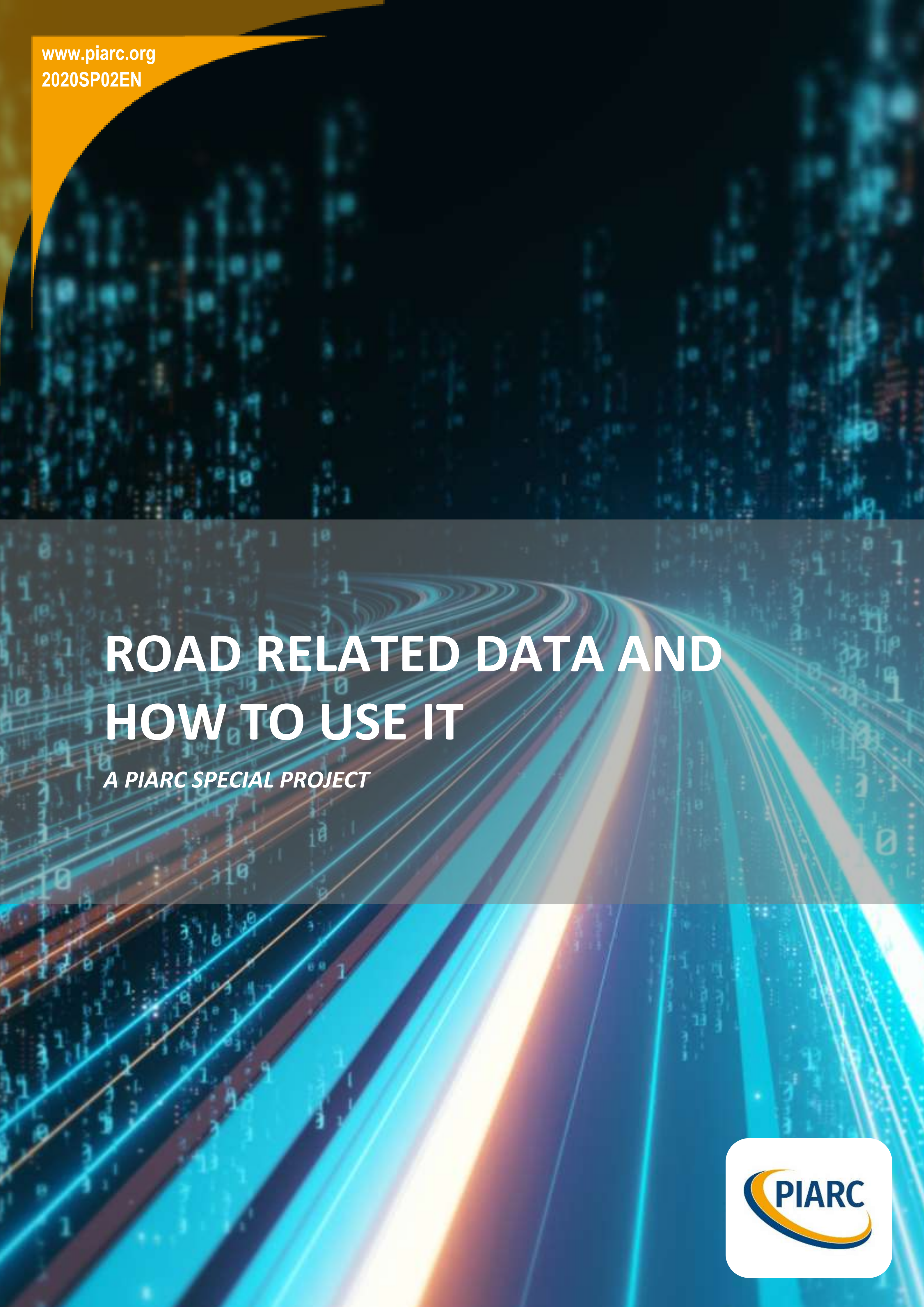

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ROAD RELATED DATA AND HOW TO USE IT

A PIARC SPECIAL PROJECT

PIARC

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.

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This report was approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated 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/or POT member(s), 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): www.piarc.org

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EXECUTIVE SUMMARY

2020SP02EN

ROAD RELATED DATA AND HOW TO USE IT

Background

The management of road infrastructure has been experiencing major changes over the past decade, mostly due to the increased demand from road users, the increased deterioration of road infrastructure and from the evolution of user expectations. In addition, new challenges such as climate change and emerging (and potentially disruptive) technologies and service models are changing supply and demand dimensions as well as offering data collection and analytics capability in their own right. This has led to a need for the use of emerging state-of-the-art technologies to collect and process relevant data in order to facilitate the maintenance and management of the road network while providing smooth and stress-free journeys to road users.

Objectives

To address this, the World Road Association (PIARC) commissioned Atkins to undertake a global research project to gather and collate the different approaches used in High, Middle and Low income countries to collect, process and use road related data, focusing on the state-of-the-art methods which can deliver efficiencies, facilitate the operation and management of the road network and improve the provision of services to road users. The research also explored various business models which are already in place or could be adopted by road administrations while considering possible cooperation with private data providers. The research was divided into the following three interrelated phases:

a. **Literature review:** Desktop research on the new, future and emerging data collection and analysis methods used worldwide using various sources;
b. **Stakeholder engagement:** An online survey targeting road administrations in both High Income Countries (HIC) and Low Middle Income Countries (LMIC) covering all geographical regions; and
c. **Business model analysis:** Exploring the different scenarios and business models which are being or can be adopted by road administrations in both HIC and LMIC based on deep dive interviews with organisations in selected countries from both income brackets (the Netherlands and South Africa).

Literature Review

The aim of the literature review was to explore a range of data types, collection methods and their applications, assess the Technology Readiness Level (TRL) for each method, and present key findings for road administrations to learn from.

The review built on previous work by BASt to cover a wide range of data and information types related to road infrastructure, and the end result was an extensive thematic review in this report (over 80 sources), plus a larger combined set of indexed resources made available on the PIARC website (over 200 sources) for further reference.

The review covered under three overarching themes (road network, road user and context), and the tools and technologies identified in the literature were classified into seven categories as outlined in the figure below.

EXECUTIVE SUMMARY

- Road Condition and Maintenance Related Data and Information
- Traffic Related Data and Information
- Data from Connected and Autonomous Vehicles (CAVs)
- Road Technologies Related Data and Information
- Data Generation for and from Social Media
- Road Safety Related Data and Information
- Disaster Management Data and Information

The gathering of condition and maintenance data and information is one of the most common themes in literature relating to road data; with several approaches and tools being used over the years. This report covers collection methods such as in-vehicle sensors, smartphones, Unmanned Aerial Vehicles (UAVs) as well as traditional surveys and inspections carried out by engineers and inspectors.

Due to the increase in vehicle numbers and population plus a changing balance of transport modes traffic congestion is one of the main challenges in urban centres. Extracting hidden knowledge in the data collected from various sources, such as Global Positioning Systems (GPS) systems, mobile phone networks, commuting smart cards, and environmental and traffic sensors provides valuable insight for road administrations to manage traffic. Furthermore, the introduction of Intelligent Transportation Systems (ITS) and Connected and Autonomous Vehicles (CAVs) has stimulated a hike in the interest of using information and driving assistance systems with the main objective of improving road safety and driving comfort. These systems also have the potential to significantly improve the efficiency of traffic management systems, provide better accessibility for all users and minimises the impact on the environment.

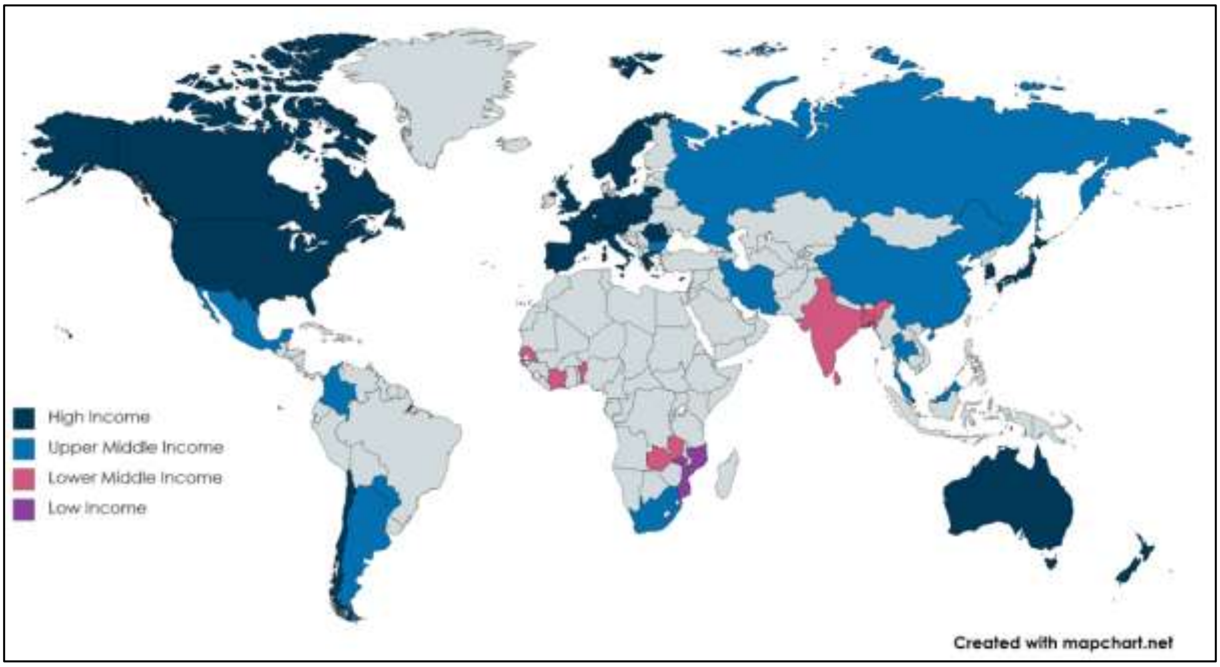
Data from social media, as well as data from smartphones sensors such as the accelerometer, GPS, microphone and camera, provide road administrations with real-time and low-cost solutions for better data collection. However, there are still challenges concerning the management and analysis of big data such as its volume, velocity, variety, and veracity. It is evident from the literature reviewed that collecting real-time information on the operation of roads and the vehicles travelling on them creates an enormous amount of useful information to support the development of innovative services and applications to benefit not only road administrations but also the users, businesses and public services that rely on the road network.

Road administrations are encouraged to conduct a high-level review of the findings to understand the range of technical capabilities covered and identify areas of relevance to their own situation. A more detailed focus can then be applied to specific topics and data types along with the associated state-of-the-art data collection methods. PIARC members should benefit from learning from existing technical knowledge that is presented here and on the website, and use this to inform local pilots or applications.

Stakeholder Engagement (Online Survey)

The stakeholder engagement phase consisted of an online survey sent out to all PIARC members that was intended to capture an understanding of applications of data by road administrations. This process identified use cases for the review and benchmarking of current approaches, which would support plans to improve or introduce applications of data, and promote engagement and collaboration with other members.

A total of 80 responses across 46 countries were received and analysed. The majority of responses were from road administrations covering both HIC and LMIC as shown in the figure below, all geographical regions and urban and rural countries. The survey was formed of 12 main questions covering a range of topics under three overarching themes; road user, road network and context. Quantitative and qualitative methods were used to conduct the survey analysis. The majority of responses received were from HIC with 63% out of the 46 countries who participated, those of which were primarily urban countries.



The highest volumes of responses were received for the questions related to inventory and condition data, traffic data, management of roadworks and data sharing with road users. For each question, the following topics were those with the strongest responses from PIARC members:

- **Asset inventory and condition data:** Asset management systems (software), road sensors, vehicles with mounted cameras and traditional human surveys.
- **Traffic data and information:** Fixed road sensors or inductive loops, traffic cameras and traditional human surveys.
- **Maintenance and operations:** Geographic Information System (GIS) mapping, Intelligent Transport Systems (ITS) and Asset management systems (software).
- **Asset and investment planning:** GIS mapping, Asset management systems (software) and lifecycle planning tools.
- **Disaster management:** Weather sensors, data from third parties and road network usage related software.

- **Data and information sharing:** Information related to traffic volumes, accidents, roadworks and diversion routes is mostly shared on government websites and using social media platforms.
- **User satisfaction and feedback:** Mostly through traditional surveys and using social media or other platforms. The data gathered is then used to develop annual reports, set Performance Indicators and inform investment decisions.
- **Benefits and pontential uses of CAVs:** HIC conduct research and trials mostly related to CAVs data opportunities for road network operations and management purposes.
- **Data exchange with third parties:** Road data is mostly shared between road sector organisations, road operators and private companies.
- **Economic, social and environmental factors:** Data from sensors or monitoring equipment to measure air quality, and data from relevant government agencies for health and economy.

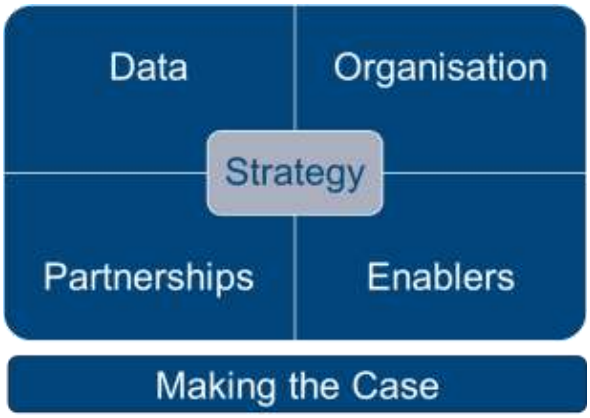
There was high response rate from both HIC and LMIC regarding the use of dedicated sensors to capture inventory and condition data of road infrastructure assets, and weather sensors to effectively prepare for natural / man-made disasters. Road administrations indicated there is yet to be widespread adoption of state-of-the-art technologies in collecting inventory and condition data such as Vehicle Telematics, CAVs, Artificial Intelligence, Machine Learning and Computer Vision techniques.

A number of organisations across different countries stated that they are sharing information related to road traffic and accidents through means of social media channels and websites to communicate the necessary information to road users and also for research purposes. The survey also showed that sensors, monitoring equipment and data from environmental agencies are used to monitor air quality to develop a better understanding on how it changes over time, thus allowing road administrations to adapt their road management approach and take any necessary actions. Some organisation also mentioned using data from traffic volumes, traffic speed and noise levels to allow road administrations to identify the social and environmental benefits and impacts on road users and the public, as well as supporting the decision-making process in relation to network accessibility and future investments.

Road administrations should undertake a high-level review of the survey findings to understand the range of topics covered and identify areas of interest. They should carry out a detailed review of current and future practices that will provide greatest value to their own circumstances, and identify opportunities to introduce or improve applications of data. An action plan should be developed for specific prioritised applications, and again, the finding should encourage road administrations to engage and collaborate with other PIARC members.

Business Model Analysis

A framework has been developed for road administrations to either use in the development of their approach to utilising data in the delivery of services or to support the improvement of existing practices. The guidance is structured along the six themes outlined in the figure below, with each theme including a definition of the subject, an outline of different approaches, a set of recommendations for road practitioners, and case studies from various organisations (primarily from the deep dives but also supplemented with additional learning from around the world where appropriate).



A summary of what is covered within each of the themes is below:

- **Strategy –** regardless of the resources available to a road administration, there should be alignment between the high-level objectives of the organisation and the delivery of operations and services to users in order to maximise the value and effectiveness of the use of data. This section covers the importance of strategic planning, and how authorities should either develop or improve in this area to ensure that data is properly integrated into their decision making process.
- **Data Sources –** with a strategy in place to provide line of sight from organisational objectives through to delivery of services, careful selection and use of data is essential to support decision making and communication. This section outlines the various data types that can be used, either in terms of existing data, newly collected data, or newly accessed data, and the common principles that should apply regardless of their source.
- **Organisation and Management Approach –** to deliver better use of data within a road administration, it is essential that resources are deployed in a way that will ensure sufficient capacity and capability are available for the required functions. This section outlines the different structures that can be used to deliver a data-driven approach within a road administration, how resources can be managed, and how performance is monitored.
- **Partnerships –** road administrations should not expect to deliver services on their own, and should make best use of partnerships with a range of potential organisations. This may include options to generate added value for public services, to potentially monetise data or to release open data for use by external parties. This section provides insight into the issues around partnering with such organisations, including who may be involved and how it may be facilitated.
- **Enablers –** road administrations require a range of enablers within their organisation to support the implementation of data-driven practices. This section covers a number of key themes that are essential to successfully deliver a data strategy, including the importance of leadership, skills and behaviours within the organisation, and the tools and processes to allow people to get the most out of data, along with examples of potential support for practitioners.
- **Making the Case –** implementation or improvement plans focused on data may cover the technical aspects robustly, but without a through case for investment, they may well face difficulties in being delivered in reality. This section covers the development of such cases, which should clearly frame the costs involved whilst articulating the potential benefits that can be achieved, plus how related messaging can be communicated and key stakeholders convinced.

Conclusions and Recommendations

The research has confirmed that the pressures on road administrations in terms of increasing demand and expectations continue to grow, and current international disruption following the emergence of Covid-19 means that there are likely to be more challenges to deal with in the short-to-medium term. It was clear from the findings that there is great interest and appetite in the potential for data to help with this, and there are already excellent examples of global good practice.

The project objectives have been met through the various elements to this report, both in terms of technical information provided, guidance and recommendation for road administrations and potential activities to support the dissemination and adoption of the report.

The literature review and online survey have provided an extensive overview of the state-of-the-art in road related data, and identified numerous use cases that are intended to help PIARC members review their own progress and learn from colleagues from around the world. This includes the deployment of data and technology across the whole spectrum of activities within road administrations, and has demonstrated that the application of data is feasible and can prove successful within all types of organisations, regardless of size of country, geographical location or income level.

The business model provides the structured guidance and more detailed case studies that can help road administrations develop their approach to using data and improve value of services. This includes setting a strategy and organizational approach to using data, partnership with external parties, development of new or improved services.

The 20 recommendations below, which are also referenced within the report, provide a clear framework for road administrations to systematically compare their current practices and develop tailored action plans. These also complemented by a further 4 recommendations for PIARC to consider, to supporting member organisations in their journey to deliver better services through smarter use of data.

Ref.	Relevant Chapter	Page	Recommendation (Further Detail in Main Report)
R1	**Literature Review**	37	Learn from the literature review, then act and improve
R2	**Online Survey**	87	Learn from the online survey, then act and improve
R3	**Business Model – Strategy**	92	Use a strategic approach, both at organisation level and also in terms of data as a discipline
R4			Develop an action plan for data using SMART (Specific, Measurable, Achievable, Relevant and Time-bound) principles
R5			Collaborate, learn and review
R6	**Business Model – Data Sources**	97	Treat data as a valuable asset
R7			Make better use of existing resources
R8			Consider access to existing external data before collecting more primary data
R9	**Business Model – Organisational and Management Approach**	105	Understand the different organisational model options to deliver data functions and use the most appropriate for the road administration
R10			Maintain a flexible approach to accessing staff resources

Ref.	Relevant Chapter	Page	Recommendation (Further Detail in Main Report)
R11			Monitor performance and apply continuous improvement
R12	**Business Model – Partnerships**	112	Engage with other road organisations and the private sector to identify opportunities to develop partnership arrangements for the shared collection and use of data
R13			Understand the difference between information and data
R14			Recognise the opportunities and value that open data can provide
R15	**Business Model – Enablers**	122	Demonstrate clear leadership both within the road administration and also to the private sector
R16			Develop more than just data-orientated skills, but also behaviours and culture within the road administration
R17			Use the right tools to analyse data and communicate findings
R18	**Business Model – Making the Case**	127	Develop an investment case for data, and evaluate improvements and subsequent benefits
R19			Communicate in accessible language, with technical detail to support
R20			Consider pilot projects to demonstrate principles and secure interest
R21	**PIARC**	138	Share learning through networks
R22			Help shape common approaches to managing road data
R23			Provide greater focus on themes with scope for improvement
R24			Support the development of new skills within the sector

CONTENTS

TABLES

FIGURES

GLOSSARY OF ACRONYMS

Acronym	Definition
ADEPT	Association of Directors of Environment, Economy, Planning & Transport
AFCs	Automated Fare Collection System
AI	Artificial Intelligence
ANPR	Automatic Number Plate Recognition
APIs	Application Programming Interfaces
ATM	Active Traffic Management
AVLS	Automated Vehicle Locations System
BASt	Federal Highway Research Institute of the German Government
BLE	Bluetooth Low Energy
BSMs	Basic Safety Messages
CAVs	Connected and Autonomous Vehicles
CCTV	Closed-circuit television
CFVD	Cellular Floating Vehicle Data
CPR	Close-Range Photogrammetry
CV	Computer Vision
ECAMS	Enhanced Continuous Asset Monitoring Solution
ECU	Engine Control Units
FCD	Floating Car Data
FHWA	The Federal Highway Administration of the USA
FWD	Falling Weight Deflectometer
GIS	Geographical Information Systems
GMS	Global System for Mobile Communications
GPS	Global Positioning System
HIC	High Income Country

Acronym	Definition
HOs	Handovers
HPMS	Highway Performance Monitoring System
HSM	Highway Safety Manual
IoT	Internet of Things
IRI	International Roughness Index
IS	Information Systems
ITS	Intelligent Transportation Systems
LCMS	Laser Crack Management System
LiDAR	Light Detection and Ranging
LMIC	Low Middle Income Country
MaaS	Mobility as a Service
MENA	Middle East and North Africa
MIS	Meteorological Information System
ML	Machine Learning
NLUs	Normal Location Updates
ÖBB	Austrian Federal Railways
PIARC	World Road Association
PLUs	Periodic Location Updates
POT	Project Oversight Team
RMDAs	Road Measurement Data Acquisition System
RRD	Road Related Data and how to use it
RTRRMS	Response-Type Road Roughness Measuring System
RWIS	Road Weather Information System
SANRAL	The South African National Roads Agency
SCANNER	Surface Condition Assessment for the National Network of Roads
SCT	Mexico’s Ministry of Communications and Transport

Acronym	Definition
SHQR	Safe and High Quality Roads
SNS	Social Networking Sites
TFIMP	Traffic Flow Intensity Measurement Points
TMAS	Travel Monitoring Analysis System
TMG	Traffic Monitoring Guide
TRL	Technology Readiness Levels
TSL	Terrestrial Laser Scanner
UASs	Unmanned Aerial Systems
UAVs	Unmanned Aerial Vehicles
VANET	Vehicle Ad-hoc Networks
VMS	Variable Message Signs

1. INTRODUCTION

1.1. PROJECT BACKGROUND

The World Road Association (PIARC) has established a Special Projects mechanism to enable it to respond outside the usual four-year Technical Committee cycle to emerging issues and priorities identified by its members. This report covers the "Road related data and how to use it (RRD)" Special Project and provides an overview and compilation of the state-of-the-art while undertaking a global review across High, Middle and Low income countries.

