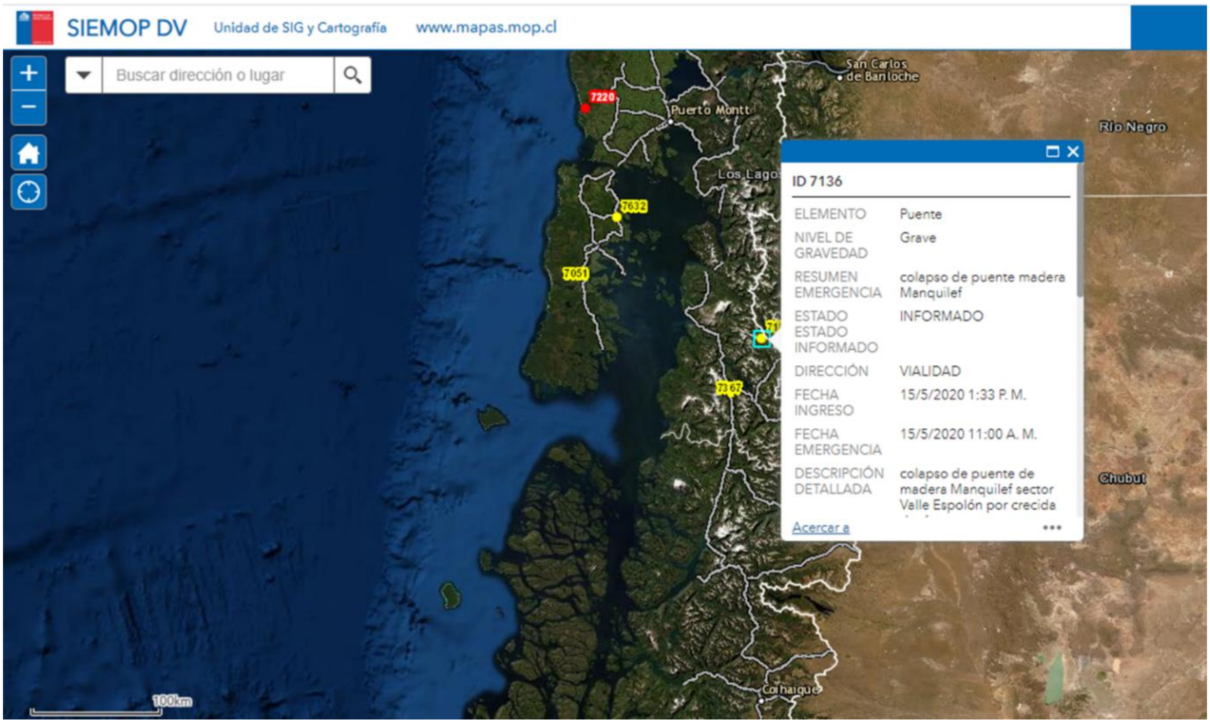
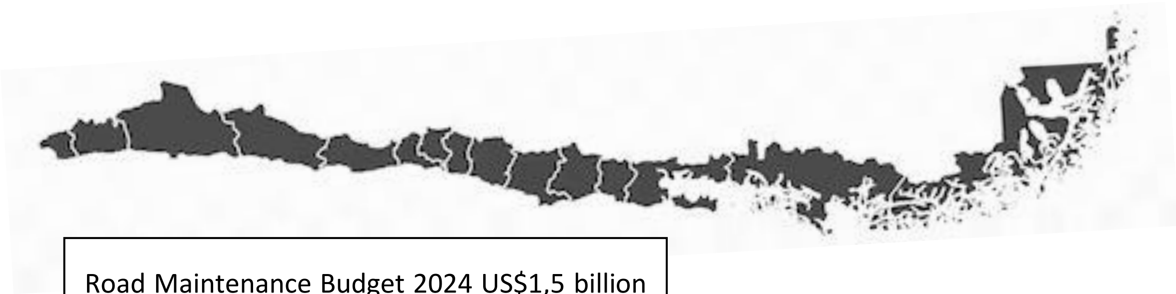


Fig. 2 – Road Administration Emergency Map

Closed Source of information has several benefits, but it is limited due to only Road Administration Agents are allowed to record information.