The management of road infrastructure has been experiencing major changes over the past decade, mostly due to the increased demand from road users, the increased deterioration of road infrastructure and from the evolution of user expectations. In addition, new challenges such as climate change and emerging (and potentially disruptive) technologies and service models are changing supply and demand dimensions as well as offering data collection and analytics capability in their own right. This has led to a need for the use of emerging state-of-the-art technologies to collect and process relevant data in order to facilitate the maintenance and management of the road network while providing smooth and stress-free journeys to road users.

1.2. PROJECT OBJECTIVES

The objectives of this research set by PIARC are:

- Providing an overview and compilation of both existing "business as usual" data and state-of-the-art data collection and analysis technologies;
- Identifying the potential of the use and deployment of data;
- Enabling PIARC members to consider possible cooperation with private data providers;
- Enabling PIARC members to develop appropriate approaches and strategies for road infrastructure management and provision of services to road users;
- Exploring how provision of services to road users could be improved using advanced data collection methods; and
- Providing a starting point for road administrations who are looking to improve the management of their road network by the use of improved data, information and/or knowledge of existing assets.

1.3. STRUCTURE OF REPORT

This report has been structured in the following format:

- **Section 2:** Methodology and Approach – outline of the stages used to deliver the project;
- **Section 3:** Literature Review – review of technical literature from academic and industry sources;
- **Section 4:** Stakeholder Engagement (Online Survey) – survey of PIARC members;
- **Section 5:** Business Model from a Road Administration Perspective – structured guidance and case studies;
- **Section 6:** Conclusions and Recommendations – summary of findings and advice for implementation;
- **Section 7:** References – detailed reference of relevant documents covered by the report; and
- **Section 8:** Appendices – supporting information to the main report.

2. METHODOLOGY AND APPROACH

2.1. INTRODUCTION

The project was undertaken based on a structured methodology incorporating the following activities:

- Desktop research on new, future or emerging technologies for data collection and analysis;
- Identifying, reviewing and summarising case studies from both High Income Countries (HIC) and Low Middle Income Countries (LMIC);
- Engaging with road authorities of both HIC and LMIC;
- Exploring the different scenarios and business models which are being or can be adopted by road administrations in both HIC and LMIC;
- Producing a detailed report summarising the project findings in a clear and structured manner; and
- Producing dissemination material to support the launch of the report and take up by members of PIARC.

Whilst the project objectives were set prior to the COVID-19 pandemic, these remain relevant and unaffected by the disruption which has taken place during the delivery of this research. An example of how data has been used to understand the impact of COVID-19 measures on mobility is included as a case study in Section 5, and it is expected that road administrations will continue to adapt their ways of working and using data to align with future restrictions.

Figure 1 below outlines the core methodology followed while undertaking this project.

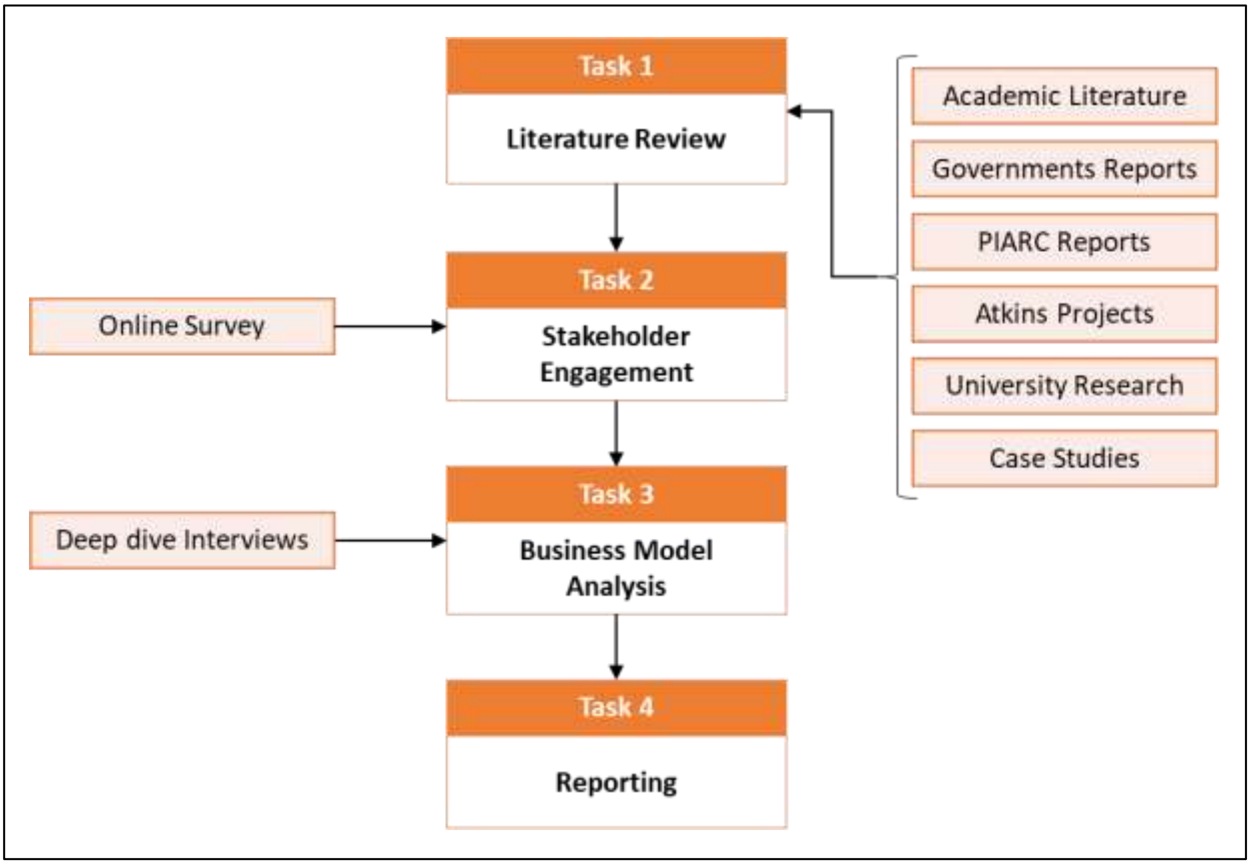


Figure 1: Project Methodology

To deliver the research successfully, the Atkins team worked closely and in collaboration with PIARC and the POT members throughout the project. Membership of the project team and POT is outlined in the earlier Authors / Acknowledgements section.

2.2. LITERATURE REVIEW

An initial data gathering task was undertaken, to complete the following objectives:

- Review proposed Big Data, Smart Data and Smart Road definitions and refine/agree new definitions as necessary;
- Refine and group the various data and information types in a clear and structured manner to facilitate undertaking the research and reporting on the findings;
- Carry out a robust literature review using existing literature provided by BASt[1] as a starting point and building on that using other data sources; and
- Build the necessary information required to inform the survey to be undertaken as part of the stakeholder engagement task.

Figure 2 depicts the three interrelated themes used as the basis for this research where the user of the road network sits at the core of the three themes. The following are the key data/information types covered in this research under each of the three themes:

Theme 1: Network

- Conventional data (inventory data, asset condition data and asset inspection data)
- Operational data (traffic data and information, traffic loading, ITS and roadworks)
- Maintenance data (routine maintenance and winter maintenance)
- Resilience (disaster management and emergency planning)

Theme 2: User

- Road user behaviour and travel modes
- Connected vehicles
- Provision of information
- Accidents
- Journeys and delays
- Satisfaction and feedback

Theme 3: Context

- Environmental
- Social
- Economic

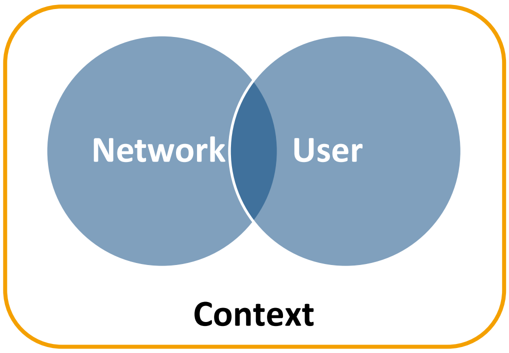


Figure 2: Research Themes

The literature review was planned following the project team's engagement with a global panel of Atkins experts from multiple disciplines, and was undertaken utilising the data and information available from the following sources:

- Literature review conducted by the Federal Highway Research Institute of the German Government (BASt) including academic literature and research on Connected and Autonomous Vehicles (CAVs);
- Atkins past projects/case studies and in-house knowledge;

[1] The list of literature was part of a BASt previous project and was provided publicly as part of the Call for Proposals for this project.

- Further information from academic literature databases (ScienceDirect, Google Scholar, Institute of Civil Engineers, etc.);
- University of Birmingham dedicated research[2];
- EUROSTAT, OECD and any other relevant websites identified;
- Online government Reports/Databases;
- Available literature and information relevant to LMIC from open sources and from within regional groups;
- National PIARC Committees and member organisations;
- The relevant technical reports and publications available on PIARC's website;
- Other data or information provided by PIARC POT members; and
- Case studies provided during the subsequent stakeholder engagement task.

2.3. STAKEHOLDER ENGAGEMENT (ONLINE SURVEY)

Information from the literature review formed the basis of survey targeting national road administrations within PIARCs membership.

As of June 2020, PIARC's membership (Figure 3) consists of:

- 13 Low-Income Countries (largely made up across East and West Africa);
- 36 Lower-Middle Income Countries (largely made up across North Africa, Central Asia, South East Asia);
- 27 Upper-Middle Income Countries (largely made up across South America and the Middle East); and
- 48 High Income Countries (largely made up across Europe, North America, Australasia, the Far East, and the Middle East).

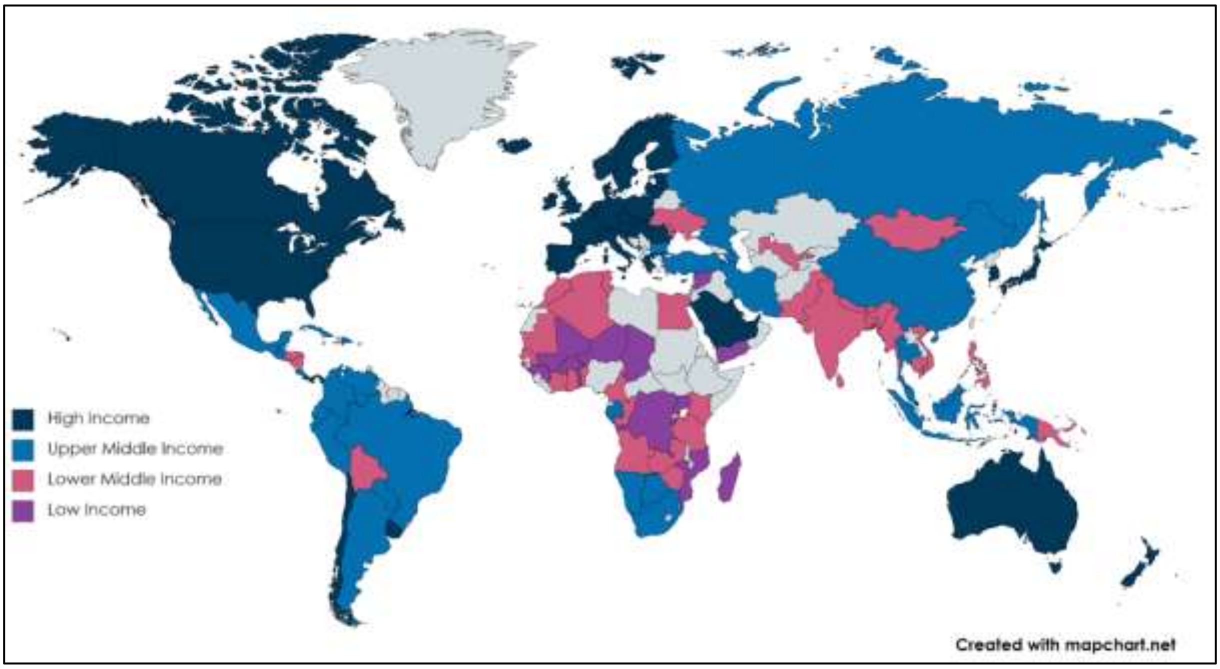


Figure 3: PIARC Membership

The survey was designed in collaboration with the POT (see Appendix A for the English version of the questionnaire template) and issued to all members of PIARC via the PIARC General Secretariat. To

[2] Research undertaken as part of an MSc thesis tailored specifically to this project and supervised by Atkins Project Manager.

maximise engagement with stakeholders and encourage higher response rate, the survey was provided in three languages as per PIARC's usual research practice: English, French and Spanish.

Whilst participation from 40 organisations across different countries was the initial target, the initial survey response exceeded this number, which the POT acknowledged as strong interest in the subject from PIARC's membership. However, the initial set of responses provided a lower than expected coverage of LMICs and geographical spread, and as a result, the survey was extended. A total of 80 responses across 46 countries were received, analysed and included in this report, which successfully expanded coverage to provide an increased focus on LMICs and a wider geographical spread.

2.4. BUSINESS MODEL ANALYSIS

Whist undertaking the literature review and stakeholder engagement, a number of different scenarios and business models were identified which are being or can be adopted by road administrations in both HIC and LMIC. This included potential new services which road administrations can provide to road users using the relevant data and technologies.

The project team and the POT identified two nations for further detailed investigation via deep dive interviews across both HIC and LMIC, based on work undertaken in the Netherlands and South Africa. Atkins arranged a number of Microsoft Teams calls to undertake the interviews, led the discussions, captured notes, and then drafted content to feed back to the POT. The deep dive interviews were structured to follow the required framework for the business model content:

- Strategy
- Data sources
- Organisation and Management Approach
- Partnerships
- Enablers
- Making the case

The findings from the deep dive interviews were then analysed for key principles and examples of good practice, which formed the basis for guidance to road administrations. These were supported by a number of additional case studies from the online survey plus further research, and were underpinned by a series of recommendations against each theme within the framework.

2.5. REPORTING

Each of the previous stages of the project were drafted into project report format, with reviews undertaken within the Atkins project team and comments / approval provided by the POT. The final version was prepared for publication on the PIARC website, and its launch was supported by a presentation to the PIARC Council in December 2020.

3. LITERATURE REVIEW

3.1. INTRODUCTION

The literature found was classified into the following categories:

1. Road Condition and Maintenance Related Data and Information;
2. Traffic Related Data and Information;
3. Data from Connected and Autonomous Vehicles (CAVs);
4. Road Technologies Related Data and Information;
5. Data Generation for and from Social Media;
6. Road Safety Related Data and Information; and
7. Disaster Management Data and Information.

The initial research also reviewed different definitions identified online for each of the terms Big Data, Smart Data and Smart Road. The definitions found online were compared against those proposed by BASt and stated in the Call for Proposals document. Following consultation with the POT, it was concluded that Big Data and Smart Data definitions proposed by BASt were more comprehensive than those found online and thus retained, while the Smart Road definition was extended by the project team based on additional sources. The definitions and references are outlined below:

Big Data refers to data volumes that are too large, too complex, too fast moving or too weakly structured, for example, to be evaluated using manual and conventional data processing methods. Big Data is usually coming from different sources in different formats. Big Data is often used as a collective term for digital technologies, which are held responsible in technical terms for a new era of digital communication and processing and in social terms for a social upheaval. Big Data also describes the complex of technologies that are used to collect and evaluate these amounts of data, including Artificial Intelligence (AI) and Internet of Things (IoT). For this project, Big Data also includes Social Network Data (Oussous, et al., 2018).

The term **Smart Data** refers to useful, high-quality and secure data stocks which are often generated from Big Data by means of algorithms taking into account data security and protection, as well as data quality, utility and semantic aspects. Smart Data can be used both to gain knowledge from raw data and to generate new models for data analysis (Jähnichen, 2015).

A **Smart Road** uses the Internet of Things (IoT) to monitor, measure, analyse, communicate and act on the road network, based on information captured from physical infrastructure such as sensors and solar panels. This can be combined with software infrastructure including Artificial Intelligence (AI) and big data to achieve an improved performance with regards to safety, efficiency, comfort and environmental impact, while allowing communication between vehicle and infrastructure to improve the operation of both the network and Connected and Autonomous Vehicles (CAVs) (Thomas, 2012).

3.2. ROAD CONDITION AND MAINTENANCE RELATED DATA AND INFORMATION

A number of approaches and tools have been used to collect data and information related to the condition and maintenance of roads over the years. Radopoulou & Brilakis (2016) conducted a study that reviewed the current methods used for monitoring road condition. Their research concluded that all methods found in the literature have multiple benefits, however, none of them is approaching the automation of road defect detection holistically. Also, none of the identified methods can address all limitations in current practices simultaneously. Although it is very useful to automate part of the data collection and road monitoring process, a complete and holistic approach is what the industry aims to achieve.

Similarly, research currently being conducted by Harvey, Lea, & Tsai (2019) states that cost-effective inventory data collection methods have not yet been fully developed for full network surveys. They argue that current inventory data collection methods mainly include pavement information and fail to collect data about other assets such as road markings, cycle lanes and paths, footways, vehicle barriers, signage, curb ramps and other safety concerns such as drainage inlets.

This section of the literature review will discuss different collection methods currently being used or still under research to gather road condition and maintenance data, and how the data collected is then being used. This report covers collection methods such as in-vehicle sensors, smartphones, UAVs as well as traditional surveys and inspections carried out by engineers and inspectors. The report also covers CAVs which are increasingly being used for the collection of road condition and inventory data. Further details of each of the collection methods mentioned is covered in following sections.

The following sections provide details on the different uses of road condition and maintenance data and describe the different approaches to collect and analyse road data as outlined in the literature.

3.2.1. ROAD INVENTORY

Road administrations and transport agencies need to adopt cost effective methods to capture inventory data for roads and roadside assets. In-vehicle automated, or semi-automated methods are becoming more popular across the world for rapid and comprehensive collection of network inventory data. The development of systems to obtain real-time understanding of road assets is of great interest as stated by Castillo, et al. (2015). Proper planning and management of roads play an essential role in socio-economic growth of any nation, and information on the road inventory and its geometry is used as a benchmark by transport authorities and other related agencies for evaluating, monitoring and prioritising road projects.

Jalayer, et al. (2014) conducted a study to identify cost-effective methods for collecting highway inventory data to implement a Highway Safety Manual (HSM). They conducted field trials for collecting HSM-related highway inventory data on four types of roadway segments (rural two-lane two-way roadways, rural multi-lane highways, urban and suburban arterials, and freeway). The findings of this research indicated that five potential methods (GPS data logger, "robotic total station" electronic distance measuring systems, mobile LiDAR, and combination of video/photo log method with aerial imagery) are all capable of collecting HSM-related information. Similarly, in India, Husaina & Vaishyab (2018) proposed a methodology to detect the road surface and its corresponding centre line and boundary lines using terrestrial LiDAR data. Using a terrestrial laser scanner (TSL), they successfully captured the road surface along with corresponding centreline and boundary lines using a TLS (FARO Focus3D X 330). The research concluded that this method could be used in the future to collect information about road inventory in a cost-effective way.

3.2.2. ROAD CONDITION AND MAINTENANCE

Asset management systems and solutions are mostly used to assist with the analysis of data and maintenance information. However, they are only useful if the quality and quantity of asset data are reliable. Flores & Trevizan (2019) argue that the introduction of IT systems for asset management provide a real opportunity to launch an asset management system that combines a robust database, a means of recording interventions, a database of projects to be executed and capacity to monitor works, quantities of materials, physical and financial resources and indicators of efficiency and effectiveness.

In Latin America and other LMIC countries, road administrations struggle to successfully adopt efficient ways to manage their assets mostly due to the limited resources available. This triggered some road administrations seek innovative and efficient ways for asset maintenance and management to be able to respond to the road users expectations with the available resources . Similarly, as outlined by Lepert & Maman Sanda (2015), the Republic of the Niger are keen on implementing a maintenance management system that is more elaborate and capable of projecting further into the future and anticipate implementation of the system in few years' time. This same approach has already been employed, in several West African countries facing the same challenges experienced by the Niger such as Mali, Guinea and Chad.

3.2.2.1. *IN-VEHICLE SENSORS*

In-vehicle sensors are currently considered essential components of any vehicle regardless of its class, as these can improve a vehicle's performance, monitor its operation and the status of its parts, and enhance the driving experience. In the context of this report, in-vehicle sensors are any sensor located on any type of vehicle for the purpose of remote sensing, defined as the gathering of information at a distance using airborne, satellite or terrestrial sensors. There are multiple types of sensors and methodologies that can be used to collect road condition data using in-vehicle remote sensing, some are described below.

Castillo, et al. (2015) presented a parameter estimation algorithm to obtain the slip and the friction coefficient and, from these data, the road condition and the optimal slip of the surface where the vehicle is travelling. Their method uses ABS and ESP standard sensors installed in vehicles, as opposed to other existing in-vehicle methods that required the use of special sensors such as optical sensors, radars or cameras. The results obtained showed that the proposed system can detect the friction characteristics of the surface. However, further research is still required to verify the accuracy of this approach, especially in low and very low adherence conditions.

Remote sensing with in-vehicle sensors is an effective tool for use in road and geotechnical asset management and is associated with many potential benefits. In their study, Bhreasail, et al. (2019) concluded that sensors are likely to be used as a semi-automated process to detect and interpret changes in Highways England's geotechnical assets in the future. However, expert knowledge and experience are still required to interpret machine outputs. Regular repeatable surveys, with comparable specifications, are still required to enable semi-automation to detect significant changes in geotechnical assets.

Similarly, several studies proposed methods for assessing the condition of road surface using vehicle-mounted lasers. Li et al. (2020) proposed a robust and comparatively low-cost point laser system that measures the reflection time to identify the location and the amount of fretting based on histogram analysis. Petitclerc, et al. (2018) suggested a new approach to tag road condition data to a specific location on the road network. The approach combines high resolution high accuracy transverse road profile data acquired by a LCMS system (Laser Crack Measuring System) with a highly accurate GNSS-INS (Global Navigation Satellite System-Inertial Navigation System) to measure road surface condition and to generate a survey grade accuracy terrain map of the road surface.

Xia (2018) proposed an approach to detect pavement defects using imagery from a car equipped with HD video camera. In their study they propose Convolutional Neural Network, one of the most popular deep neural networks applied to analyse visual imagery, to locate and classify different types of pavement defects including cracks, breaks and potholes. Additionally, the study proposed methods for assessing the severity level of defects based on their size, shape and texture.

Table 1 below maps the collection methods against the different data types to provide an overview of how data and information related to the condition and maintenance of roads are being/can be gathered and used across different countries and road administrations. The table also provides the list of literature references used to review and assess the collection methods for each data type based on the relevance of each article. In addition, a useful MS Excel spreadsheet including a long list of articles' sources covering all seven topics mentioned above is available on PIARC's website.

To assess the maturity of each technology or collection method, NASA's Technology Readiness Levels (TRL) were grouped and used throughout the table. Figure 4 below shows the different TRLs which cover the three maturity phases: research, development and deployment. It must be noted that the assessment of TRLs throughout this section is based on the professional and technical judgement of the project team and may be subjective based on the available evidence in the literature references.

Figure 4: Technology Readiness Levels (TRL) description

Table 1: Road asset management data collection methods and data types

Data Type/Usage	Collection Methods				References in Literature
	In-vehicle sensors	Smart Phones	UAVs	Other sensors (acoustic, piezoelectric, optical, etc.)	
Road Inventory	TRL 9 (Deployment)	n/a	TRL 8-9 (Deployment)	n/a	(Castillo, et al., 2015) (Forslöf & Jones, 2015) (Lepert & Maman Sanda, 2015) (Trevizan, 2015) (Husaina & Vaishyab, 2018) (Flores & Trevizan, 2019) (Harvey, et al., 2019)
Road condition and maintenance	TRL 9 (Deployment)	TRL 4-6 (Development)	TRL 8-9 (Deployment)	TRL 2-3 (Research)	(Ghose, et al., 2012) (Douangphachanh & Oneyama, 2013) (Castillo, et al., 2015) (Brunauer & Rehrl, 2016) (Liikennevirasto, 2016) (PIARC, 2016) (Radopoulou & Brilakis, 2016) (Fedele, et al., 2017) (Singh, et al., 2017) (DfT C-ITS Project, 2018) (Inzerilloa, et al., 2018) (Pan, et al., 2018) (Petitclerc, et al., 2018) (Xia, 2018) (Congress & Puppala, 2019) (Bhreasail, et al., 2019) (Basavaraju, et al., 2020) (Li, et al., 2020)
Winter Maintenance	TRL 9 (Deployment)	n/a	n/a	TRL 2-3 (Research)	(Chapman, et al., 2014) (Kociánová, 2015) (PIARC, 2016) (PIARC, 2018) (Gui, et al., 2019)

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3.2.3. ROAD INVENTORY

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3.2.4.2. *SMARTPHONES*

Several studies have demonstrated that road condition analysis can be conducted using the accelerometers fitted in smartphones. These accelerometers can capture the variation in movement caused by the road surface, assuming that different road surface conditions cause vehicles to vibrate differently.

Ghose, et al. (2012) describe the "Road Condition Monitoring App" which is a monitoring and alert system for the road conditions of a city using the embedded sensors in the smartphones of vehicle users. The application had classifiers for rough roads, bumps as well as potholes, to have a more complete picture of the roads. A study conducted by Douangphachanh & Oneyama (2013) involved driving along good, fair, poor and bad road sections with smartphones recording accelerometer and GPS data. The study concluded that a simple model may be enough to estimate road roughness condition from accelerometer data, however there were some issues with the approach because the data varies significantly with the type of smartphone, types of vehicle and the speed used to capture the data. In 2015, Forslöf & Jones stated that smartphones can be used as RTRRMS (Response-Type Road Roughness Measuring System) to collect road condition data in a simple and cost-efficient way. In their study, they explain how research conducted by the University of Pretoria in 2013 concluded that '*RoadRoid'* (a smartphone app for road surveys) was consistent enough to collect data under varying vehicle conditions.

Similarly, Singh, et al. (2017) proposed and validated a prototype of 'Smart-Patrolling' on the roads of the city Chandigarh in India. 'Smart-Patrolling' detects and identifies the potholes and bumps of the road by using an accelerometer equipped on a smartphone. It was designed based on the significant changes in the readings of the accelerometer. Furthermore, Basavaraju, et al. (2020) stated that the use of machine learning techniques to classify road anomalies based on sensor data collected from smartphones is a viable and cost-effective way of monitoring road conditions.

In the 2016-2018 Digitalisation Plan in Finland, the Finnish Transport Agency (Liikennevirasto, 2016) mentioned how the automatic data collection through mobile applications enables better maintenance and more precise work procedures. Forslöf & Jones (2015) and Brunauer & Rehrl (2016) both asserted that with continuous data collection, road administrations can better monitor changes in road roughness over time and predict minor changes and pavement defects at an early stage. However, there are some challenges like having to calibrate accelerometers of different smartphones and different vehicle cushioning characteristics, and finding adequate segment lengths for linear matching to ensure long-term trend analysis and comparability of results (Brunauer & Rehrl, 2016).

3.2.4.3. *UNMANNED AERIAL VEHICLES (UAVS)*

Unmanned Aerial Vehicles (UAVs) or Unmanned Aerial Systems (UASs) or, commonly known as drones, are becoming a popular data collection method for road condition and maintenance management. A survey conducted as part of the study *'The Use of Unmanned Aerial Systems for Road Infrastructure'* (PIARC, 2018) found that Austria, Belgium, Canada, Germany, Iran, Japan, Malaysia, Norway, Tanzania and USA, have performed a number of research projects for the use of UASs in civil applications including asset monitoring and maintenance. The PIARC study concluded that the key benefits of this technology are that it is low cost, readily available, efficient and can reach remote locations that are hard for humans to access and therefore can be safer.

Commercial UAV remote sensing technologies were introduced for pavement assessment in 2008 Zhang (2008). Since then, UAV imagery has demonstrated an important capability to ascertain the condition of paved and unpaved roads.

Inzerilloa, et al. (2018) and Pan, et al. (2018) proposed an approach that uses UAV imagery to detect pavement distress based on 3D reconstruction. The 3D reconstruction approach uses the asset location and measures the crack profile captured by the UAV to virtually reconstruct and visualise the defect. Congress & Puppala (2019) studied the use of UAV–CRP (Close-Range Photogrammetry) technology to inspect pavements built over expansive soils and obtained the characteristics and distress information. They concluded that UAV–CRP technology provides a more detailed pavement distress information than the available traditional methods currently used. Even though the UAV–CRP technology might not match the accuracy level of the laser devices, the UAV–CRP data can still be used as a quick tool to collect pavement condition data.

3.2.4.4. *OTHER FIXED SENSORS*

Fedele, et al. (2017) outlined the preliminary results of the application an acoustic sensor to moritor the effect of traffic (in terms of vibration and noise) on the condition of the road pavement. Their study considered the road pavement as the medium in which part of the energy generated by the vehicular traffic propagates. Signals from traffic-induced vibrations and sounds may be recorded by means of a microphone placed in a hole drilled into the road. The study concluded that different levels of damage can be associated to recorded signals (acoustic signatures). Each acoustic signature is different in term of peak levels and position, and periodogram shape, for example when cracks are present on the section there is a reduction of the peak frequency and an increase of the peak amplitude. In-lab tests proved the feasibility of this new method, although a more comprehensive study is still needed at this stage.

3.2.5. WINTER MAINTENANCE

Effective traffic management during extreme events is crucial, especially in countries that are frequently exposed to these phenomena. Meteorology and weather-related road condition forecasting are rapidly evolving fields, and asset owners are seeking to institute resilient and sustainable organisations and practices (PIARC, 2018). Effective management of winter road maintenance is only possible when based on relevant information related to the current and future weather conditions and surface conditions on specific road sections. That is then combined with real-time information related to vehicle movements and maintenance activities to create the basis for informed decision-making for effective winter maintenance and efficient fleet management (Kociánová, 2015).

Over the last few decades, road winter information systems have evolved from simple 'Ice Detection Systems' which detected when ice formed on a road sensor, to mature prediction systems consisting of multiple outstations, thermal mapping and forecast models. This approach has quickly spread across the globe and has been considerably refined as computer processing power and communications improved (Chapman, et al., 2014). The *'Advanced technology for data collection and information to users and operator'* (PIARC, 2016) study investigates innovative approaches for data collection and sharing of information to users and operators for the purpose of safer winter operation, with particular focus on vehicle-based technology. The improved knowledge about road surface conditions and the weather environment gained through real-time data collected using in-vehicle sensors has created opportunities to make informed decisions and automate winter service programmes.

Gui, et al. (2019) proposed the use of piezoelectric and reflection type optical sensors to detect the thickness of ice or water film, and the presence of snow on pavements. The combination of these two sensors extends the function of each other to achieve the goal of classifying six road conditions (dry, water, dry snow, slush, ice, ice covered with snow) and measuring ice and water film thickness with the upper limit higher than 5 mm. More importantly, the successful application of the sensor fusion method on the road condition detector suggests that more elements can be integrated into the detector for richer functionality such as estimating the friction of road surface.

3.3. TRAFFIC RELATED DATA AND INFORMATION

Smart Transportation as defined by Dabiri & Heaslip (2018) is a cost-effective and significant component of Smart Cities that promises to develop intelligent and novel transport models. Dabiri & Heaslip (2018) state that the principal challenge is traffic congestion due to a dramatic increase in vehicle numbers and population plus a changing balance of transport modes, and they propose a cost-effective approach to optimise the transportation network by extracting hidden knowledge in the data collected from various sources, such as GPS systems, mobile phone networks, commuting smart cards, environmental sensors, as well as traffic sensors.

This section of the literature review will discuss traffic data and the different collection methods used to gather it. Three main data collection methods were identified: Traditional sensors, Smart Sensors and Cameras. Table 2 maps the methods used to collect data for different usage and purpose to provide an overview of how traffic data is being gathered and used across countries and road agencies.

The table uses NASA's Technology Readiness Levels (TRL) to assess the maturity of each technology or collection method. The table also provides a list of literature references for each data type.

Table 2: Traffic management data collection methods

Data Type/Usage	Collection Method				References in Literature
	Traditional Sensors	Smart Sensors	Cameras	UAVs	
Traffic Management	TRL 9 (Deployment)	TRL 7-9 (Deployment)	TRL 9 (Deployment)	TRL 2-4 (Research/ Development)	(Ang & Seng, 2016) (Lai, et al., 2016) (Takeuchi & Oka, 2016) (Chen, et al., 2017) (Lee, 2017) (Dabiri & Heaslip, 2018) (Elloumi, et al., 2018) (Karouani & Elhoussaine, 2018) (Zenkert, et al., 2018) (Zen Traffic Data, 2018) (Emami, et al., 2019) (Ghosh, et al., 2019) (Gheorghiu, et al., 2019) (Khan, et al., 2020)

3.3.1. TRAFFIC MANAGEMENT

3.3.1.1. *SENSORS*

Economic growth typically results in an increase of both freight and passenger traffic, which creates additional demand on the transport network. Chen, et al. (2017) stated that developing a sustainable, intelligent, and green transportation system is of crucial importance. They presented one practical solution that uses cutting-edge wireless information and communication technologies to provide real-time transport related information services to road administrations and road users. As a result, transportation efficiency can be significantly improved, making traffic flow more smoothly, and keeping travellers better informed whilst allowing them to make smarter route selections and enhancing their overall journey experience.

Recent developments in sensor technologies and availability of various transport sensors in the era of connectivity are paving the way for the development of more precise and accurate traffic prediction algorithms in which data from various sensors are fused. In Australia, Emami, et al. (2019) proposed a Kalman Filter algorithm to predict the flow of vehicles in urban arterials with signalised intersections, using the data from both fixed sensors and probe vehicles to provide a better estimation of traffic flows. Similarly, Ang & Seng (2016) and Karouani & Elhoussaine (2018) both concluded that the number of sensors/devices available for integration into 'networked systems' is increasing rapidly, and that the emergence of new technologies such as IoT and large-scale wireless sensor systems enables the collection of data from a large volume and variety of networked sensors. Sensors allow for large amounts of traffic related data to be captured instantaneously to provide real-time traffic information.

Generally, people tend to actively participate in the process of recording data about different aspects of their life using technologies such as GPS systems, cellular networks, social media services, and Automated Fare Collection System (AFCs) smart cards. Such diverse and advanced sensing technologies can deliver large-scale data and information on travel behaviours, which can be fed into advanced learning algorithms and data analytic models to bring a variety of benefits. This may include modern traffic management and control strategies, robust vehicle detection systems, mining mobility patterns, travel demand analysis, incident detection, air quality measurement, urban planning, and emergency systems (Dabiri & Heaslip, 2018).

Smartphone Bluetooth sensors have also been proposed as a tool to provide low cost traffic analysis. Gheorghiu, et al. (2019) introduced the use of Bluetooth Low Energy (BLE) technology to collect information about vehicle passengers' activities and detect the communications in road junctions. Based on the time of each detection and the distance between detectors the speed, direction and current position of the vehicle can be determined.

The use of Probe Vehicle Data or commonly known as Floating Car Data (FCD) makes it possible to respond to the various issues of road safety and the reduction of congestion (Karouani & Elhoussaine, 2018). Lai, et al. (2016) proposed analytical models to estimate traffic flows based on cellular floating vehicle data (CFVD) which analyse signals like handovers (HOs), call arrivals (CAs), normal location updates (NLUs) and periodic location updates (PLUs) cellular networks. The same types of input data may be also used to generate longer-term forecasts of future traffic conditions.

In Japan, Takeuchi & Oka (2016) introduced Active Traffic Management (ATM) as a leading-edge technology to manage traffic flow, reduce congestion and improve road safety. Information such as accidents, congestion, weather, road defects, obstructions and lane closures are collected in real-time via control centres. This information is then processed and delivered using a wide range of mediums. Variable Message Signs (VMS) have also been introduced to alert users to evolving roadway conditions. VMS are then used to communicate congestion prediction and real-time information to encourage drivers to alter routes based on journey time reductions.

Zenkert, et al. (2018) proposed a smart mobility strategy based on the analysis of large datasets which are collected from different sensors, all deployed at various places in Aarhus, Denmark. Those datasets include various data types related to pollution, weather, road traffic, parking, as well as cultural events information. The smart mobility approach uses the pollution and road traffic information from the data and analyses it to calculate routing possibilities and to find the least polluted way from start to end points based on current conditions indicated by the sensor data. Similarly, Traffic Scotland collects information about roadworks, accidents, congestion and weather events and uses it to improve the operational efficiency of the Scottish trunk road network. Traffic Scotland provides information on current Scottish trunk road traffic conditions that will help road users make informed decisions as to the timing, routing and travel mode choice regarding for their journeys. This information can help to reduce disruption caused by incidents, minimising the effects of congestion and thereby improving the safety and efficiency of the road network.

Detection based technologies such as inductive loop detectors are also being used for traffic management purposes. The *'Inductive loop detection systems and methods'* (Myers & Gurghian, 2019) describe several methods to receive image data from camera on a vehicle to determine the geographic position of the induction loop on the road. Based on the image data and the geographic position of the vehicle, the detector determines the exact location of inductive loop in a roadway.

3.3.1.2. *CAMERAS*

Today, a significant proportion of data related to road occupancy, vehicle speed, accident detection, traffic collision and weather information comes from CCTV systems or GPS signals (Lee, 2017). Ghosh et al. (2019) developed an adaptive traffic monitoring system based on computer vision technology by utilising fixed point cameras to detect, classify, count and measure the speed of vehicles on the road.

The system considers factors like the shadow effect of vehicles used to ensure hight data accuracy. In Norway, Namazi, et al. (2019) proposed the use of vehicle-mounted monocular cameras to collect traffic data from multiple lanes. This dynamic aims to detect the distance between vehicles and the speed of vehicles to achieve large-scale traffic inspections and detect real-time traffic conditions.

In Japan, a vehicle trajectory database generated by image sensing technology includes nearly 100% of each vehicle’s trajectory in several sections of the Hanshin Expressway. The data is captured by cameras installed on light poles on the expressway, then, vehicle trajectory data is generated using image processing technology. The database intends to achieve safer and more comfortable journeys for all highway users. Since the database includes vehicle trajectory data and location data of all vehicles, it can be utilised not only for driving and traffic analysis but also to visualise and understand other complex traffic related issues (Zen Traffic Data, 2018).

3.3.1.3. *UNMANNED AERIAL VEHICLES (UAVS)*

The use of UAVs for traffic management is another area that is being explored as they can cover larger areas at a relatively low cost and the inspections can be undertaken remotely. Elloumi, et al. (2018) assessed the performance of traffic management by using UAV technology. They proposed a method that used UAVs trajectories to gather traffic information by organising multiple cooperative UAVs. Amongst the benefits of using UAVs for traffic monitoring, the study stated the possibility of vehicle identification when equipped with cameras and image processing capabilities. Moreover, they can be deployed to any area of interest without the need for additional infrastructure. Nonetheless, UAVs are limited by battery life and their use is not completely regulated yet and may causes privacy, safety and security issues.

In Saudi Arabia, Khan, et al. (2020) proposed a new model for speed limit and traffic violation monitoring system that combines UAVs and 5G technology. Their study aimed to detect and record high-speed or any other driving violation on highways. Additionally, the system would send alerts to the drivers using 5G. The projected results are positive, but this system still needs improvement and application in real environments.

3.4. DATA FROM CONNECTED AND AUTONOMOUS VEHICLES (CAVS)

As stated in the ‘*Cooperative Vehicle Highway Systems*’ report (PIARC, 2016), the emergence of information and communication technology has had a profound impact on vehicle and roadside systems. Embedded electronics account for more than 30% of the cost of a vehicle, including a multitude of sensors and actuators, various computers, Engine Control Units (ECU) and internal digital networks for interconnectivity. The introduction of these technologies has stimulated a hike in the interest of using information and driving assistance systems with the main objective of improving road safety and driving comfort, and also for car manufacturers to remain prominent within a highly competitive market. These systems also have the potential to significantly improve the efficiency of traffic management systems and provide better accessibility for all users. Table 3 maps the different data types collected using CAVs. The table uses NASA’s Technology Readiness Levels (TRL) to assess the maturity of each technology or collection method. The table also provides a list of literature references for each data type.

Table 3: Data types collected using CAVs

Data Type/Usage	Collection Method CAVs	References in Literature
Road Condition	TRL 4 (Development)	(DfT C-ITS Project, 2018)
Traffic Management	TRL 4-6 (Development)	(Xu, et al., 2019)
Safety	TRL 4-6 (Development)	(Chen, et al., 2017) (Kamrani, et al., 2017) (Siems-Anderson, et al., 2017)

3.4.1. ROAD CONDITION DATA

In the UK, the Department for Transport (DfT C-ITS Project, 2018) is using CAVs with LiDAR to undertake inspection activities and support the analysis of road condition and asset maintenance requirements. LiDAR data is being integrated into existing processes, aiming to identify where this approach can be used instead of manual inspections. Additionally, the Department for Transport has funded the Enhanced Continuous Asset Monitoring Solution (ECAMS) project with Transport for West Midlands, which will take data from connected vehicles to measure road quality and identify potholes. Data will be collected by sensor units such as accelerometers and gyroscopes, then fed into a new road surface asset management and quality system which looks at current road inspection regimes and identifies where ECAMS data can support future road inspections. This provides road managers with constant road asset information to respond to asset deterioration at an early stage and predict asset failures before they occur.

3.4.2. TRAFFIC MANAGEMENT

In China, Xu, et al. (2019) proposed a real-time adaptive signal-control algorithm for signalised intersections in a connected vehicle environment. In this method, data from connected vehicles, including elapsed time, vehicle stops and queue state index, are collected by a roadside unit at an intersection. The results of data integration are used to reveal real-time traffic conditions and predetermine the next signal phase. The actual phase sequence and duration are finally determined with restrictions on the minimum and maximum green light time.

3.4.3. SAFETY

Traditionally, evaluation of road safety at intersections has been largely reactive, based on historical crash frequency data. However, emerging data from CAVs can complement historical data and help to proactively identify intersections which have high levels of variability in sudden changes in driving behaviours prior to the occurrence of crashes (Kamrani, et al., 2017). Their study demonstrated a proactive intersection safety methodology using real-world large-scale connected vehicle data. The study quantifies volatility in instantaneous driving decisions using intersection-specific Basic Safety Messages (BSMs) and its relationship with observed crash frequencies, while controlling for other variables. Such a method can complement the state-of-the-art in evaluating intersection safety based on observed and expected crash frequencies.

The Wyoming Department of Transportation deployed a Connected Vehicle pilot project to address hazardous weather issues that are common on their roads. Siems-Anderson, et al. (2017) presented the Pikalert System, a collection of modules designed to ingest and quality check vehicle-based observations, and to assess, forecast and disseminate road weather hazards and warnings. By melding vehicle observations with traditional ancillary observations (e.g. weather radar, Road Weather Information System (RWIS) stations), Pikalert uses connected vehicle data to fill in the gaps between RWIS stations and other ground observations.

3.5. ROAD TECHNOLOGIES RELATED DATA AND INFORMATION

Datta, et al. (2016) suggested that Intelligent Transportation Systems (ITS) and connected vehicles together with the IoT have the potential of providing more efficient and sustainable transportation systems that minimises the impact on the environment.

Table 4 maps data gathered from vehicles (including CAVs) or from Intelligent infrastructure for ITS. The table uses NASA's Technology Readiness Levels (TRL) to assess the maturity of each technology or collection method. The table also provides a list of literature references for each data type.

Table 4: ITS data collection methods

Data Type/Usage	Collection Method		References in Literature
	Vehicles (Including CAVs)	Intelligent Infrastructure	
ITS	TRL 7-8 (Deployment)	TRL 7-8 (Deployment)	(De Marinis & Adiletta, 2015) (Patey & Wickham, 2016) (ADEPT, 2017) (Kühn, et al., 2017) (PIARC, 2019) (Turcanua, et al., 2020)

From a transport infrastructure perspective, the '*Cooperative Vehicle Highway Systems'* report (PIARC, 2016) states that today roads are equipped with many detection and information devices allowing road operators to gain knowledge of the network condition and to provide information, recommendations and instructions to users and operators. These integrated transport systems aim to improve road safety, promote multi-modality and facilitate commercial transactions (electronic tolls, e-commerce, etc.).

3.5.1. INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

ITS have been widely used to mitigate various transportation challenges and will continue to play an increasingly important role in securing the future of sustainable mobility (Makano, 2017). The emerging ITS and vehicular applications, however, require substantial efforts in real-time information collection and big data processing to allow quick decision making and feedback to fast-moving vehicles, which imposes significant challenges on the development of an efficient vehicular communication platform.

Vehicles today are able to produce huge amounts of information known as Floating Car Data (FCD), gathered from sensing the internal operation of the vehicle and the external environment. Adding networking capabilities to a vehicle allows it to share this information with other vehicles and with the wider infrastructure. Collecting real-time FCD information from vehicles opens up the possibility of having access to an enormous amount of useful information that can boost the development of innovative services and applications in the domain of ITS (Turcanua, et al., 2020).

Assistance systems are increasingly supporting the operation of vehicles in three ways: stabilisation, driving and navigation. By introducing new kinds of sensor technologies, the vehicle can take over for a certain time and the driver just monitors the driving process. However, if a high degree of reliability is provided by the vehicle system, the driver may only have to take over control in exceptional situations – or not at all. Kühn, et al. (2017) conclude that the experiments conducted so far have clearly shown that prior knowledge of the geometrical elements of a roadway is essential to support highly automated driving scenarios. To support this, road administrations should make digital road data available with a standard degree of detail and a format that can be processed. It is possible to improve the safety of automated vehicles by analysing in real-time what is happening on the road and adapting the driving style to actual traffic conditions.

Many countries in the world are investing in this approach, but many face constraints such as:

- Political environment not suitable for data sharing and exchange;
- Privacy issues related to data publication and distribution; and
- Lack of policy and governance to control and regulate information exchange within different operators.