LINKING PLAN

Chile is divided into 16 regions and each of these regions into smaller units called provinces, which at the national level total 52. In each of these provinces there is machinery and personnel that perform maintenance on part of the road network. In addition, there are Network Contracts that maintain another part of said network.



Road Maintenance Budget 2024 US$1,5 billion for 90.000 km road network

These road maintenance modalities are deployed throughout the national territory, which is why they become the main generators of information when facing emergencies.

Fig. 3 – Modalities of Road Maintenance

There is no special emergency budget, it is used the same for road maintenance during Response phase, due to tasks are similar to maintenance activities.

In order to coordinate information from the different regions, a procedure called the Linking Plan was created, which indicates the activities that each of the actors must carry out when facing emergencies.

This Plan is part of the annual guidelines that are delivered to regional and provincial actors.

Once emergency effects on roads are detected, an Emergency Record is generated, which in addition to being part of the emergency map and communicating what is happening to the entire country, will later be one of the requirements for the incorporation of affected sectors in the Recovery contracts or tasks to be done.

Fig. 4 – Road Administration Agents checking road damages

Operational decisions are made at the provincial and regional level. The central level must ensure that the regions deliver correct information, support the registration of that information, procure new resources and documentation to process contracts, etc.

WHAT'S NEW

The Chilean Highway Administration is taking a step forward by generating an interface for the user, incorporating a mobile application for smartphones, which allows collecting information in the field more easily and quickly.

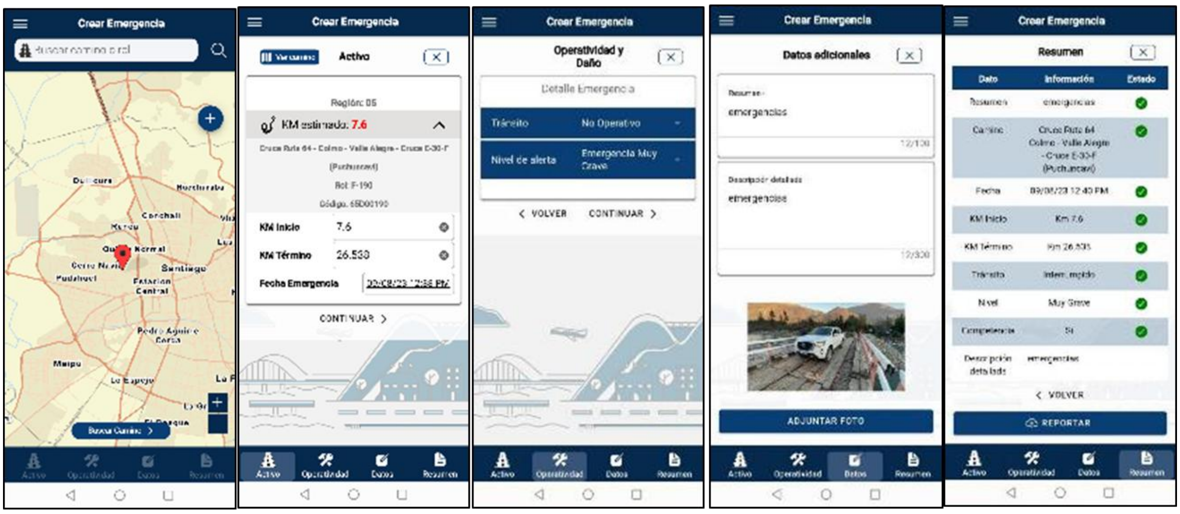


Fig. 5 – Mobile Application for SIEMOP users

BENEFITS TO THE ROAD AGENCY AND ROAD USERS

Before the incorporation of SIEMOP, emergency information was not systematized and had very low accuracy. There was no agreed road network in the organization and each of the Regions used their own isolated databases, which did not allow the generation of comparable layers of information.