The following sections outline the differences in how ITS are being deployed in HICs and LMICs.

3.5.1.1. *HIGH INCOME COUNTRIES (HIC)*

Managed Motorways have established ITS as an integral part of the network and an essential tool for a road network operator. Patey & Wickham (2016) stated that whilst the aims of ITS are broadly similar across high-income countries – reduced congestion, more reliable journey times, reduced environmental impact from travel and improved safety – the approaches taken are markedly different. For example, where in Australia the basic building block is Coordinated Ramp Signaling, an approach used in England has added capacity by use of a dynamic hard shoulder. However, both approaches use the core principles of ITS as a tool for network operations as outlined by Patey & Wickham (2016): detection, analysis and decision making, information and instructions, communications, driver behaviour and infrastructure.

Digital innovation has the potential to deliver the highways systems of the future, improving roads, network management and user experience. To support this, the UK Government has set out a commitment to transformation driven by digital, technology and social innovation, where transport services can be integrated into a single demand-led service, defined as ‘Mobility as a Service’ (MaaS) (ADEPT, 2017).

Similarly, in Italy, the systematic adoption of information and communication technologies to improve safety, efficiency, competitiveness and sustainability of Italian road networks, represents a tremendous opportunity for the country as a whole for the next decade (De Marinis & Adiletta, 2015). In this context, ANAS Services Ltd. has developed and rolled out a new ITS system, named ANAS Road Management Tool (ANAS RMT), with the goal to improve efficiency and effectiveness of road network management. The new system was specifically developed according to ANAS needs to control all operations and activities on the road network with one single system to monitor current events on the network and promptly manage road operations, and to integrate information coming from different sources and visualise them on maps.

3.5.1.2. *LOW-MIDDLE INCOME COUNTRIES (LMIC)*

ITS technologies have been widely used to mitigate many transportation challenges and will continue to play an increasingly important role in securing the future of sustainable mobility. Yet, the ‘Uses of ITS including consideration of planning for future improvements, upgrades and the economy’ report by PIARC (2019) states that due to the complexity of integration of Information Systems (IS) in the field of ITS, it is desirable for developing countries to define and develop ITS architectures at the national level – these will function as overarching frameworks within which individual components or groups of components of ITS can be deployed. Such approaches will ensure that systems developed and deployed at different places and times are interoperable and compatible with each other including existing ones. Isolated development managed by disparate parties without any master framework to guide the work can lead to incompatible and non-interoperable systems that will hinder further development and expansion of ITS in the country.

The ‘Low-cost ITS’ report by PIARC (2019) investigated the development and the different aspects of low cost ITS solutions. This report stated that providing a definition of low-cost is an impossible task because the boundary between traditional and low-cost approaches is not so clear. A solution may be low cost for stakeholders who operate a service or for the end user who benefits from it. For operators, any solution aimed at improving the efficiency of infrastructure investment, maintenance and operation will require cost to implement but should provide overall savings across the lifecycle. For the road user, the cost includes both the investment in and maintenance of their vehicle's equipment and/or smartphone as well as any service subscription when the provision of service is not free.

So far, almost all floating vehicle-based applications are focused on traffic information and incident, accident and congestion detection. But as shown in the PIARC report, services based on floating car data is becoming more widely available and new services are likely to appear in the near future, many of which will help make the road safer and more efficient. It was noted though that implementation of some of those services could not be considered through conventional approaches and processes. The report recommends that whenever the low-cost solution does not compromise the quality, availability or resilience of service, it should be preferred over any other solution.

LMICs may face challenges in finding efficient ways to manage their assets given the constraints on financial resources. The deployment of low-cost approaches, although in early days, is promising and it is very likely that new services that were not previously explored will be deployed at lower cost to benefit both LMICs and HICs.

3.6. DATA GENERATION FOR AND FROM SOCIAL MEDIA

Road traffic analysis and prediction is a critical component of modern smart transportation systems. In order to share traffic information with a large audience, traffic control organisations have started using social media.

Table 5 below maps data gathered from social media for both traffic forecasting and journey information for road users. The table uses NASA’s Technology Readiness Levels (TRL) to assess the maturity of each technology or collection method. The table also provides a list of literature references for each data type.

Table 5: Data types generated for and from Social Media

Data Type/Usage	Source		References in Literature
	Twitter	Facebook	
Traffic Forecast & Events Detection	TRL 8-9 (Deployment)	TRL 8-9 (Deployment)	(Minh, 2016) (Chen, et al., 2017) (Badrinaaraayanan, et al., 2018) (Alomari, et al., 2019) (Dabiri & Heaslip, 2019) (Mounica & Lavanya, 2020)
Journey Information	TRL 8-9 (Deployment)	n/a	(Zhang, 2017) (Nie, et al., 2019)

3.6.1. TRAFFIC FORECAST AND EVENTS DETECTION

Chen, et al. (2017) stated that social network information is an effective data source for traffic sensing, and the core idea of their study is making data analytics and traffic-dependent networking mutually beneficial. Their study presented a novel framework used to build a connection between real-time traffic and networking, which suggests that traffic has strong correlations with online navigation services; the more people in a particular geographic place who are searching for routes to a particular destination online, the more probable that traffic congestion will happen along the route to the destination. In which case, traffic can be predicted using data from search engines.

Mounica & Lavanya (2020) stated that data from social media can be used for transportation analysis purposes such as traffic predictions, accident zones analysis, etc. However, the data sourced from social media is highly unstructured and is of massive volume and therefore requires complex processing methods. They proposed a text retrieval system to process raw data into a proper format and concluded that social media data and ITS can be used in conjunction to deliver efficiencies and improve road safety management.

3.6.1.1. *TWITTER*

Twitter have increasingly become an important source of information in various dimensions of smart societies; one of them is the automatic detection of traffic events using Twitter data mining. Using social media data to forecast traffic events has an enormous potential, but it also faces major challenges concerning the management and analysis of big data such as its volume, velocity, variety, and veracity (Alomari, et al., 2019).

Minh (2016) explored how Twitter data could be used for traffic detection in Finland. In his study, Minh argues that the short and concise nature of Twitter messages and the well-defined and well-documented Application Programming Interfaces (APIs) provided by the service significantly facilitate data collection and analysis. Additionally, the Finnish user base of the application can be considered large in proportion to the overall population, and based on the data samples collected, their activity can already be deemed enough to build a social media-based traffic information system. The use of social media is also expected to increase over the next few years and this, paired with an intensive advertisement campaign for the appropriate traffic reporting channels, can result in significantly greater volumes of user submitted reports and thus more accurate traffic detection.

Alomari, et al. (2019) proposed a method for automatic detection of road traffic related events from tweets in Saudi dialect using machine learning and big data technologies. Results showed that the proposed method is able to detect road traffic events, as well as their location and time, automatically, without any prior knowledge of the events. Dabiri & Heaslip (2019) also proposed a Twitter-based traffic-event detection framework to be used as a complementary source for monitoring traffic conditions and detecting traffic incidents. Deep-learning architectures require a large volume of training samples to efficiently learn patterns and variations inside the data, so for their study they collected large volumes of tweets and annotated them into three labels: 1) non-traffic, 2) traffic incident, and 3) traffic information and condition. After obtaining traffic-related tweets, the last step is to identify the location of the occurred traffic event. However, the irregularity and incompleteness of the location information in the tweets makes the geocoding problem more challenging.

3.6.1.2. *FACEBOOK*

In India, traffic control organisations use Facebook pages to share the important traffic information in the form of posts. These posts can be of many types such as general safety information, accidents, water logging, live traffic updates, reasons for traffic disruption, traffic diversions, etc. This important information can be used by the government to identify the major traffic issues in cities, and Government organisations can analyse how an issue is affecting a city over a period of time and/or compare the intensity of an issue across multiple cities. It can also be used by individual users to understand the various traffic issues in their localities (Badrinaaraayanan, et al., 2018).

3.6.2. JOURNEY INFORMATION

Social networks such as Facebook and Twitter are used by the public to express their perceptions and circumstances in various aspects of their lives. People publish tweets and post Facebook messages related to transportation systems to report what they have seen on the road, especially when an unusual or unsafe situation (e.g., pothole, traffic incident, etc.) occurs. However, many of those posts fail to get a timely response from referred agencies. Nie, et al. (2019) proposed a novel approach to monitor and detect critical real-time information from public awareness. Their study used tweets to demonstrate a keyword-extraction process using the Term Frequency method to gather valid transportation terms in public tweets. A machine learning-based model was trained to identify transport related tweets from the live stream. The results showed that the trained machine learning model's overall performance was over 80%. This framework can be employed by public agencies to identify key public posts related to transportation in a timely and proactive manner.

Current ITS requires swift responses to emergency situations, good capability of road facilities, flexibility of traffic operations and an effective road knowledge feedback system prepared to report this information to road users (Zhang, 2017). Integrating crowdsourced data into transport operations requires new techniques and methodologies from fields such as computer science, Geographical Information Systems (GIS), social networks, etc. Zhang (2017) highlighted the potential benefits of blending traditional loop detector data, social media data and other geographic information for advanced traveller information.

3.7. ROAD SAFETY RELATED DATA AND INFORMATION

Statistics show that one of the global leading causes of death by injury are road traffic accidents. In recent years, thanks to new technology in roads and vehicles and improved operations and behaviours, the number of accidents has been falling steadily, but the main cause of traffic accidents continues to be rear-end collisions. In a survey done by Khalil, et al. (2017) it was observed that a proportion of road accident deaths are due to the late arrival of the emergency services to the site of the accident. In such cases the injuries are not as severe to cause immediate death, however, due to a delay in the arrival of the rescue team, the injuries can become fatal. Their research explains how this can be mitigated or avoided with the use of technologies such as the Vehicle Ad-hoc Networks (VANET) for accident detection.

The following sections will describe different methods being used to detect collisions and predict areas of concern and thus make roads safer.

Table 6 provides an overview of the different methods used to collect data about accident detection and road safety improvements. The table uses NASA's Technology Readiness Levels (TRL) to assess the maturity of each technology or collection method. The table also provides a list of literature references for each data type.

Table 6: Road safety data collection methods and data types

Data Type/ Usage	Collection Method						References in Literature
	Sensors	Smart phones	GPS and GMS	VANET	Ultra-sonic sensors	UAV and UAS	
Accident Detection	TRL 8-9 (Deploy.)	TRL 4-7 (Develop.)	TRL 8-9 (Deploy.)	TRL 8-9 (Deploy.)	TRL 1-3 (Research)	n/a	(Alwan & Alshaibani, 2015) (Mohammadi, et al., 2016) (Ozbayoglu, et al., 2016) (Khalil, et al., 2017) (Khalil, et al., 2018)
Road Safety	n/a	n/a	n/a	n/a	n/a	TRL 4-7 (Develop.)	(Steinbrucker, 2020)

3.7.1. ACCIDENT DETECTION

The recent significant increase in available accident data can make it challenging to analyse the factors causing road accidents. Li, et al. (2017) described a method for mining frequent patterns causing road accidents from collected data sets. It makes use of association and classification rules to discover patterns between road accidents on existing roads and predict road accidents on new roads.

Automatic road accident detection techniques using smartphones, GSM and GPS technologies, and VANET aim to timely inform emergency services about the location of an accident. Alwan & Alshaibani (2015) proposed an accident detection and notification system that uses smartphones sensors such as accelerometer, GPS, microphone and camera. These sensors can record vehicle acceleration, estimate vehicle speed, detect high decibel acoustic events and store video records which increases the probability and the accuracy of detecting an accident. However, one of the main obstacle is determining whether the occupant is inside or outside the vehicle while the vehicle is travelling at a low speed. The study concluded that further research is needed to improve the accuracy of the detection phase and reduce the probability of false positive signs.

The use of VANET is regarded by Khalil, et al. (2017) as the best method for accident detection as it not only detects an accident but also provides an optimum route for the ambulance to reach the accident site as soon as possible. In their research, they highlighted that smartphones or mobile applications can provide accident detection and notification in all vehicle types including bicycles and motorcycles. However, it may not be possible to detect all accidents with this technology as the filters utilised to prevent false positives may in fact discard some actual positive cases.

In Turkey, an automated accident detection system was implemented (Ozbayoglu, et al., 2016) using data from Istanbul's highway sensor readings and traffic database. The data is processed and consolidated using big data processing techniques and several different computational intelligence models. Similarly, in Iran, Mohammadi, et al., (2016) used data from the traffic police, trauma centres, medical emergency centres, and via the internet to develop a Minimum Data Set (MDS) to create a traffic accident information management system. The study concluded that planning for the prevention of traffic accidents requires standardised data. Existing standardised data infrastructure present policymakers and government officials with a clear opportunity to strengthen and integrate existing accident information systems to better track road traffic injuries and fatalities.

Khalil, et al. (2018) proposed a method for accident detection using ultrasonic sensors. One of the key advantages of this method is that these sensors can detect accidents in different locations and situations such as a crossing point, an underpass, a tunnel or a bridge, and additionally it might perform well under different weather conditions. This ultrasonic sensor is currently hypothetical, but practical implementation is under research. Once this methodology is fully implemented, the number of road fatalities could decrease by reducing accident response time.

3.7.2. ROAD SAFETY

A research recently conducted by ÖBB (Austrian Federal Railways) has examined the different uses of UAVs. The following areas of road safety application emerged as being particularly efficient: natural hazards during terrain movements and snow profiles, support for crisis management in the occurrence of events, accidents and damage and ongoing traffic monitoring (Steinbrucker, 2020). The first results of the project were promising but showed that the use of drones in the transport infrastructure sector is still largely in its early stages. Simple applications can already be implemented without any major issues, however when it comes to integrating the information from the drone into the existing IT infrastructure or processing it, further work is still required to make it usable in the long term and suitable as a technical solution.

3.8. DISASTER MANAGEMENT DATA AND INFORMATION

The quality of the information available to road organisations greatly influences the quality of disaster management activities. Current trends in disaster management include an emerging realisation that greater focus is required on the interaction of disaster management activities with the public to produce better results. This compares to the traditional disaster management approach of prioritising making infrastructure safe. The Disaster Information Management for Road Administrators technical report (PIARC, 2019) highlights case studies and best practices for improving management techniques in disaster situations.

Table 7 maps the methods and usage of data related to risk and disaster management to provide an overview of how data is being gathered and used across countries and road agencies. The table uses NASA's Technology Readiness Levels (TRL) to assess the maturity of each technology or collection method. The table also provides a list of literature references for each data type.

Table 7: Disaster management data collection methods and data types

Data Type/Usage	Collection Method					References in Literature
	Satellite Images	Meteorology	Cameras	Vehicle Detection	GIS	
Disaster Management	n/a	TRL 9 (Deploy.)	TRL 9 (Deploy.)	TRL 9 (Deploy.)	n/a	(PIARC, 2016)
Disaster Relief	TRL 9 (Deploy.)	TRL 9 (Deploy.)	TRL 9 (Deploy.)	TRL 9 (Deploy.)	TRL 9 (Deploy.)	(Khan, 2018) (Hanshin Expressway, 2017)

3.8.1. DISASTER MANAGEMENT

Whilst the Coronavirus (COVID-19) pandemic and resulting impacts on the use of road networks and its users emerged after the project objectives had been set, many of the overall data requirements and planning approaches are relevant to work on disaster management that PIARC has already done.

The 'Risk Management for Emergency Situations' technical report published by PIARC (2016) concluded that in view of potential, future large-scale and/or combined disasters, dynamic risk management is needed more than ever. Road administrations should aim to improve the robustness of the road transport system so that it becomes resilient to minor disturbances, remain functional during emergencies and does not become inoperable due to the failure of other systems. Through selected case studies, the report analysed how emergency situations affecting the road transport system are managed by different countries and road administrations. The report considered in particular the issues of coordination between the different authorities, coordination between different transport modes, the information to users and the response from the public.

Similarly, 'The Disaster Information Management for Road Administrators' technical report (PIARC, 2019) presented disaster information management and disaster management with the public as key approaches to manage disasters while adapting to the society changes. In Japan, Hanshin Expressway monitors meteorological conditions including earthquakes and traffic conditions continuously, providing necessary information to customers and making available disaster management equipment and facilities to ensure the safety of customers. Based on the lessons learned from the damage of the Great Hanshin Earthquake, Hanshin Expressway is working on seismic retrofit of existing bridges as well as construction of new bridges.

3.8.2. DISASTER RELIEF

The Hanshin Expressway Disaster Management Centre serves as an emergency base that conducts integrated and comprehensive response actions in the event of a disaster. The Disaster Management Centre is connected to emergency terminals installed at departments and to cameras installed in the expressway to support disaster response activities. When an earthquake of seismic intensity of five or more occurs, they immediately close the entrances to the expressway, implement road closures and conduct emergency inspections. Additionally, highly visible LED lamps are used for road message signs. In the event of a major earthquake, three types of messages will be shown, "Earthquake Occurred - Warning," "Earthquake Occurred - Slow Down," or "Earthquake Occurred - Pull Over."

Furthermore, Hanshin Expressway uses GIS systems to predict the damage caused by an earthquake and to identify priority routes using information about seismic waves location and seismic intensity location. A vehicle counter system is used to provide the number of vehicles that are between each entrance and exit at any given time (not traffic flow). Additionally, terrain and structures models are used to predict the post-event situation of viaduct roads through a combination of earthquake simulation and driving simulation.

Similarly, in Bangladesh, Khan (2018) presented a novel approach to finding the shortest path to a disaster site so that the relief team can reach the affected area as soon as possible. The study presented a device that can automatically download two images with the help of the satellite, one right after the disaster and the other is just before the disaster. The device will then compare the two images to find out the damaged area with an image processing algorithm. After getting all the information about the damaged area, it will run a 'route-find' algorithm to locate the shortest way to reach the affected area. Khan (2018) stated that when a serious disaster occurs, it takes a long time for authorities to grasp the damages occurred through an inspection patrol, even if they ignore minor damages and focus only on serious damages. In such situations, the device presented can play a crucial role.

3.9. SUMMARY AND RECOMMENDATIONS

3.9.1. SUMMARY OF FINDINGS

The literature review above identified a broad range of technologies and data sources (over 100 sources), with even more information shared via an indexed spreadsheet available on the PIARC website (over 200 sources). This source of knowledge should be used by road administrations to understand the state-of-the-art in particular areas of interest and review what is possible. The technical papers and reports should then be used to inform the approach at a local level, providing a robust starting point for development and potential learn lessons to apply.

The following are the key opportunities and challenges regarding the use and collection of road data identified from the literature review.

- Road condition analysis conducted through the use of accelerometers fitted in smartphones provides the potential for data collection to be done continuously, therefore allowing road adminstrations to monitor road condition on an ongoing basis. However, this needs to be balanced against reduced detail of information compared to some traditional, lower frequency approaches. The extent of road data collection should also focus beyond inventory and condition of pavements and cover the full range of highway assets (road marking, streetlighting, barriers, drainage assets, etc.).
- The use of drones as data collection method for asset condition and maintenance management provides a low cost, readily available and efficient option for road administrations and can reach remote locations which are difficult to access. Areas of improvement include the integration of information from drone surveys into existing IT infrastructure or work processes and how this supports decision making, plus better alignment with wider management of airspace surrounding road infrastructure.
- In-lab tests proved the feasibility of using an acoustic sensors to monitor the effect of traffic on the condition of the road pavement. Signals from traffic-induced vibrations and sounds are recorded by means of a microphone placed in a hole drilled into the road; the different levels of damage can be associated to the different acoustic signature recorded. Smart mobility strategies need to be based on the analysis of large datasets, from a range of sources including

sensors and third party data providers. This can provide benefits across local areas or wider regions including national level, but requires skills to understand the full range of data (e.g. road traffic, pollution, weather, etc.), processes to analyse and utilise the data (e.g. big data techniques) and platforms/systems to support this.

- Critical real-time information of public experience can be monitored and detected from social media. This may involve using approaches such as keyword-extraction and machine learning-based models to identify and process transport-related comments from live streams of data.
- The introduction of CAVs onto road networks creates opportunities for increased understanding of road infrastructure, the service it is providing and the environment that it is operating in via onboard sensors. This needs to be balanced with the data requirements that CAVs need in order to function safely, such as up to date and consistent data on road layout and restrictions. The reliability and security of these data flows are critical.
- Common data standards and architecture are required at national level and ideally internationally to provide consistency and interoperability across vehicles, infrastructure, systems and processes. This will enable greater effectiveness of solutions, reduce risks of unintended harm and promote a more stable environment for innovation to be encouraged (either within road administrations or through private sector partners).
- Using social media data to forecast traffic events has an enormous potential, but it also faces major challenges concerning the management and analysis of big data such as its volume, velocity, variety, and veracity. Twitter-based traffic-event detection framework can be used as a complementary source for monitoring traffic conditions and detecting traffic incidents. However, the irregularity and incompleteness of the location information in the tweets makes the geolocation of events more challenging.
- Using smartphones sensors such as the accelerometer, GPS, microphone and camera for accident detection provides a real-time and low-cost solution. However, there are still challenges with this technology as the detection system is not able to determine whether the smartphone detecting the accident is inside or outside the vehicle while the vehicle is travelling at a low speed.
- Disaster management techniques may combine data from vehicle tracking, sensors covering seismic location and intensity, ground and structural modelling, and simulation systems to identify sections of the road network for prioritised responses.
- Collecting real-time information on the operation of roads and the vehicles travelling on them creates an enormous amount of useful information to support the development of innovative services and applications to benefit not only road administrations but also the users, businesses and public services that rely on the road network.

3.9.2. RECOMMENDATIONS FOR ROAD ADMINISTRATIONS

R1. Learn from the literature review, then act and improve:

- Conduct a high-level review of the findings to understand the range of technical capabilities covered, and identify specific areas of interest.
- Review specific topics and data types in more detail, including the associated state-of-the-art data collection methods, via the content of the report plus the additional literature resources listed separately on the PIARC website.
- Learn from existing technical knowledge, and use this to inform local pilots, trials or applications which will in turn add to the advancing state of knowledge.
- Continue to maintain and update the literature as new technologies, processes and standards evolve along with their potential to collect, analyse and utilise data.

4. STAKEHOLDER ENGAGEMENT (ONLINE SURVEY)

4.1. INTRODUCTION

Following on from the literature review, an online survey was conducted to capture further insight on how different types of road data are collected and used by road administrations across different countries. 46 countries, covering different geographical regions and income levels, completed a questionnaire consisting of 12 main questions, covering three themes related to road data; Road Network, Road User and Context.

The 12 main questions included in the questionnaire are outlined in Table 8 below:

Table 8: Questions from Online Survey

Ref	Question
1	Do you collect and analyse inventory data and condition data for road infrastructure assets?
2	Do you collect and analyse traffic related data?
3	Do you collect or use road related data for the management of roadworks and the overall road network?
4	Do you collect or use certain data which can be linked to the development or optimisation of programmes of work for routine maintenance as well as for winter maintenance and operations (including identification of priority routes)?
5	Do you collect our use certain data which can be linked to investment planning of road assets and the management of road infrastructure? This includes asset planning, route planning or network wide planning.
6	Do you have any system(s) in place for effective situation observation or effective response to natural/man-made disasters or emergencies that can affect the road network and its users? (e.g. earthquakes)
7	Do you share any data / information with the users of the road network?
8	Do you actively seek and collect feedback on the satisfaction of road users in a formal method?
9	Have you conducted any research or field trials on the benefits or use of Connected and Autonomous Vehicles (CAVs)?
10	Do exchange/share any road related data with third parties or other national/global stakeholders?
11	Do you have any methods in place to measure air quality, transport emissions, noise levels or any other environmental aspects related to road infrastructure?
12	Do you gather any data on the benefits/impacts on the road network related to social or economic factors (e.g. health and wellbeing of the public, prosperity of local communities, etc.)

Responses were in the form of multiple choices to a provided list of technologies and collection methods, as well as providing comments. The analysis of responses was therefore conducted using quantitative and qualitative methods to develop a better understanding of how road data is collected and used by different countries. Each of the income level, geographical region and urban / rural status (as per the World Bank definition of whether the country is predominantly urban or rural) were distinguished throughout each question.

Analysis was conducted in Microsoft Power BI to create interactive visuals and gain insights into the comments provided by several countries to aid the analysis across the three classifications. Each question was also analysed by its sub-questions to interrogate the data and the comments from a qualitative perspective. The world map in Figure 5 shows the representation of responses across geographical regions, further distinguished by their income level to have an overall view of responses. The majority of countries who responded were HICs mostly covering Europe and Central Asia.

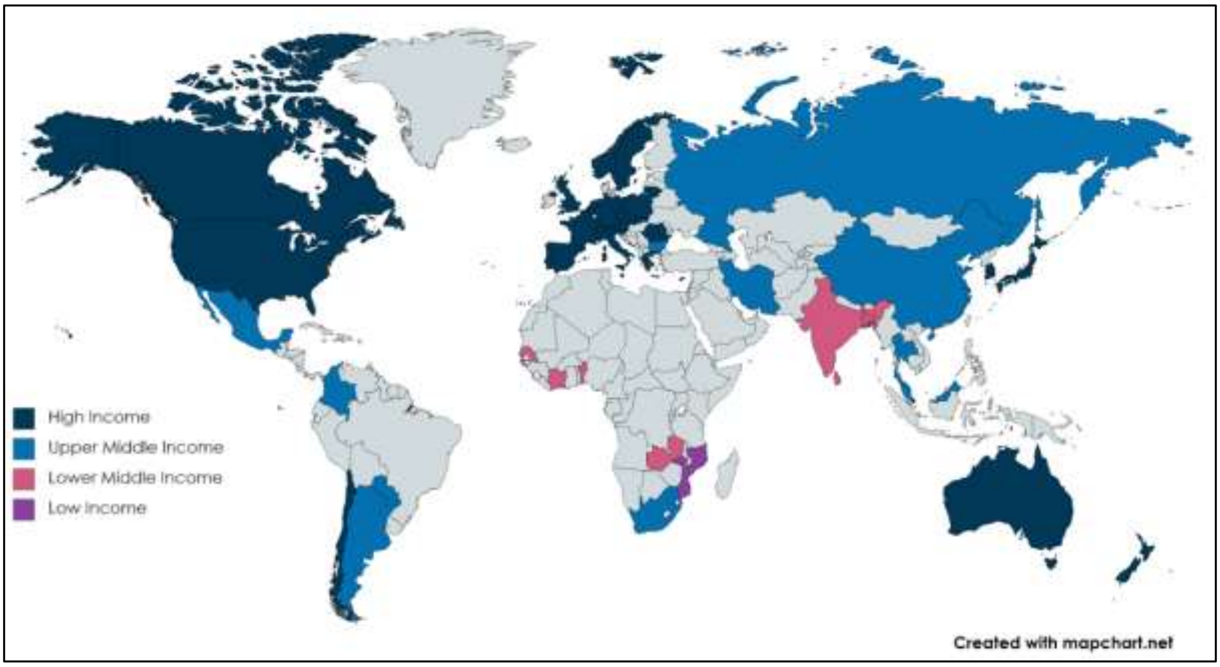


Figure 5: World map showing the countries who participated and their income levels

Figure 6: Figure 6 shows the proportion of countries responded from each income level[3] where the majority of responses across the survey were from HICs with 61% and LMICs form a total of 39%.

Figure *8* 7 shows the overall split across the survey responses from urban and rural countries[4] with 72% of overall responses came from urban countries, thus there may be an over-representation of urban countries who responded.

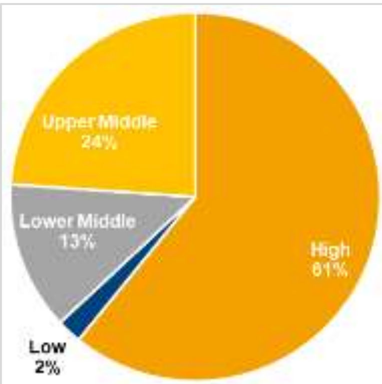


Figure 6: Overall split of responses by income level

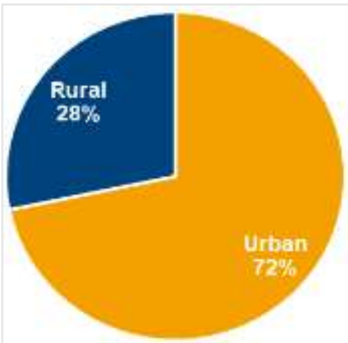


Figure 7: Overall split of responses from urban/rural countries

[3] According to the World Bank country classification.

[4] Rural countries are defined as top 50% of countries with highest rural population according to the World Bank.

Figure 8 provides a breakdown by proportion for each geographical region[3] whereby 48% of all responses were from Europe and Central Asia with fewer responses from the Middle East and North Africa (MENA), North America and South Asia regions.

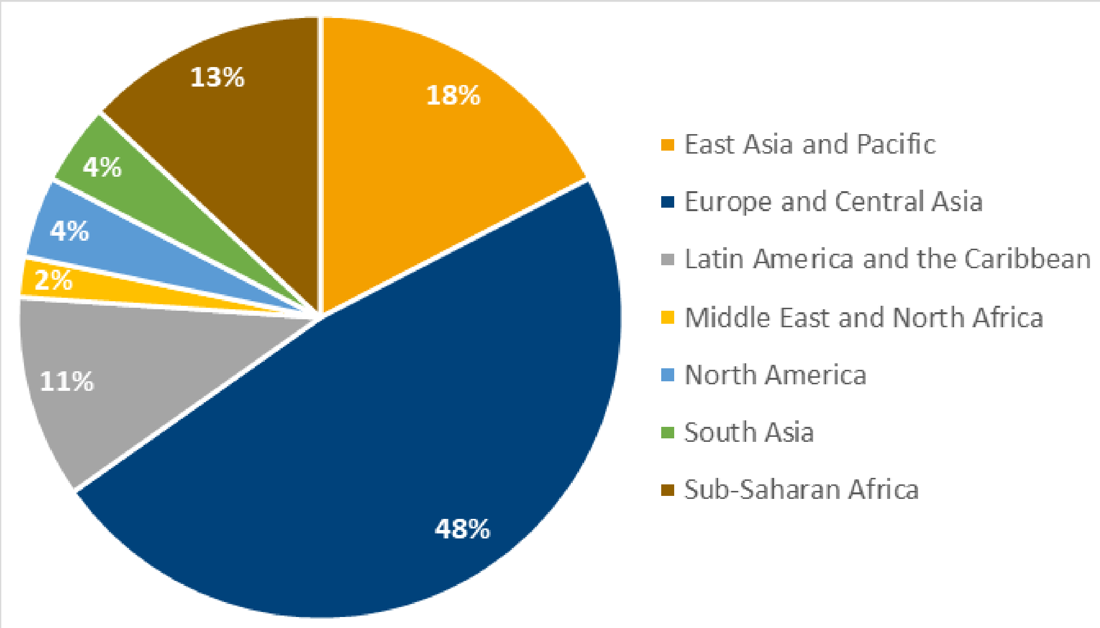


Figure 8: Overall split of responses by geographical region

4.2. ROAD NETWORK

4.2.1. Q1: DO YOU COLLECT AND ANALYSE INVENTORY DATA AND CONDITION DATA FOR ROAD INFRASTRUCTURE ASSETS?

A total of 43 countries across 76 organisations responded to question 1 (Q1). Three countries who participated in the survey did not respond. Participants had the option to select and provide examples for any of the following sub-questions (methods or technologies):

- Smart vehicles with mounted cameras
- Light Detection and Ranging (LIDAR)
- Unmanned Aerial Vehicles (UAVs)/Drones
- Accelerometers or Smartphones
- Road sensors
- Machine learning (ML) and Computer Vision (CV)
- Artificial Intelligence
- Satellite imagery
- Multispectral imagery
- Connected and Autonomous Vehicles (CAVs)
- Vehicle telematics
- Asset management system (software)
- Cloud-based software and storage systems
- Traditional human surveys
- Data from third parties or other organisations.
- Other

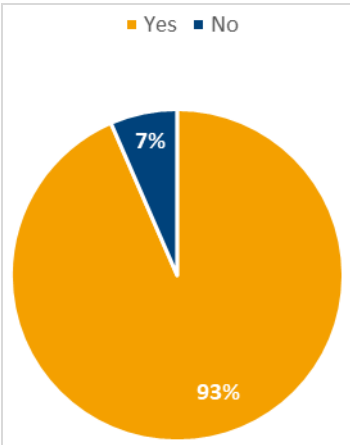


Figure 9: Q1 split of responses

Tables 9 and 10 and, Figures 9, 10 and 11 provide a breakdown of each of the three classifications across the countries who responded to Q1.

Table 9: Number of responses by income level for Q1

High	Upper Middle	Lower Middle	Low
27	11	4	1

Table 10: Number of responses across geographical regions for Q1

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
21	5	8	2	1	4	2

The majority of responses were from HICs with 65% and the combined total number of responses with from LMICs are 35%. Almost three quarters of all responses for Q1 were from urban countries with 26% from rural countries. Most responses for Q1 were from Europe and Central Asia which corresponds to a high proportion of HICs responses.

Many comprehensive responses were recevied from most countries across all sub-questions. The highest number of responses was for the use of 'Asset Management Systems (Software)' followed by

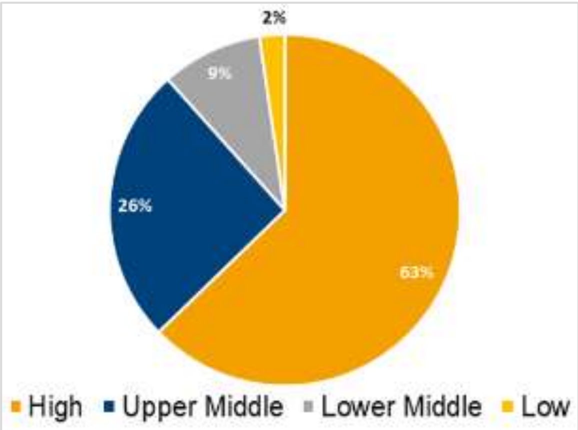


Figure 10: Proportion of responses by income level for Q1

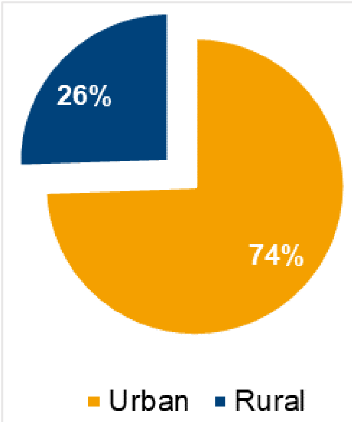


Figure 11: Proportion of responses for urban/rural countries for Q1

'traditional human surveys', 'road sensors' and 'vehicles with mounted cameras'. The high number for Asset Management Systems was expected across the countries with a more balanced representation between the HICs and LMICs. However, the majority of these 36 countries were urban, with few examples from rural countries where their comments mainly refer to maintenance of the road network.

'Road sensors' had the highest response for HICs where countries commented that their main purpose for using road sensors was for winter maintenance and health monitoring of the road condition. 'Asset Management Systems' had the second highest response rate for HICs where countries recurringly mentioned using several systems including cloud-based software and storage systems. Interestingly, HICs had a high number of responses for 'Traditional human surveys' with commentry on these surveys proving to be cost effective and used infrequently for asset inspections. Considering the HICs had fairly significant responses for the sub-questions relating to imagery, there were far fewer examples provided by HICs for Machine Learning (ML) and Computer Vision (CV). ML and CV would be useful to analyse the imagery of the network to provide further granularity in condition monitoring which could enhance their supply of data.

The least number of responses were in the 'Vehicle telematics' group, all of which were HICs and mostly urban with one rural country response.

LMICs have generally followed a similar trend across the sub-questions to the HICs. Similar to HICs, LMICs had the highest number of responses for Asset Management Systems and Traditional human surveys. The next most common sub-question answered by LMICs are where using Smart vehicles with mounted cameras, accelerometers and smartphones, Road sensors and Cloud-based storage systems. There was a similar response level for cloud-based systems as with the data capture from cameras and smartphones which is not surprising due to the memory size required for imagery. Vehicle Telematics and Multispectral imagery had the fewest or no responses from LMICs. Figure 12 provides further details on the level of response for each sub-question. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

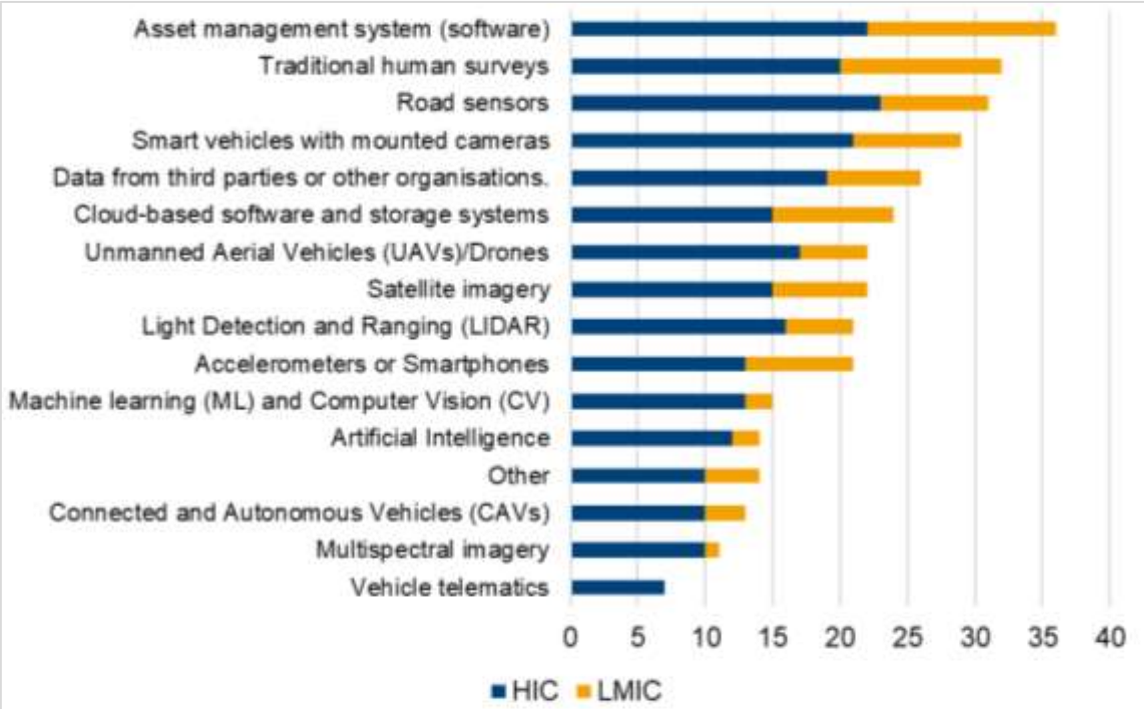


Figure 12: Breakdown of Q1 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.2.1.1. *SMART VEHICLES WITH MOUNTED CAMERAS*

Smart vehicles with mounted cameras had one of the highest number of responses where most of the responses were from HICs. Some countries report on different uses to capture pavement condition data such as longitudinal profiles, rutting, skid resistance, etc. The following are examples of responses from a mixed range of income levels and geographical regions:

- **Bangladesh, LMIC:** A Road Measurement Data Acquisition System (ROMDAS) is used on smart vehicles mounted with cameras for video logging modules, profilometer at the front and Laser Crack Management System (LCMS) at the back of the vehicle. Rough meter is used for collecting pavement inventory data. Falling Weight Deflectometer is used to identify structural capacity of pavement.

- **Mexico, LMIC:** Equipped vehicles are used for road assessment while measuring the International Roughness Index (IRI), Rut Depth, Macrotexture, Friction Coefficient, Road Marking, Night Visibility, Daytime Visibility of Road Markings, and Transit Signal Retroreflection Coefficient.
- **Chile, HIC:** Visual Inspection are conducted to collect data on the structural and functional deterioration of the road and to determine track characteristics such as road widths and berms.

4.2.1.2. *LIGHT DETECTION AND RANGING (LIDAR)*

LIDAR is collected to capture the topographical terrain plans where some of the countries have explained their purpose for capturing this type of data for producing geometric road projections. Others have used LIDAR to detect roadside features for validation reasons and for health monitoring of the network.

- **Mexico, LMIC:** Use of LIDAR technology to produce topographical terrain plans minimizing the effect of vegetation. LIDAR along with digital aerial colour photography and global airborne GPS positioning have been used to produce third-dimensional images and digital topographical plans to be used on road projects.
- **Japan, HIC:** Used to investigate detect damages and undertake condition surveys for pavement, expansion joint surface gap for noise origin survey, tunnel deformation scanning for health monitoring due to earth pressure, and slope deformation scanning for slope condition monitoring due to weathering.
- **Canada, HIC:** The annual integrated data collection program includes collecting LIDAR data for the highway network to capture cross-sectional slopes, clearances, and other roadside features for investigation and validation purposes.

4.2.1.3. *UNMANNED AERIAL VEHICLES (UAVS)/DRONES*

The majority of countries who responded to the sub-question related to UAVs have reported using UAVs for bridge inspections or change in land and terrain. Some other responses covering the uses of UAVs to collect data for physical road monitoring and road damage detection are detailed below.

- **Mexico, LMIC:** For physical road monitoring, photogrammetry, IRI measurement and Deflections.
- **China, LMIC:** Data collection for detection of road infrastructure and road damage.

4.2.1.4. *ACCELEROMETERS OR SMARTPHONES*

Accelerometers or smartphones and their use are mostly reported by HICs and urban countries. The responses generally reported the use of accelerometers to collect data on the regularity and evenness of the pavement surface, IRI of the pavement, and structural condition surveys.

- **Japan, HIC:** Used accelerometers and seismometer for assessing the triggers to traffic control, road service condition survey and damage inspection and prioritisation. Also testing use of accelerometers for road condition surveys in order to replace human inspections.
- **Paraguay, LMIC:** Used for IRI measurement in research work.
- **Bangladesh, LMIC:** Smartphone cameras are used to capture and view the pavement condition during emergency works especially during severe weather and disasters.

4.2.1.5. *ROAD SENSORS*

The majority of countries from different income levels have reported they use of road sensors to collect traffic condition data to monitor the weight loaded on the road pavement. Some countries have reported using different type of sensors to monitor weather conditions to understand how weather can impact the pavement structure.

- **Thailand, LMIC:** Used to detect load permit, long-term pavement performance assessment and road deterioration model development.
- **Mexico, LMIC:** Equipment used to detect the capacity, classification and registration of weights and dimensions of the vehicles, including magnetic sensors, piezometrics, scanners, video cameras and their combinations.
- **Belgium, HIC:** Road temperature for winter maintenance.

4.2.1.6. *MACHINE LEARNING (ML) AND COMPUTER VISION (CV)*

The majority of responses for ML and CV were from HICs where countries reported on their use of ML and CV for automation in analysis of imagery and video footage to detect road assets, changes in pavement condition and pothole detection.

- **China, LMIC:** Quick identification and classification of signs, road defects, etc. Data collection for automatic analysis of road infrastructure condition and road damage.
- **Czech Republic, HIC:** Research projects and project preparation for traffic condition predictions.
- **Portugal, HIC:** Pavement cracking identification. Looking to use advanced road traffic analysis and prediction, and detecting road asset objects from imagery/videos.
- **Korea, Rep., HIC:** Pothole detection with stereo cameras.

4.2.1.7. *ARTIFICIAL INTELLIGENCE (AI)*

The AI sub-question had some responses which relate to the ML and CV sub-questions, thus some countries have responded similarly as per the responses for ML and CV. Some countries reported on the use of AI for detection of pavement deterioration, decision making algorithms and risk assessments.

- **UK, HIC:** RoadAI project is being developed as a viable alternative to SCANNER surveys, with automation aiming to avoid the human variability associated with other systems.
- **Portugal, HIC:** C-ITS is used for data aggregation and advanced road traffic analysis and prediction, finding statistically significant clusters & patterns over road assets and object detection from CCTV (deep learning). Looking to use AI/ML applications in road network operation (traffic condition prediction and modelling, traffic and incident management, asset assessment and maintenance, road safety and traffic signal control systems).

4.2.1.8. *SATELLITE IMAGERY*

Similar to other sub-questions, the majority of responses were from HICs and urban regions. The level of response for this data collection method is similar to that data collection using UAVs, Accelerometers and Smartphones, and LIDAR. Countries mostly responded to this sub-question with the use of satellite imagery across assets. The main focus on roads using satellite imagery is to identify slope movement and assess road layouts as depicted in the below examples.

- **Japan, HIC:** Used for investigating soft ground deformation and assessing the roadside condition instead of using conventional aerial photography.
- **Mexico, LMIC:** Used to collect inventory for road infrastructure and determine track rights.

4.2.1.9. *MULTISPECTRAL IMAGERY*

The responses related to multispectral imagery were mostly linked to tunnels, pavements and the environment. Some countries mentioned using this approach to collect data for further understanding on pavement textures, thickness of pavement layers and evenness as shown in the following examples:

- **Korea, Rep., HIC:** Measuring pavement evenness and surface texture (pilot implementations).

- **Chile, HIC:** Used Geostrad to determine the thickness of pavement layers and create a detailed road inventory.

4.2.1.10. *CONNECTED AND AUTONOMOUS VEHICLES (CAVS)*

The majority of countries who responded to this sub-question were either in a testing phase of using CAVs or intending to use CAVs to capture data in the future. From the responses, CAVs are being utilised for capturing data related to road assets, traffic volumes, and for inventory and condition surveys as shown in the following examples:

- **Mozambique, LMIC:** Inventory and condition survey of paved roads to collect all required data to feed into the Asset Management System.
- **China, LMIC:** Monitoring the surrounding environment and obtaining information on roads, vehicle positions and obstacles through the use of automatic control, visual computing, artificial intelligence and other technologies.