In this scenario, the construction of emergency maps was practically impossible, given the differences between the databases managed by each of the units.

There was also no exact information on mileage, so positioning a point on the network was also practically impossible.

In addition to the above, the information was not managed digitally, so the management of the information was too laborious, inaccurate and late, so in conclusion it was irrelevant.

However, with the acquisition of the EAM System for the management of information on the maintenance of the road network, and given that the management of Assets is handled within the system (which in this case is Roads and Machinery, as the only and official base), it was possible to establish a module (SIEMOP) that would allow the identification of the effects of emergencies within this network, and that could subsequently be linked to the work carried out in the Response phase.

In this way, it was possible to generate emergency maps and have, for the first time, an ordered, replicable, unique database of information on the effects of emergencies on roads.

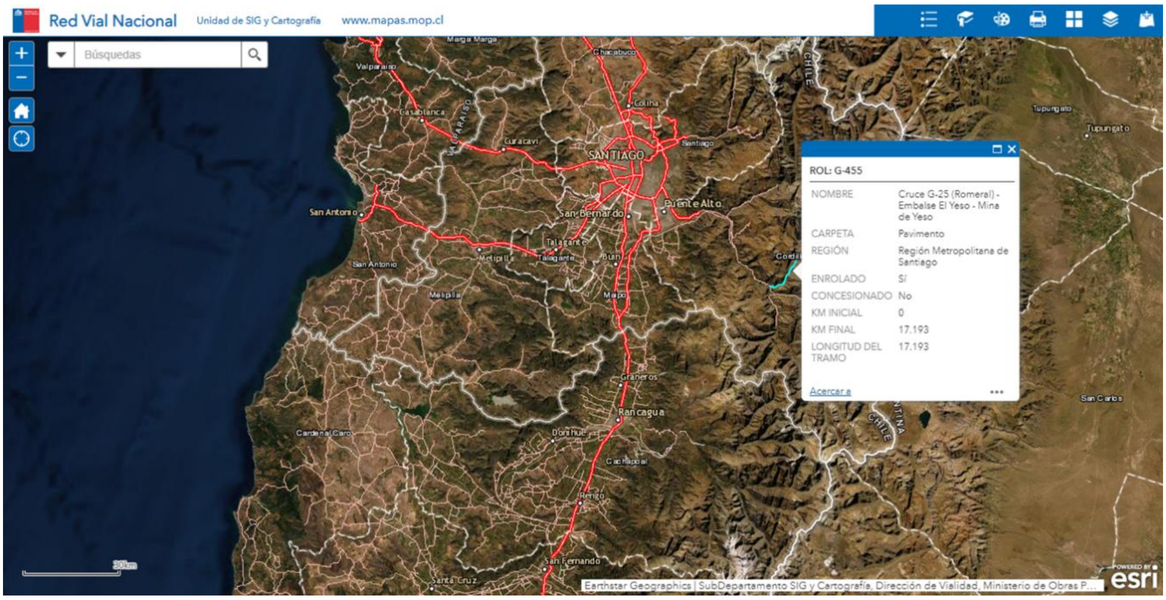


Fig. 6 – Digitalized Chilean Road Network

ROAD ADMINISTRATION CHALLENGES

Within the emergency cycle, although the stages of Response, Recovery, Mitigation and Preparation are defined, for this cycle to be resilient, it must have a permanent concern for the activities that each of the agents must carry out, or in other words, during an emergency, one cannot improvise and each relevant actor must know and be very clear about what they must do. This is why resilience can be achieved by carrying out Training, Coaching or Coordination with the relevant agents on a permanent basis.