4.2.1.11. *VEHICLE TELEMATICS*

Vehicle Telematics had the lowest number of responses, all of which were from HICs, most of which were urban. The responses varied and some reported on using vehicle telematics for winter maintenance as indicated in these examples:

- **Norway, HIC:** Winter road maintenance monitoring, CCAM Pilots.
- **Slovakia, HIC:** Maintenance vehicles to mark road work locations.
- **UK, HIC:** Understanding operational vehicle utilisation (particularly for fuel economy) and systems operations; vehicle positioning/recording (ExacTrak) for winter maintenance optimisation/operation. Other ADEPT local highway authorities use alternatives to these e.g. Masternaut.

4.2.1.12. *ASSET MANAGEMENT SYSTEM (SOFTWARE)*

This sub-question received the highest number of countries and organisations responding with examples. Organisations provided examples of using various systems such as RAMM, MAXIMO and TIMS as their asset management system for pavements and other assets. Some organisations mentioned that they are building their own asset management system software. The responses indicated that countries are using the systems to store inventory and condition data for maintenance and planning purposes.

- **Canada, HIC:** Used to store asset condition data for pavements and bridges, predict asset condition under different budget scenarios, and select projects.
- **Mexico, LMIC:** Management of operations and monitoring of all road infrastructure assets, collecting information in real-time and carrying out preventive and corrective measures to maintain good levels of service.

4.2.1.13. *CLOUD-BASED SOFTWARE AND STORAGE SYSTEMS*

In this sub-question, countries have responded with using cloud-based storage systems to store 3D point cloud, GIS and LIDAR data as they are large data sources, either currently or in future. This approach is also being utilised for storing data associated with operations and maintenance of the road network:

- **Japan, HIC:** InfraDoctor, a cutting-edge system for supporting infrastructure maintenance management using GIS and 3D point cloud data to automatically detect pavement condition by special frequency analysis. The method builds the system to output results automatically by loading road surface condition surveys data on GIS. It shows replacement targets by visible colouring and calculates replacement cost.

- **UK, HIC:** New cloud-based asset management system is being built in-house to store and analyse data associated with the operation and maintenance of the Scottish trunk road network.

4.2.1.14. *TRADITIONAL HUMAN SURVEYS*

Traditional human surveys are a popular approach across the majority of the countries who responded to this questionnaire. Some countries have regulations where they require experts to conduct surveys manually across their road network. Responses have included examples of how traditional human surveys have been utilised for capturing road surface condition data where other methods cannot be used.

- **New Zealand, HIC:** Annual complete surveys are carried out to measure asset condition. For example, the network is inspected after winter to ensure that the scope and location of the resurfacing and rehabilitation programs for the coming summer responds to unexpected deterioration in pavement or surface condition.
- **UK, HIC:** Walked inspections of the Scottish trunk road network are undertaken annually to validate inventory data and collect condition data for assets that cannot be assessed by other methods.

4.2.1.15. *DATA FROM THIRD PARTIES OR OTHER ORGANISATIONS*

There are several responses in this sub-question where countries have indicated their use of data from third parties including survey data for maintenance and road condition monitoring purposes. This sub-question was the fifth most popular sub-question from all countries who responded to Q1. Third party organisations included local government, road operators and non-road related organisations such as hydrometeorological/water bodies:

- **Colombia, LMIC:** Generated mapping of natural threats in the country, providing valuable information for the analysis of risk management for the road network and other modes of transport.
- **Greece, HIC:** Road markings and asphalt performance and quality measurements by third party companies.

4.2.1.16. *OTHER*

"Other" was one of the least popular sub-questions in Q1 where participants had the option to include a collection or analysis method or technology which was not listed. Almost all responses were from HICs. The responses varied where some countries referred to using different types of survey methods on the road network such as using GPR, GPS and FWD data.

- **United States, HIC:** FHWA receives roadway geospatial network and various data attributes via its Highway Performance Monitoring System (HPMS) program from State and local providers using a multitude of acquisition methods. FHWA also receives annual submittals from State Department of Transportations of bridge safety inspection related data in compliance with the National Bridge Inspection Standards. FHWA does not directly collect these data but received it from partners either by law or on a voluntary basis.
- **Malaysia, LMIC:** Uses GPS (Trimble) to collect information on road alignment and other road assets including bridges.

4.2.2. Q2: DO YOU COLLECT AND ANALYSE TRAFFIC RELATED DATA?

There was a total of 44 countries across 75 organisations who responded to question 2 (Q2). Two countries did not respond to Q2. Participants had the option to select and provide examples for any of the following sub-questions (methods or technologies):

- Fixed road sensors or inductive loops
- Acoustics and Radar
- Traffic cameras
- Laser counters
- Probe vehicle: GPS or smartphones real-time information
- GPS Satellites
- Social media
- Traditional human surveys
- Data from third parties or other organisations
- Other

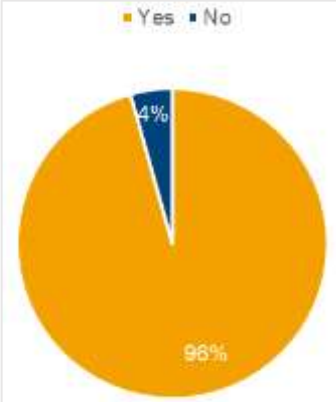


Figure 13: Q2 split of responses

Tables 11 and 12, and Figures 13, 14 and 15 provide a breakdown of each of the three classifications across the countries who responded to Q2.

Table 11: Number of responses by income level for Q2

High	Upper Middle	Lower Middle	Low
27	11	5	1

Table 12: Number of responses across geographical regions for Q2

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
21	5	8	2	1	5	2

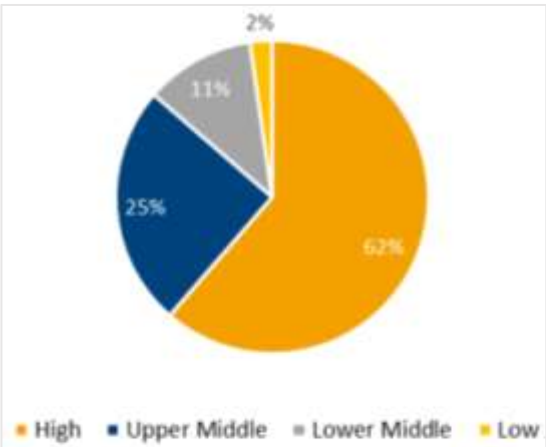


Figure 14: Proportion of responses by income level for Q2

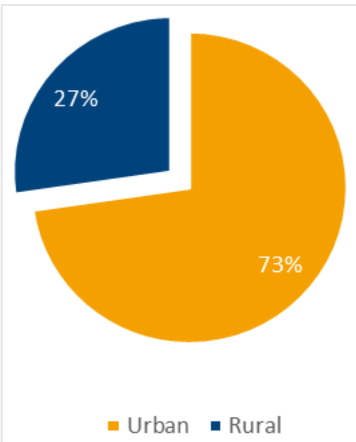


Figure 15: Proportion of responses for urban/rural countries for Q2

Similar to Q1, the majority of responses for Q2 were from HICs with 61% and the combined total number of responses from LMICs were 39%. Almost three quarters of all responses were from urban countries and 27% from rural countries. Most responses for Q2 were from Europe and Central Asia which corresponds to a high proportion of HICs responses.

The majority of countries with high income level and urban countries provided details on 'Fixed Road sensors or inductive loops' and 'Traffic cameras' as shown in Figure 16 below. Interestingly, 'Traditional human surveys' had almost the same number of responses in Q1 as in Q2 with an almost identical split across income levels and urban/rural regions. This indicates countries are mostly still using traditional human surveys to capture data for a number of purposes.

'Laser counters', 'GPS Satellites', 'Social media' and 'Other' were sub-questions which equally received the lowest number of responses. The 'Other' sub-question had responses where organisations collected traffic related data for across asset types for purposes such as using connected and automated vehicles and aerial surveys. Generally, the responses received for "Social Media" were regarding reports of incidents on the network via Twitter, Instagram or Facebook. It was also mentioned that these channels are used to communicate road network related information to the road user.

Figure 16 shows that LMICs have provided fewer examples of collecting and analysing traffic related data, however, the responses followed a similar trend to the HICs. LMICs had the highest number of responses for 'Traditional human surveys' which was the 3rd highest for the HICs. LMICs had the fewest responses regarding using 'laser counters' and 'social media' which was also similar to the response trend from HICs. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

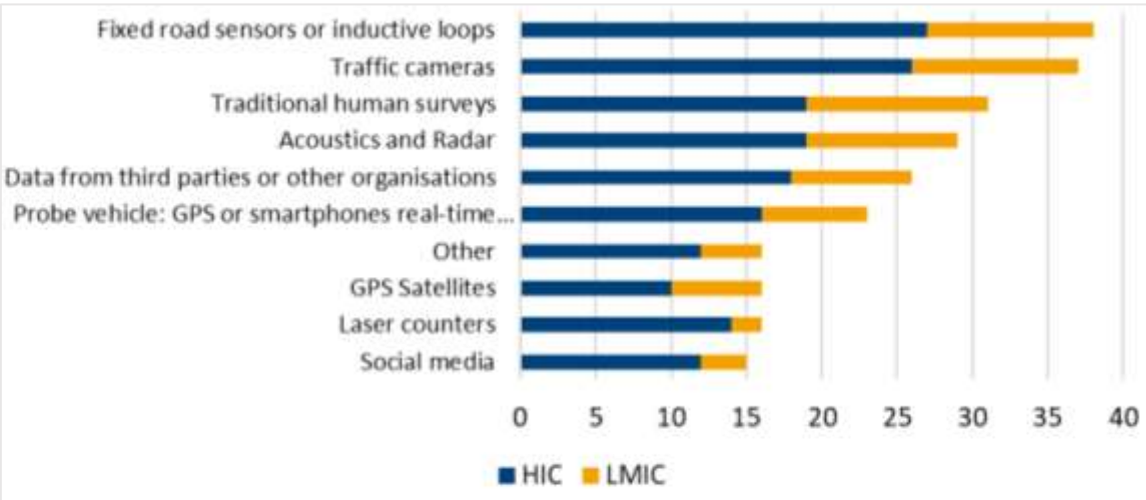


Figure 16: Breakdown of Q2 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.2.2.1. *FIXED ROAD SENSORS OR INDUCTIVE LOOPS*

This sub-question received the highest number of countries responding, with the majority of responses from HICs and urban countries. The countries who responded mostly use fixed road sensors to monitor traffic flows and traffic speed. Some countries are using sensors to understand the traffic loads applied on the road based on traffic volumes.

- **New Zealand, HIC:** Installed sensor technologies in roads which are integrated with roadside infrastructure to gather information about traffic volumes and flows. Bending plate weigh in motion sensors are in use. The network is being expanded and related automatic number plate recognition equipment being added to assist the management of weight limits on freight carriage.
- **Russian Federation, LMIC:** Induction loops are applied for measuring weight and dimension characteristics of vehicles. Traffic Flow Intensity Measurement Points (TFIMPs) collect data on intensity, structure and speed of traffic flow.

4.2.2.2. *ACOUSTICS AND RADAR*

All responses for Acoustics and Radar are either from high income or upper middle income countries where 50% of responses are from Europe and Central Asia. Most countries responded with the use of microwave radars for collecting data on traffic volumes and speed control. Only a few countries mentioned the use of acoustics for road assets and other uses such as the following example:

- **Austria, HIC:** Acoustic event detection in tunnels.

4.2.2.3. *TRAFFIC CAMERAS*

The countries who responded to this sub-question provided examples of using traffic cameras mainly for road assets and also for tunnels. Based on the results, traffic cameras have mostly been used for monitoring the volume of traffic and incident detection.

- **Mexico, LMIC:** Cameras are used for traffic monitoring have been installed on some roads mainly for safety purposes and for timely response for traffic accidents. Cameras are used to monitor traffic on urban or intercity collection highways and on roads in suburban areas, as well as on primary urban roads. Monitoring is.
- **Japan, HIC:** Used to monitor traffic flow and traffic congestion.

4.2.2.4. *LASER COUNTERS*

Countries not only responded to the use of laser counters to capture the volume of traffic, but also mentioned using laser counters for vehicle height detection, vehicle classification, travel time and speed. The majority of responses were from Europe and Central Asia and there were only two responses from LMICs.

- **Portugal, HIC:** Used for measuring Traffic, Daily traffic counters and Excess Height Detection.

4.2.2.5. *PROBE VEHICLE: GPS OR SMARTPHONES REAL-TIME INFORMATION*

This sub-question had the number of responses equating the overall average of number of responses to Q2. Most countries responded with the use of smartphones for information on real-time traffic, speeds, traffic conditions and safety:

- **Russian Federation, LMIC:** GLONASS is applied for monitoring work of road equipment.
- **Spain, HIC:** Data from INRIX, covering free flow speeds, network analysis and study of applicable road safety measures.

4.2.2.6. *GPS SATELLITES*

GPS Satellites were reported by countries to capture location information for traffic conditions and speeds between journeys. Some countries have also mentioned using this approach for identifying damaged pavements and for existing road layout.

- **New Zealand, HIC:** Anonymised records from vehicle navigation systems are increasingly used to provide sample data on trip origins and destinations and detailed speeds along the trip.

- **Australia, HIC:** Travel time monitoring, bus journey monitoring and use on some public transport and freight for signal prioritisation.

4.2.2.7. *SOCIAL MEDIA*

Most countries who responded to the social media sub-question reported that they use social media primarily for communicating with the road user regarding roadworks, planned network closures and incidents. They also seek feedback from road users regarding road and traffic information through means of Twitter, Instagram and Facebook.

- **Mexico, LMIC:** Use of Twitter to identify incidents and emergencies on roads and communicate them to users.
- **South Africa, LMIC:** Tracking of social media trends regarding Freeway Management System (FMS) messaging put out on social media.
- **Australia, HIC:** Used for incident location identification, providing public notices, monitoring comments, updates on projects and roadworks and for disseminating information to the public.

4.2.2.8. *TRADITIONAL HUMAN SURVEYS*

There were several responses to this sub-question from both HICs and LMICs. Most countries responded with the use of Origin-Destination Surveys to supplement the planning of road projects. Some countries are using traditional human surveys to analyse pedestrian mobility and real-time information on selected locations to monitor road traffic.

- **Malaysia, LMIC:** Origin-destination surveys for pavement design and road network maintenance planning.
- **Mexico, LMIC:** Applied Origin-Destination surveys for freight and passenger transport on the roads. The information is used for identification of the main origin-destination pairs, the type of goods transported, the percentage of empty cargo vehicles, the occupancy rate of passenger buses and light vehicles, the age of heavy vehicles in circulation, their vehicle classification, etc.
- **Zambia, LMIC:** Carried out on selected traffic counting stations on the road network.

4.2.2.9. *DATA FROM THIRD PARTIES OR OTHER ORGANISATIONS*

Data provided by other organisations mostly include information on traffic flows and journey times. This information includes, but not limited to, camera imagery and real-time data provided by authorities, traffic police and mapping/transport apps.

- **Japan, HIC:** Traffic data and traffic camera images obtained from other road administrations are used to monitor traffic flow.

- **Canada, HIC:** Private data providers' sensor systems are used to collect vehicle data including consolidated road use data, travel times and other aggregated data that can be used to estimate current traffic conditions for Integrated Traffic Management Centres.

4.2.2.10. *OTHER*

Responses in this sub-question included other methods of capturing traffic related data for pavements and other assets on the road network such as bridges.

- **New Zealand, HIC:** Electronic road user charging points and electronic logbooks. Systems for automatic recognition of number plates to support free-flow toll roads. Anonymised eRUC records from freight vehicles are required in batches to provide fine details of travel routes and times.
- **Senegal, LMIC**: Temporary pneumatic cable road counters.

4.2.3. Q3: DO YOU COLLECT OR USE ROAD RELATED DATA FOR THE MANAGEMENT OF ROADWORKS AND THE OVERALL ROAD NETWORK?

Similar to Question 1, a total number of 43 countries across 73 organisations responded to question 3 (Q3). Three countries did not respond to Q3. Participants had the option to select and provide examples for any of the following sub-questions (methods or technologies):

- Intelligent Transport Systems (ITS)
- Closed-circuit television (CCTV) and video surveillance
- Geographic Information System (GIS) mapping
- Dedicated software or online interface
- Data from third parties or other organisations
- Other

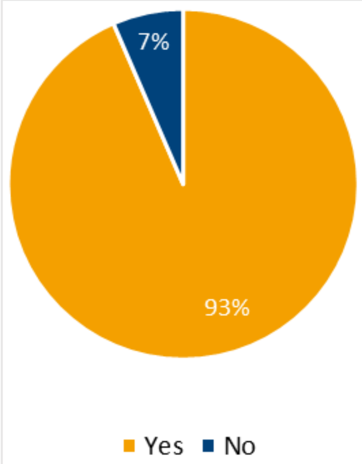


Figure 17: Q3 split of responses

Tables 13 and 14, and Figures 17, 18 and 19 provide a breakdown of each of the three classifications across the countries who responded to Q3.

Table 13: Number of responses by income level for Q3

High	Upper Middle	Lower Middle	Low
27	11	5	0

Table 14: Number of responses across geographical regions for Q3

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
21	5	8	2	1	4	2

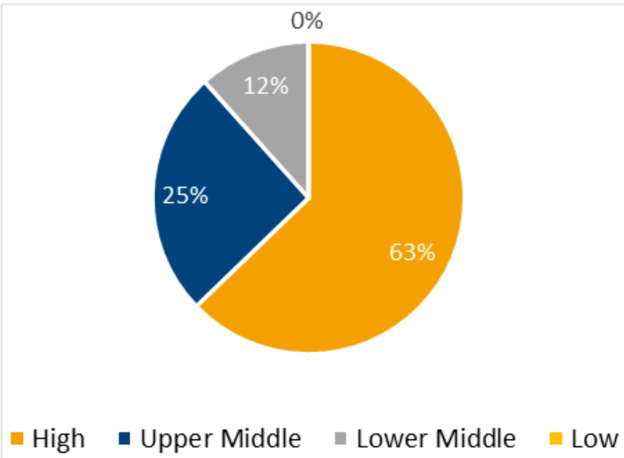


Figure 18: Proportion of responses by income level for Q3

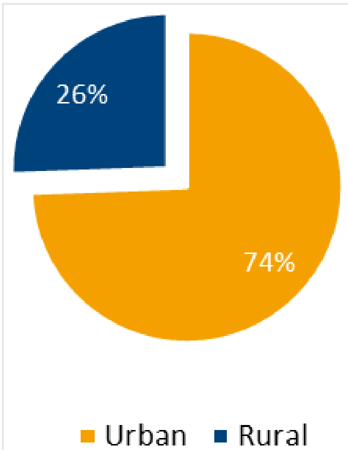


Figure 19: Proportion of responses for urban/rural countries for Q3

As with the previous questions, the majority of responses were from HICs at 63% and a total of 37% from LMICs. The proportion of HICs is also reflected in the proportion of responses from the Europe and Central Asia region at almost 50% of responses. Similar to the previous questions, almost three quarters of all countries who responded are from urban countries.

The highest number of responses was for ‘GIS mapping’ and ‘Intelligent Transport Systems (ITS)’ and were from countries with a high income level and urban countries. Interestingly, regardless of income level, the lowest number of responses was for the ‘Other’ sub-question. This sub-question included a range of responses such as the use of weather detectors as climatic pavement detectors.

LMICs followed a similar trend in response level to the HICs across the sub-questions apart from ‘GIS mapping’ and ‘ITS’. LMICs responded to the use of GIS mapping in their organisations and countries more than the use of ITS which shows that the use of GIS is more popular in their countries for the management of roadworks. Figure 20 provides further details on the level of response for each sub-question. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

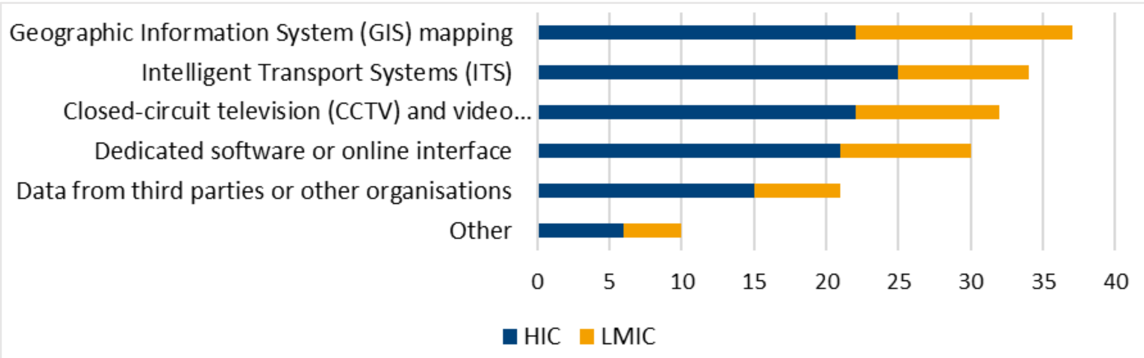


Figure 20: Breakdown of Q3 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.2.3.1. *INTELLIGENT TRANSPORT SYSTEMS (ITS)*

Almost three quarters of all countries responded to the use of ITS were from HICs and almost all responses were from Europe and Central Asia. The fewest responses were from North America, Middle East & North Africa and Sub-Saharan Africa. Responses mostly focused on the use of ITS for monitoring traffic and the impact of traffic on the road user.

- **Malaysia, LMIC:** Currently establishing Virtual National Intelligent Transportation Management Centre – Proof of Concept (VNITMC-POC). VNITMC-POC is a platform whereby all related transportation data are continuously collected from various identified agencies. Hence, the data will be processed and analysed to generate outputs including Journey Planner, Road Congestion Map and Traffic Simulation Analysis.
- **UK, HIC:** ITS systems and infrastructure are used for network efficiency (queue management and queue protection, advisory and mandatory variable speed limits); incident response; and information to drivers through roadside VMS. Transport Scotland published its “Future ITS Strategy” in 2017 (available at: www.transport.gov.scot/publication/future-intelligent-transport-systems-strategy/).

4.2.3.2. *CLOSED-CIRCUIT TELEVISION (CCTV) AND VIDEO SURVEILLANCE*

CCTV is utilised across countries generally to monitor traffic flow through normal driving conditions and roadworks for safety and congestion management. CCTV also provides real-time information to road authorities, to improve safety of road users.

- **UK, HIC:** Monitoring trunk road traffic, monitoring congestion and incident response and management.
- **Australia, HIC:** Monitoring of impacts via traffic management centre, physical visual sighting, confirmation and monitoring purposes, and incident and network management.

4.2.3.3. *GEOGRAPHIC INFORMATION SYSTEM (GIS) MAPPING*

As mentioned above, GIS mapping had an overall highest response from all countries in its use of collecting data for the management of roadworks. It was the most popular for the LMICs and the 2nd highest amongst the HICs. Most responses covered the use of GIS to gain a geographical representation of the network, asset management and road closures.

- **Russian Federation, LMIC:** Determining necessary works required for road upgrade or repair, and displaying road sections and facilities where repairing or upgrading works are in progress or planned.
- **UK, HIC:** General asset management but also for mapping and scheduling roadworks/streetworks.

4.2.3.4. *DEDICATED SOFTWARE OR ONLINE INTERFACE*

Countries responded to the use of dedicated software similarly to the use of CCTV for management of roadworks and were mostly from Europe and Central Asia.

- **United States, HIC:** The HPMS program has online software for data providers to submit, review, and analyse data.
- **Zambia, LMIC:** The software being used is interfaced with HDM-4 which is used for prioritisation of works.

4.2.3.5. *DATA FROM THIRD PARTIES OR OTHER ORGANISATIONS*

Some Countries reported examples of using data from national and local authorities for capturing information on traffic levels to prepare for activities such as roadworks. Examples of these data include cartography, speeds and traffic imagery.

- **Poland, HIC:** Companies using traffic lanes in order to perform road works (hired by third parties) are obliged to inform the road administration in advance.
- **Malaysia, LMIC:** For maintenance purposes using data from road maintenance concession companies. For planning purposes using verified highways traffic volume data from Malaysia Highway Authority, from Road Traffic Volume Malaysia for Federal Roads, and appointed registered Traffic Consultants for any other roads.

4.2.3.6. *OTHER*

This sub-question had a mixture of responses including the use of traditional human surveys. There are responses where countries utilise other forms of data capture for management of roadworks by using UAVs, satellite imagery and weather detectors.

- **Russian Federation, LMIC:** UAVs/Drones are used for monitoring construction progress to provides automatisation of control processes, commissioning and accounting of implemented works. Satellite imagery are also used to control the implementation of construction activities.
- **China, LMIC:** Weather detector covering visibility, wind speed, wind direction, rainfall and other relevant data.

4.2.4. Q4: DO YOU COLLECT OR USE CERTAIN DATA WHICH CAN BE LINKED TO THE DEVELOPMENT OR OPTIMISATION OF PROGRAMMES OF WORK FOR ROUTINE MAINTENANCE AS WELL AS FOR WINTER MAINTENANCE AND OPERATIONS (INCLUDING IDENTIFICATION OF PRIORITY ROUTES)?

There was a total of 39 countries across 61 organisations responded to questions 4 (Q4) which is the lowest out of the first 4 questions. Seven countries who did not respond to Q4. Participants had the option to select and provide examples for any of the following sub-questions (methods or technologies):

- Asset management systems (software)
- Lifecycle planning tools
- Route planning tools
- Geographic Information System (GIS) mapping
- Data from third parties or other organisations
- Other

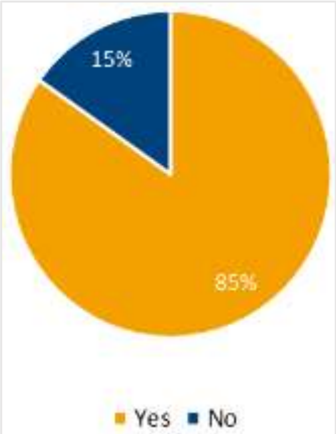


Figure 21: Q4 split of responses

Tables 15 and 16, and Figures 21, 22 and 23 provide a breakdown of each of the three classifications across the countries who responded to Q4.

Table 15: Number of responses by income level for Q4

High	Upper Middle	Lower Middle	Low
24	9	5	1

Table 16: Number of responses across geographical regions for Q4

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
15	8	13	3	0	2	2

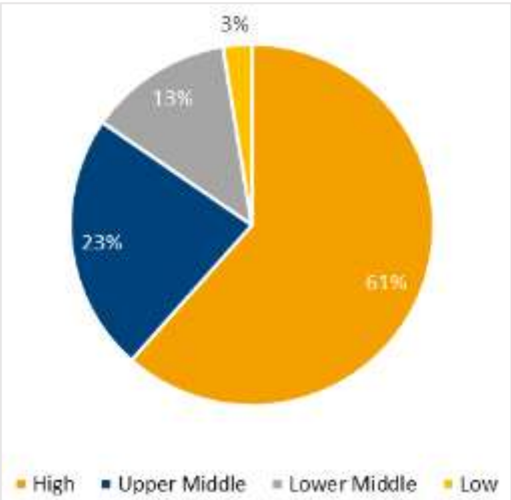


Figure 23: Proportion of responses by income level for Q4

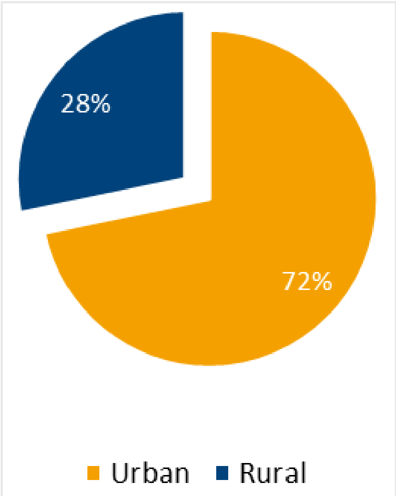


Figure 22: Proportion of responses for urban/rural countries for Q4

The majority of responses came from HICs with 61% and the combined total number of responses from LMICs were 39%. Similar to the previous questions, almost three quarters of all responses were from urban countries with 28% from rural countries. Most responses were from Europe and Central Asia which corresponds to a high proportion of HICs responses.

All responses from countries have provided more examples for Q4 where the focus is collecting data for routine maintenance or winter maintenance with the overall highest number of responses for the 'Asset management systems (Software)' and most of which are from HICs. Interestingly, there was a high level of responses from Europe & Central Asia (37%) and East Asia & Pacific (29%) geographical regions for using 'Asset management systems (Software)' as part of their maintenance strategies.

Gernerally, LMICs followed a similar trend to HICs across the sub-questions apart from collecting 'Data from third parties or other organisations' where there was only one example from an LMIC. Figure 24 provides further details on the level of response for each sub-question. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

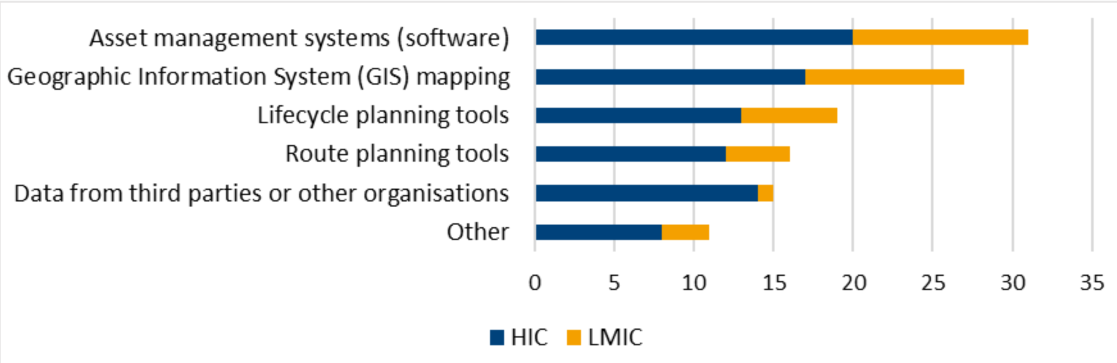


Figure 24: Breakdown of Q4 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.2.4.1. *ASSET MANAGEMENT SYSTEMS (SOFTWARE)*

As expected, this sub-question had the highest number of responses. As with Q1, the countries provided examples of the systems used in their organisations for pavements and other assets such as bridges and drainage assets. The systems store inventory and condition data for maintenance strategies.

- **Mozambique, LMIC:** Perform the analysis and decide the appropriate maintenance interventions (Routine Maintenance Management System).
- **Colombia, LMIC:** The HERMES platform centralises the information associated with the assets of the road network that is under the administration of the institute. This is manually fed with the information provided by the road and/or territorial administrators.

4.2.4.2. *LIFECYCLE PLANNING TOOLS*

The responses for lifecycle planning tools are similar to those under the asset management systems sub-questions. Some of the responses included the use of HDM-4, and use of condition data to inform maintenance programs.

- **Chile, HIC:** MAXIMO (FEMN System, customisation to the reality of Chile road management), National and Regional Road Planning Areas.

- **Switzerland, HIC:** MISTRA (Management Information System Road and Road Traffic) is used for relevant road infrastructure data.
- **South Africa, LMIC:** Pavement management systems and asset management using technologies for the collection of information on pavements and all road assets.

4.2.4.3. *ROUTE PLANNING TOOLS*

Countries who responded to using route planning tools provided details on the use of different technologies and applications as part of their route planning. With the use of Automated Vehicle Locations System (AVLS), weather sensors, organisations are well placed to make informed decisions on winter maintenance.

- **Canada, HIC:** Automated Vehicle Locations System (AVLS) uses GPS technology to track snowplow movements. Road Weather Information System (RWIS) uses road sensors to record real-time meteorological conditions and provide data that allow maintenance contractors to make informed decisions about the type and timing of specific winter maintenance activities such as when to plow or apply de-icing materials.
- **Czech Republic, HIC:** The meteorological information system (MIS) evaluates the need for road treatment from various data sources and provides this information to dispatchers in order to plan specific sites that need to be treated.

4.2.4.4. *GEOGRAPHIC INFORMATION SYSTEM (GIS) MAPPING*

Responses in this sub-question mostly include using GIS mapping to inform maintenance programmes and decisions using data captured internal and external to the organisations.

- **Austria, HIC:** National GIS system (www.gip.gv.at and www.basemap.at) for the whole transport system (including all modes) which forms the basis for all kind of analyses, Government processes as well as Traveller Information services (e.g. *www.verkehrsauskunft.at*).
- **Japan, HIC:** Monitoring system of operation and maintenance vehicles location (AVL). Mapping of weather data such as rainfall and snowfall for disaster prevention (including snow and ice control).

4.2.4.5. *DATA FROM THIRD PARTIES OR OTHER ORGANISATIONS*

Data from third party organisations is reported in real-time or pre-collected and mostly associated with weather, journey times and mapping data. This information is used to understand road surface temperatures and to inform the decision-making process as part of the winter maintenance activities.

- **Mexico, LMIC:** Information from the National Weather Service is mainly used in the hurricane and cyclone season, from May to November.
- **Switzerland, HIC:** Maps from Office of Topography swisstopo, environmental data on natural risks, data from territorial units (motorway maintenance authorities), traffic information from police.

4.2.4.6. *OTHER*

Similar to the 'Other' sub-question in the previous questions, there was low level of response from participants. In this sub-question, participants considered other factors which affect winter maintenance in their response. Some responses also highlighted the frequency of inspections, other data capture techniques, and incidents related to the road condition.

- **New Zealand, HIC:** The routine maintenance program is developed using data from the daily/weekly/monthly inspections as well as from customer feedback. The inspectors drive the entire network undertaking inspections and recording all faults. Customer feedback on network issues is collected and collated on location basis with the inspection data. Some faults are determined using automated high-speed survey such as flushed surface. All collected data is then used to determine the type of faults on the network and establish an appropriate intervention strategy to rectify them.

4.2.5. Q5: DO YOU COLLECT OR USE CERTAIN DATA WHICH CAN BE LINKED TO INVESTMENT PLANNING OF ROAD ASSETS AND THE MANAGEMENT OF ROAD INFRASTRUCTURE? THIS INCLUDES ASSET PLANNING, ROUTE PLANNING OR NETWORK WIDE PLANNING.

A total of 40 countries across 62 organisations responded to question 5 (Q5). There were six countries who did not respond. Participants had the option to select and provide examples for any of the following sub-questions (methods or technologies):

- Asset management systems (software)
- Lifecycle planning tools
- Whole Life Costing tools
- Route planning tools
- Geographic Information System (GIS) mapping
- Data from third parties or other organisations
- Other

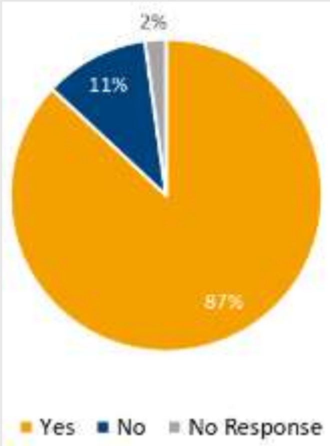


Figure 25: Q5 split of responses

Tables 17 and 18, and Figures 25, 26 and 27 provide a breakdown of each of the three classifications across the countries who responded to Q5.

Table 17: Number of responses by income level for Q5

High	Upper Middle	Lower Middle	Low
27	8	4	1

Table 18: Number of responses across geographical regions for Q5

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
20	5	7	2	0	4	2

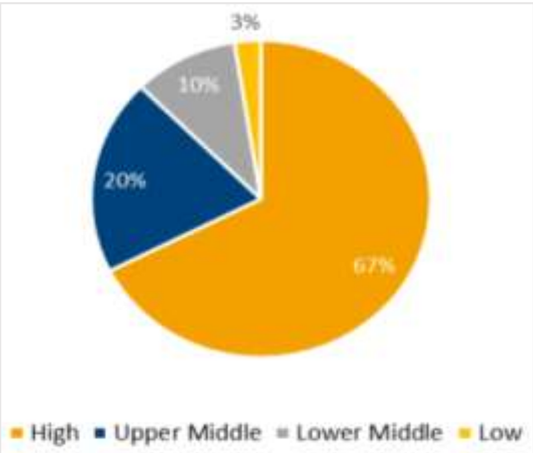


Figure 27: Proportion of responses by income level for Q5

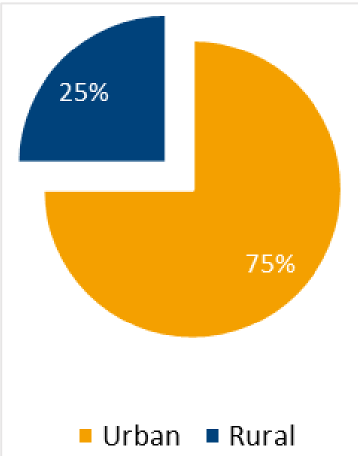


Figure 26: Proportion of responses for urban/rural countries for Q5

The tables and figures above show that the majority of responses are from HICs with a proportion of 67%. Similar to the previous questions, three quarters of all responses were from urban countries with a quarter from rural countries. Most responses were from Europe and Central Asia at 50%.

LMICs had the same trend as that of HICs across the sub-questions for Q5 where 'Asset Management systems (software)' were widely used to collect data for investment planning. Collectively, 'tools' for lifecycle planning, whole life costing and route planning showed a higher proportion of use across different countries, where some countries use the same tool for either whole life cost models or lifecycle planning. Similar to Q4, LMICs provided some of the fewest examples of using data from third parties. Figure 28 provides further details on the level of response for each sub-question. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

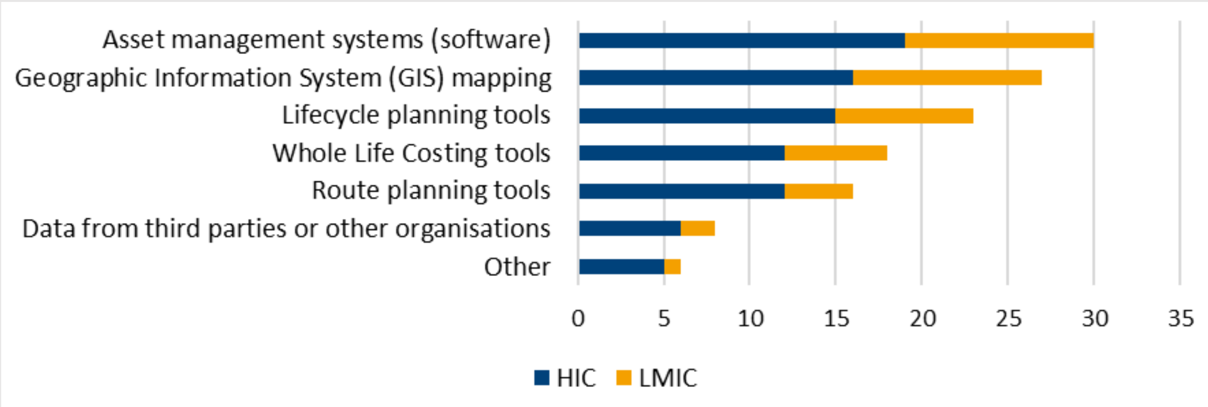


Figure 28: Breakdown of Q5 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.2.5.1. *ASSET MANAGEMENT SYSTEMS (SOFTWARE)*

Participants responded with how they use asset management software solutions for information management, planning and asset maintenance for various road asset types. These systems hold inventory and condition data which is analysed using predictive modelling or other techniques.

- **Bangladesh, LMIC:** HDM-4 model is utilised to derive yearly maintenance demand for the Roads and Highways Department (RHD). The time and location of the road network maintenance requirements is the identified and prioritised in accordance with the NPV/Cost ratio.
- **Canada, HIC:** Transportation Infrastructure Management System (TIMS) supports asset management using a common geospatial network for information management and analysis, and development of a capital plan. www.alberta.ca/transportation-infrastructure-management-system.aspx.

4.2.5.2. *LIFECYCLE PLANNING TOOLS*

The responses to this sub-question detailed using inventory and condition data in the organisations' lifecycle planning tools for various road asset types. These tools are used to ensure organisations have the information required for prioritisation, investment planning and maintenance.

- **Chile, HIC:** MAXIMO (FEMN system) is used for maintenance management of road assets. It establishes criteria, procedures, specifications and methods that indicate the conditions to be met in projects and activities related to the phases that make up the life cycle of a road project.

- **UK, HIC:** Use of the HMEP Carriageway Lifecycle Planning Toolkit to ascertain necessary investment levels for road surface maintenance. It is used to demonstrate the necessary investment levels across England through discussions with the DfT and MHCLG (leading to the £2.5bn extra 'pothole' investment across 5 years in the last Budget).

4.2.5.3. *WHOLE LIFE COSTING TOOLS*

The number of responses for whole life cost tools were fewer than the responses received for lifecycle planning tools. However, it should be noted that there is an overlap between both systems. Some countries have referred to lifecycle planning tools while responding to this sub-question.

- **Paraguay, LMIC:** The Ministry of Public Works and Communications uses a Unit Price System which updates the cost of the different items required for road works and regulates adjustments for price variations. These prices are the basis for use in HDM-4 to determine lifetime costs.
- **UK, HIC:** Acquiring commuted sums using the County Surveyors' Society's guidance on commuted sums for whole life maintenance of non-standard highway infrastructure and materials.

4.2.5.4. *ROUTE PLANNING TOOLS*

Organisations use different software solutions as part of their route planning to transport people and goods across their countries. These software solutions require traffic data and travel time data. Some organisations referred to already having specific route planning manuals for road planning and development.

- **Chile, HIC:** The Road Manual of the Road Direction VOLUME 1. Planning, Evaluation and Road Development. This volume addresses everything related to road planning and development, as well as the evaluation of road projects, whether urban or intercity (rural) roads.
- **Canada, HIC:** Alberta Spatial Economic and Travel (ASET) Model provides origin and destination travel information, and assignment of traffic on the highway network. The model provides priority routes and key economic corridors to prioritise activities and optimise investment choices.

4.2.5.5. *GEOGRAPHIC INFORMATION SYSTEM (GIS) MAPPING*

GIS mapping had the second highest number of responses from countries responding to Q5. Mapping data is used to understand distance between cities and locations of administrative regions as part of their investment planning.

- **Chile, HIC:** ArcGIS is used with FEMN (MAXIMO) to view maintenance plans on the National Road Network. It is also used for engineering designs, maps of bridges in Chile, distance between cities and other uses.
- **Russian Federation, LMIC:** Storage of all geometrical parameters data of road infrastructure. Informs investment planning with displaying the road network and projects on GIS maps to facilitate decision making and enable comparisons with the current state of the road network.

4.2.5.6. *DATA FROM THIRD PARTIES OR OTHER ORGANISATIONS*

Data from third parties received one of the lowest number of responses for Q5. It was mentioned that some of the data received from other organisations include accident data and data related to traffic volumes.

- **Slovak Republic, HIC:** Slovak Hydrometeorological Institute, Ministry of Interior, cities and municipalities and other commercial source.

4.2.5.7. *OTHER*

The 'Other' sub-question received the lowest number of responses in Q5. Of the few responses, countries provided details on using data captured in different ways for investment and decision-making frameworks as well as for asset planning purposes such as continuous asset monitoring.

- **New Zealand, HIC:** The Transport Agency uses its Investment Decision Making Framework to develop, assess and prioritise funding transport investment proposals. The review of this framework has been prompted by changes in the Government Policy Statement on Land Transport 2018 (GPS), which places more emphasis on social, economic, cultural and environmental outcomes in transport planning. This includes environmental impact, safety, resilience, access to transport, public health, urban development, and network benefits in transport planning and investment. GPS 2018 also required an investigation of the Transport Agency's evaluation methods, and this has been incorporated as a core part of the review.

4.2.6. Q6: DO YOU HAVE ANY SYSTEM(S) IN PLACE FOR EFFECTIVE SITUATION OBSERVATION OR EFFECTIVE RESPONSE TO NATURAL/MAN-MADE DISASTERS OR EMERGENCIES THAT CAN AFFECT THE ROAD NETWORK AND ITS USERS? (E.G. EARTHQUAKES)

A total of 36 countries across 58 organisations responded to question 6 (Q6). There were ten countries who did not respond. Participants had the option to select and provide examples for any of the following sub-questions (methods or technologies):

- Weather sensors
- Road network usage related software
- Data from third parties such as weather monitoring organisations
- Other

Tables 19 and 20, and Figures 29, 30 and 31 provide a breakdown of each of the three classifications across the countries who responded to Q6.

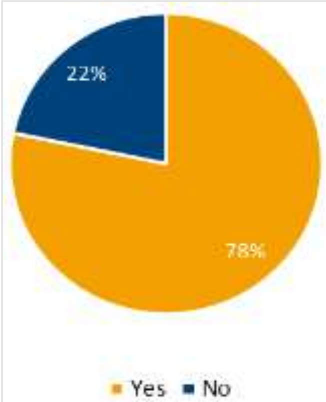


Figure 29: Q6 split of responses

Table 19: Number of responses by income level for Q6

High	Upper Middle	Lower Middle	Low
27	8	1	0

Table 20: Number of responses across geographical regions for Q6

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
20	4	8	2	1	1	0

The tables and figures of this section show that the majority of responses are from HICs reaching precisely 75%. This question on ensuring systems are in place for effective response to natural/man-made disasters had the highest proportion of responses compared to the previous questions, reaching 81% from urban countries as shown above. More than 50% of all responses for Q5 were from Europe and Central Asia which follows the same trend throughout the questionnare.