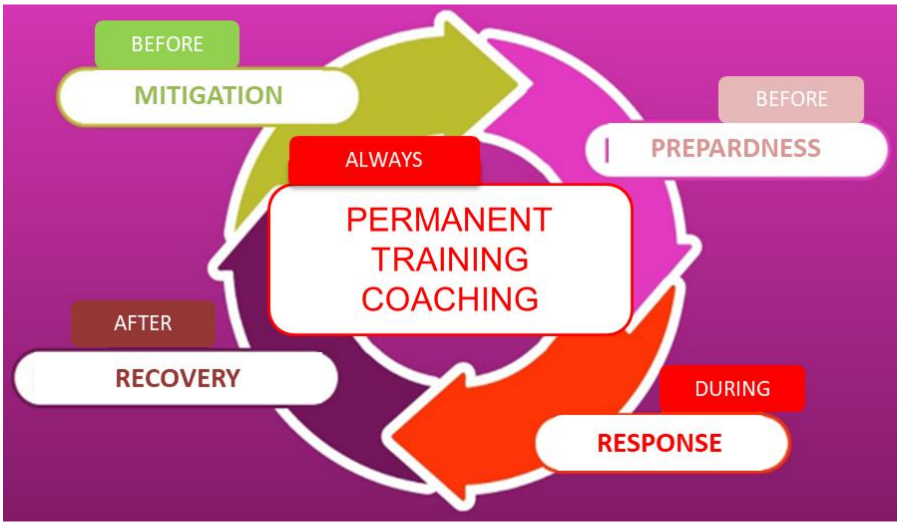


Fig. 7 – Resilient emergency cycle

CONCLUSIONS AND RECOMMENDATIONS

1.- Information during emergency situations is an expensive commodity

2.- There is no excuses to collect and manage emergency information, due to road authorities are always asking for relevant and updated information.

3.- To implement an emergency system, road network should be very well identified and GPS mapped, and also need detailed information of road components (Road surface and geometry, signaling, existing culvers, drainages, etc.)

4.- The huge amount of road network information should be managed by a computational system.

5.- Agent training programs are absolutely necessary for Closed Sources and how merge information with Opened Source.

6.- Permanent review of the Emergency records will be always necessary, in order to keep updated information available for road users.

REFERENCES

- Access to online Road Emergency MAP: https://sitministerial.maps.arcgis.com/apps/webappviewer/index.html?id=500fa188342a4b6cb9acd7b96d5a12d0
- Road Administration web site: https://vialidad.mop.gob.cl/
- IBM MAXIMO world class EAM: https://www.ibm.com/cl-es/products/maximo

ANNEX 3: CORE COMPONENTS OF UK RIA PROVIDED BY J MUNSLOW, CHAIR OF THE UK ROAD LEADERSHIP GROUP CLIMATE ADAPTATION SUBBOARD

Information required for Rapid Impact Assessment (RIA)					
Impact = (Damage x Consequences) x Duration of disruption caused					
	KoboCollect	Survey 123	Stormchain	CSPro	OpenDataKit
Requirement					
Essential information to be collected by Field Operative					
Time and date					
RIA Operative: name					
GPS co-ordinates					
Images (images of damage and any safety measures in place)					
Road Class					
Road Number					
Asset type (e.g.)					
• Stone masonry arch bridge (single-track) • Road structure • Culvert (less than 1m diameter) • Retaining Wall • Embankment • Streetlight • Safety signals • Trees					
Any unique identifier/number (on plate or written) to be matched with inventory in the asset management system/s					
Damage assessment, information including:					

Hazard e.g. landslide from above, landslide from below, river scour, debris flow, collision					
Extent of damage (e.g.)					
• Bridge collapse, total structural failure only abutments remain • Retaining wall foundations exposed by erosion or slope instability • Culvert destroyed by debris flow • Carriageway blocked by fallen trees • Carriageway blocked by collapsed building/s • Carriageway totally blocked by landslide from above • Carriageway partially eroded by river scour					
Other non-highway assets damaged/destroyed/at risk:					
• Electricity overhead/buried (pylons/cables) • Telecom/Fibre-optic overhead/buried (cables) • Gas pipes • Potable water pipes • Foul water pipes • Rail • Waterway (e.g., canal) • Other					
Specialist assessment required (e.g.)					
• Tech Bridge Inspection • Tech Expert visual inspection • Underwater Inspection • Drainage culvert or pipe machine/video • Aerial photographic • Aerial LiDAR					
Diversion required? Yes/No					
Diversion detail (e.g.)					

• "Yes, short local diversion (< 2km)", • "Yes, short local diversion + difficult - specific plan (e.g. HGV/PSV)", • "Yes, medium diversion (>2km - < 10km)", • "Yes, medium diversion + difficult - specific plan (e.g. HGV/PSV)", • "Yes, long diversion (>10km)", • "Yes, long diversion + difficult - specific plan (e.g. HGV/PSV)", • "Yes, very long diversion (>40km)", • "No diversion is available (community is isolated)", • "No diversion required"					
Visible Damage Rating (e.g.)					
• None-visible or suspected • Not assessed – currently inaccessible • Damage suspected but not visible (e.g. bridge scour) • Limited • Moderate • Severe • Total Failure					
Traffic safety measures in place and/or required					
• Full Carriageway closure • Weight limit less than 3.5T • Footway closure • Lane closure / lane restrictions • Shuttle signals					
Current status of asset:					

• Open to all permitted traffic • Open to traffic with safety measures in place (e.g. cones; weight limit) • Open to emergency responders only (with awareness and safety measures in place) • Closed awaiting detailed inspection and/or safety/stabilisation measures • Closed to all traffic (Asset requires major reconstruction before traffic can safely resume)					
Key situational information: free text (e.g.)					
• Access to lifeline facility obstructed (e.g. comms tower; hospital; evacuation centre) • Isolated community (size; characteristics) • Urgent stabilisation required to secure asset function or partial function • Etc • Etc					
Essential information to be added by Duty Manager/s - in the control room					
Unique Reference Number (URN) for each RIA submitted (to support audit onward audit of emergency response)					
Consequence assessment					

Using all information submitted in the RIA (e.g., asset type, status, aligned services affected; key situational information), especially any specific safety/stability concerns, for example adjacent occupied building at risk, precarious blocks of rock. • The manager should cross reference against: the asset inventory and other datasets to assess the consequential effect of the damaged asset for the user community/ies. • To ensure decisions are well informed, this information should be validated by peers (e.g. traffic manager) and partner agencies (e.g., electricity, gas partners if their assets are affected; education and social care departments to identify any disproportionate impacts on the vulnerable) to ensure any work to stabilise and restore this asset is correctly prioritised and the decision is defensible, i.e., the evidence used to reach this decision will likely comprise a combination of quantitative and qualitative/subjective data and information.					
Consequence Rating: these rating categories and their descriptors should be agreed and peer reviewed as part of the planning process to ensure they can be applied consistently during an emergency (e.g.)					

• "Awaiting", • "Minor", • "Limited", • "Moderate", • "Significant", • "Extreme" Descriptor - "*Significant to extreme immediate impact on community. Expedited repair of asset is critical for community functioning*"					
Basic understanding of repair task:					
"Awaiting" "Simple Discreet Repair" "Complex repair but temporary stabilisation fix possible" "Complex repair project"					
This information will be informed by the manager's preliminary assessment of three key factors:					
• Estimated length or time required to implement temporary works to allow controlled trafficability • Estimated length of time to implement permanent works • Works items and estimated quantities for above					
Impact Rating/Score: an aggregation of the damage and consequences score to inform the defensible prioritisation of works (i.e., highest impacts can be prioritised) and					
Ability to present impact rating information to decision makers (e.g. an impact matrix)					
Ability to batch report to multi-agency partners via formatted reports (Incident coordinating groups, 'Unified Command')					

Auto Batch reporting to utility companies. If yes please state format (e.g. .geojson (wfs) .pdf .csv, .shp)					
• Electricity overhead/buried (pylons/cables)					
• Telecom/Fibre-optic overhead/buried (cables)					
• Gas pipes					
• Potable water pipes					
• Foul water pipes					
• Rail					
• Waterway (e.g., canal)					
• Other					
Optional					
Chainage location					
Road link number in the network					
Length of road affected in the case of damage to carriageway					

World Road Association (PIARC)

La Grande Arche, Paroi Sud, 5e étage, F-92055 La Défense cedex