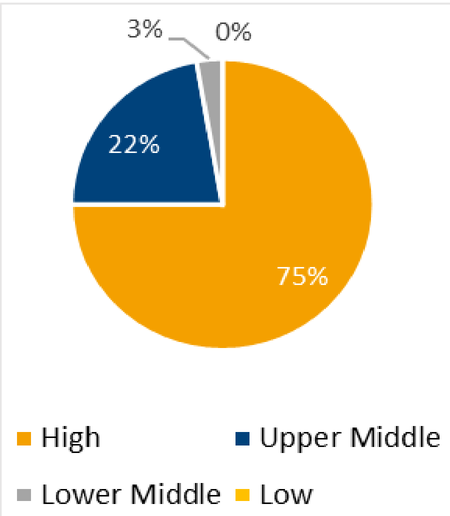


Figure 30: Proportion of responses by income level for Q6

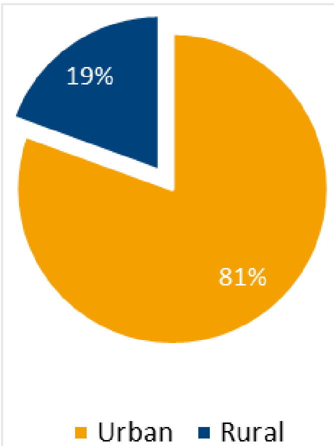


Figure 31: Proportion of responses for urban/rural countries for Q6

Figure 32 shows the LMIC had fewer examples of existing systems used for an effective response to natural/man-made disasters than HICs. Figure 32 provides further details on the level of response for each sub-question. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

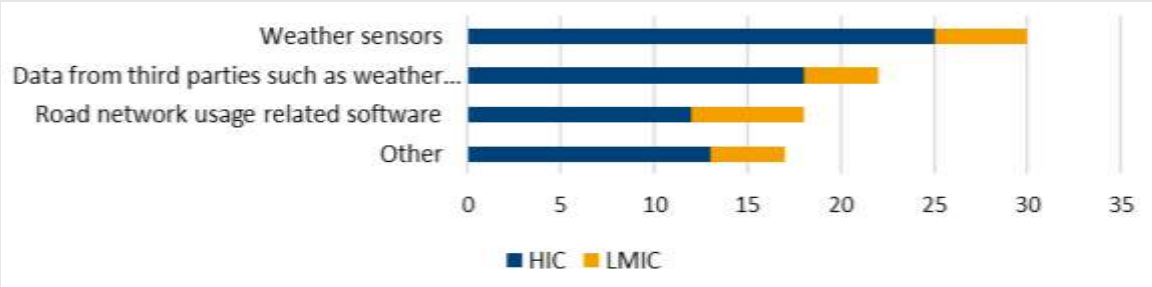


Figure 32: Breakdown of Q6 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.2.6.1. *WEATHER SENSORS*

Of the four sub-questions for Q6, weather sensors had the greatest number of responses. As with almost all other questions, HIC mostly responded to this and almost all responses were from urban countries. The responses have generally covered weather data capturing road temperatures, humidity, rainfall and other forms of precipitation for early warnings.

- **China, LMIC:** The weather detector is used to automatically detect weather information, road condition and visibility information. It includes various probes and microprocessors for information collection and processing, and can detect visibility, wind speed, wind direction, precipitation, temperature, humidity, etc. Following collection, the data is then processed and transmitted to the monitoring sub-centre to make a timely control plan according to the weather, road condition and visibility condition.
- **France, HIC:** Considerations of meteorological observations and atmospheric forecasts are combined together to provide forecasts on road sections including forecasts of sensitive weather, soil conditions and temperature.

4.2.6.2. *ROAD NETWORK USAGE RELATED SOFTWARE*

The countries who responded to this sub-question have provided details on how they use software solutions to understand where there is heavier use of the network by road users. Some organisations in the countries who responded use that information for emergency planning.

- **Chile, HIC:** SIEMOP/Emergency Technical Information System (FEMN-MAXIMO Module) is used for control of emergency works, monitoring the affected network, providing alternative road information and road safety information.
- **Thailand, LMIC**: Emergency management system for traffic management.

4.2.6.3. *DATA FROM THIRD PARTIES SUCH AS WEATHER MONITORING ORGANISATIONS*

Data from third parties was the second most popular sub-question from Q6. Some countries are using the information and data from weather monitoring organisations to understand the anticipated weather patterns and develop a winter maintenance response plan.

- **Mexico, LMIC:** SCT has a guide for hydrometeorological and geological emergency care on the country's federal road network. Risk information is obtained from the National Disaster Prevention Center.

- **Norway, HIC:** Data and weather products from the Norwegian Meteorological Institute are free of charge and are available for both winter maintenance and warning services for avalanches, landslides and/or flooding.
- **Canada, HIC:** The Department uses weather forecasts from Environment and Climate Change Canada and monitoring bulletins developed by the Department of Public Safety that take into account several third-party observations and forecasting systems. The Department also receives accurate weather forecasts prepared by Envirometr International Inc. three times a day during the winter season.

4.2.6.4. *OTHER*

One country has referenced their national disaster funds to respond to emergencies, and another has mentioned snow avalanche detection to detect avalanches in starting zones above the road. The following is an example from Japan:

- **Japan, HIC:** Investigating the use of social networking sites (SNS) information for prompt earthquake damage detection on highways. Also investigating the SNS information for detecting deterioration of concrete and neighbouring fires. National Institute for Land and Infrastructure Management has developed and utilized an automatic delivery system of “Earthquake Spectrum Analysis Information” for effective response to earthquake disasters. The system collects and organises ground motion data immediately after an earthquake. Next, it creates “Earthquake Spectrum Analysis Information” that compares these data with the damage-border drawn from damage to structures of the past earthquake disasters so that the damage scale can be estimated. Then, the system automatically delivers the Information via email to administrative officials in order to support their decision making immediately after an earthquake.

4.3. ROAD USER / DATA SHARING

4.3.1. Q7: DO YOU SHARE ANY DATA / INFORMATION WITH THE USERS OF THE ROAD NETWORK?

To further understand how organisations and countries share data and information with road users, Question 7 (Q7) was split into the following two main questions:

1. What kind of data/information do you share with road users?
2. How do you share that data / information with road users?

A total of 44 countries across 72 organisations responded to Q7. The two main questions within Q7 had a similar response level across both, with 44 countries and 40 countries responding to the first and second questions respectively. Overall, two countries did not respond to Q7. Participants had the option to select and provide examples for any of the following sub-questions:

1. What kind of data/information do you share with road users?
    a. Traffic volumes
    b. Traffic information
    c. Accidents information
    d. Public awareness
    e. Maintenance plans and roadworks
    f. Diversion routes
    g. Other
2. How do you share that data / information with road users?
    a. Government websites
    b. Social media
    c. Open data sources
    d. Other

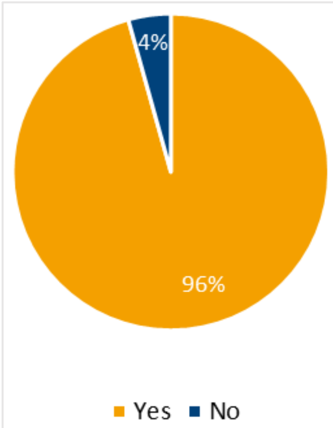


Figure 33: Q7 split of responses

Tables 21 and 22, and Figures 33, 34 and 35 provide a breakdown of each of the three classifications across the countries who responded to Q7.

Table 21: Number of responses by income level for Q7

High	Upper Middle	Lower Middle	Low
28	11	4	1

Table 22: Number of responses across geographical regions for Q7

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
22	5	8	2	1	5	1

Q7 is the first question in the 'road user/data sharing' theme and it had the highest proportion of responses received from the questionnaire at a response rate of 96% of all survey participants. Similar to the other questions, LMICs have provided lower response rate of 36% of those all survey participants. The figure above shows the urban/rural countries split of responses at 75% for urban countries and 25% for rural countries. Following a similar trend of geographical regions across the previous questions, Europe and Central Asia had more responses than any other region.

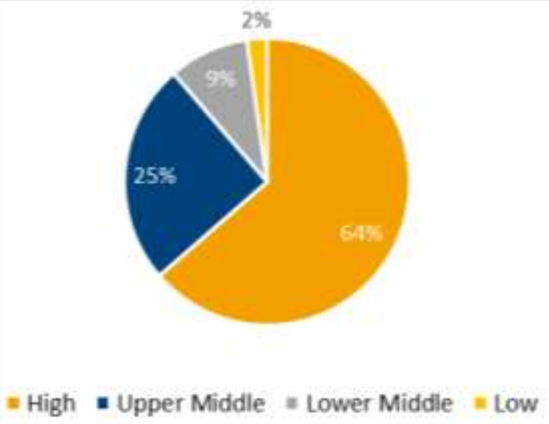


Figure 34: Proportion of responses by income level for Q7

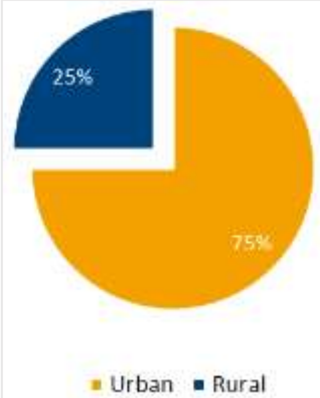
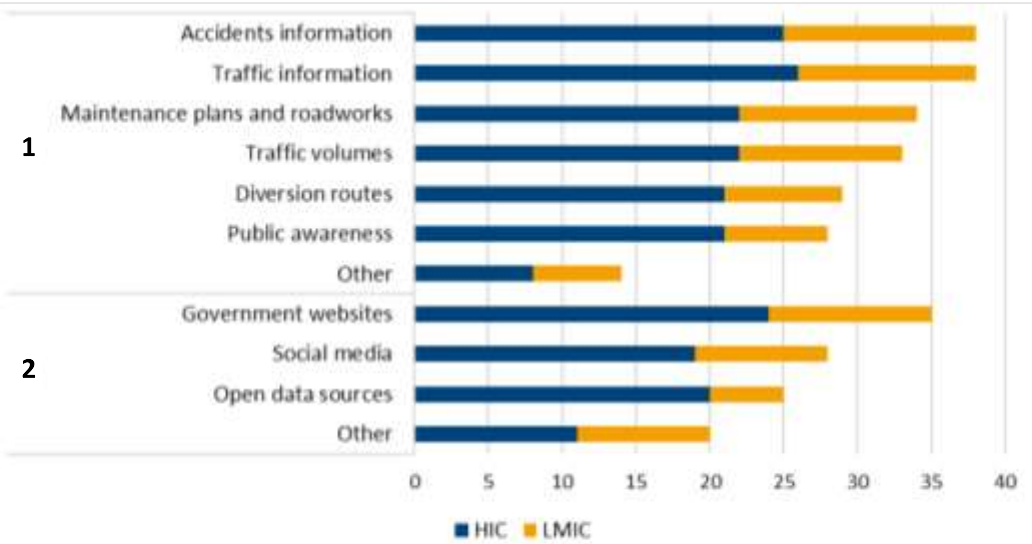


Figure 35: Proportion of responses for urban/rural countries for Q7

Between the two questions, LMICs have followed a similar trend to HICs. Both LMICs and HICs responded with more direct examples to the sub-questions than providing examples for other uses. High response rate was received across all countries who responded to the question related to the kinds of data/information shared with road users while providing examples on the traffic and accident information.

For the second part of the question related to how the data/information is shared with road users, most countries responded to using Government Websites as their means to disseminate information to road users. There was a fairly high proportion of countries who responded to using 'other' means of distributing information publicly although some responses provided overlaps with other sub-questions such as using open data sources. Figure 36 provides further details on the level of response for each sub-question. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.



Note: 1 = What kind data/information do you share with road users?, 2 = How do you share that data/information with road users?

Figure 36: Breakdown of Q7 responses by income level

4.3.1.1. *WHAT KIND OF DATA/INFORMATION DO YOU SHARE WITH ROAD USERS?*

Traffic volumes

Some organisations mentioned that they share traffic volume information via annual reports of peak hour volume, capacity, growth and levels of service. Some organisations also make the data publicly available and sometimes it is used for research purposes.

- **Mexico, LMIC:** Annual Road Data are publicly available as well as the Annual Average Daily Transit (TDPA) of all road sections and their vehicle configuration.
- **Japan, HIC:** Very limited data is shared. Usually travel time or congestion information are shared rather than traffic volumes.
- **United States, HIC:** FHWA receives data on a monthly basis from over 6,000 permanent traffic counters in all 50 states through the online Travel Monitoring Analysis System (TMAS) following the FHWA Traffic Monitoring Guide TMG formats. This data is used for both federal and public reports as well as for research purposes.

Traffic information

Some organisations mentioned that they disseminate information and open data of the road network through their official websites and social media platforms. Some organisations also release road maintenance information to communicate diversions to the road users.

- **UK, HIC:** The Traffic Scotland website provides a wide range of information related to traffic and travel information, network performance, incident management and journey planning.
- **South Africa, LMIC:** Information to road users related to delays caused by various planned/unplanned incidents. Predicted travel times to major interchanges are posted on variable message signs.
- **Colombia, LMIC:** Traffic information will be shared soon in the ITS project with the National Road Safety Agency and the National Road Cargo Dispatch Registry.

Accidents information

Some organisations mentioned that they share information on traffic accidents and alternative routes due to road closures through their official websites and social media platforms.

- **Mexico, LMIC:** The information is available to the public on the SCT website. The interpretation and use of information varies; mainly used for analysis and statistics such as identifying accident causes, developing projects to eliminate conflict points with high frequency of accidents, and for quantifying the economic impact of traffic accidents.
- **Malaysia, LMIC:** Accident data from Royal Malaysian Police (RMP) is used to identify and prioritise Blackspot locations which needs treatment. The list of blackspots is shared with relevant authorities to disseminate to the public, and also to diagnose and determine the possible causes of accidents to enable appropriate engineering countermeasures to be implemented on site.

Public awareness

Some responses have detailed their public awareness campaigns for road user safety and way-finding applications for diversions, roadworks and incidents. Some organisations also disseminate information through social media platforms.

- **Russian Federation, LMIC:** Informing residents of urban areas on roadworks in progress or implemented within the framework of the National Project “Safe and High Quality Roads” (SHQR) and providing information on road infrastructure building stages.
- **Australia, HIC:** Way finding apps & media updates and reporting, Roadworks, incidents, disruption, travel planning or through third party apps and diversion routes.

Maintenance plans and roadworks

The main purpose of sharing information on maintenance plans and roadworks is to allow road users to plan their journeys by knowing the duration of works and any alternative routes which can be used if required. Some organisations share the expected travel times with road users using way-finding applications and Variable Message Systems (VMS).

- **Poland, HIC:** All of the maintenance works and roadworks are planned, registered and shown on website so road users can check it and choose alternative routes. The set of information related to traffic safety and parking places are also shared.
- **South Africa, LMIC:** Inform road users of current and planned roadworks or road maintenance. That is communicated via social media, VMSs and road administration website.

Diversion routes

Information related to diversion routes is shared with road users if there are roadworks, road closures and/or accidents on the road network. Responses have shown that information on diversion routes are displayed on VMS, through social media or through the organisation's official websites.

- **Mexico, LMIC:** Information about diversion routes using signs on site and through Twitter and other social networks.
- **Poland, HIC:** VMS and/or prismatic signs are used to inform road users of accidents and enable them to show alternative routes. Traditional signs showing alternative routes are also used in case of long-lasting accidents.

Other

Some organisations mentioned sharing information related to the road environment, socio-environmental studies and designs of road projects with road users through various platforms.

- **New Zealand, HIC:** The Open Data Portal is a public platform where the NZ Transport Agency shares open data. Data can be explored, analysed, and downloaded in a range of formats. www.opendata-nzta.opendata.arcgis.com. The following is a link to a wide range of customer facing tools. www.www.nzta.govt.nz/traffic-and-travel-information. The Location Referencing Application Programming Interface (API) provides access to authoritative data representing locations along the State Highway network. The Location Referencing API includes: Logical network structure, Spatial Centerline, Linear/Spatial Translation and Directionally tolerant location search.

4.3.1.2. *HOW DO YOU SHARE THAT DATA / INFORMATION WITH ROAD USERS?*

Government websites

Some organisations use their government websites to disseminate information and others do not due to their organisations' overall approach or due to other reasons or constraints.

- **Poland, HIC:** Traffic data and other information is shared using two distribution channels; National Access Point at the following website (www.kpd.gddkia.gov.pl) and GDDKiA map of road conditions (www.www.gddkia.gov.pl/pl/21/mapa-warunkow-drogowych).
- **Singapore, HIC:** Data is shared via LTA one-motoring website (www.onemotoring.com.sg), LTA Data Mall (www.mytransport.sg/content/mytransport/home/dataMall.html), My Transport app, and third party apps.

Social media

Generally, countries have responded with sharing information on traffic, accidents, special events and awareness campaigns through social media, their organisations' websites, radio and/or television.

- **Canada, HIC:** Facebook and Twitter are used to share information such as Spring Road Restrictions, Winter Seasonal Weight Programs, Open Houses. Manitoba 511 also has a twitter account to communicate road closures, new construction and detours to the public.
- **Japan, HIC:** Company's website, mew-ti, Facebook and Twitter are used to share information. A mobile app named i-highway is also used.

Open data sources

Some organisations make traffic information publicly available on their official website or other external websites.

- **Belgium, HIC:** www.opendata.vlaanderen.be/dataset?tags=real-time+verkeersinformatie.
- **UK, HIC:** DATEX II (data exchange standard) feeds from the Traffic Scotland system, which is made available free of charge to anyone who wishes to use it.
- **Czech Republic, HIC:** National data access point www.registr.dopravniinfo.cz/cs/index.html.

Other

Some organisation mentioned other forms of sharing information with road users through billboards, VMS, dedicated websites or through published reports.

- **Russian Federation, LMIC:**
  1. The SHQR web page contains detailed information on all the facilities of the National Project. Its interactive map presents information on every region of the Russian Federation (length of regional and urban road networks, road surface installation schedule, funding, and a diagram of target indicators) as well as pictures before and after roadworks.
  2. Processing appeals of citizens through an official reception at VK social network. More than 50 appeals are processed on a daily basis with a response period of 24 hours.
  3. Russian and international sectorial exhibitions.
  4. Informing users on traffic and road surface conditions (weather conditions) through variable message signs.

4.3.2. Q8: DO YOU ACTIVELY SEEK AND COLLECT FEEDBACK ON THE SATISFACTION OF ROAD USERS IN A FORMAL METHOD?

To further understand how organisations and countries actively seek feedback on road user satisfaction, Question 8 (Q8) is split into two:

1. Which platform do you use to conduct those satisfaction surveys?
2. How do you utilise the output of those surveys?

A total number of 26 countries across 43 organisations responded this question which is the lowest number of responses out of the survey. The two questions within Q8 had a similar response level across both, with 26 countries responding to the first and 25 responding to the second. Overall, a total of 20 countries did not respond to Q8. Participants had the option to select and provide examples for any of the following sub-questions:

1. Which platform do you use to conduct those satisfaction surveys?
    a. Government websites
    b. Dedicated online platform
    c. Social media
    d. Traditional surveys
    e. Bespoke / tailored research
    f. Other
2. How do you utilise the output of those surveys?
    a. Setting Performance Indicators
    b. Informing investment decisions
    c. Informing engineering options (design / construction / operation / maintenance)
    d. Developing annual reports
    e. Other

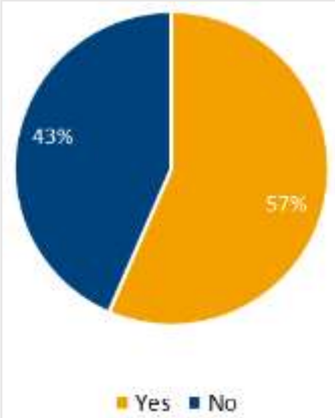


Figure 37: Q1 split of responses

Tables 23 and 24, and Figures 37, 38 and 39 provide a breakdown of each of the three classifications across the countries who responded to Q8.

Table 23: Number of responses by income level for Q8

High	Upper Middle	Lower Middle	Low
19	4	3	0

Table 24: Number of responses across geographical regions for Q8

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
13	2	6	2	0	1	2

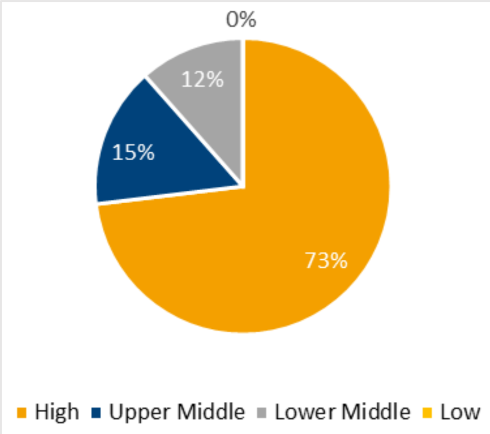


Figure 38: Proportion of responses by income level for Q8

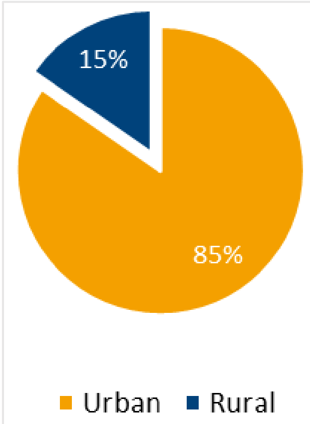
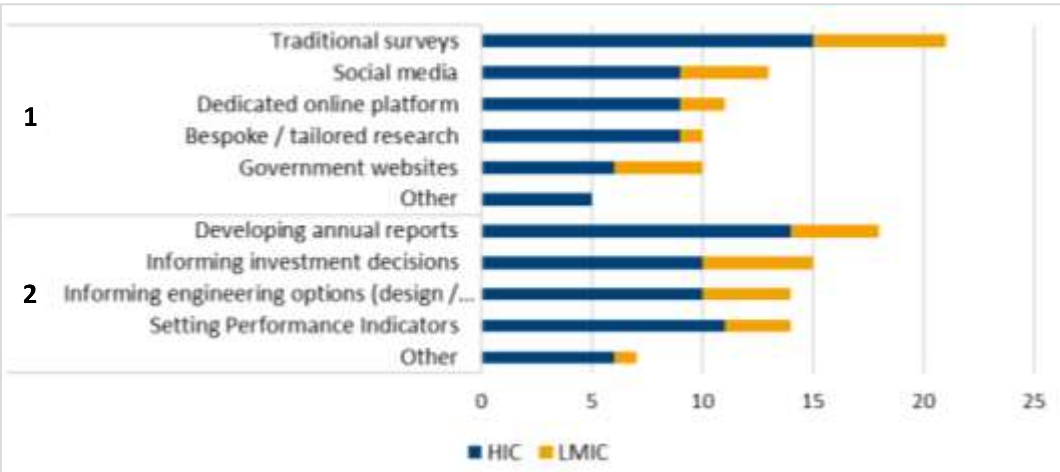


Figure 39: Proportion of responses for urban/rural countries for Q8

This question received a low level of responses in the questionnaire with only 57% of all countries responding. Of the 57%, almost three quarters of responses were from HICs and a large proportionate of responses were from urban countries. Similar to the other questions, LMICs have responded less than HICs with a total of 27%. Following a similar trend across geographical locations, Europe and Central Asia have responded in higher quantities than any other location with a response level of 50%.

The most common approach to conduct satisfaction surveys was through 'Traditional surveys' across HICs and LMICs which aligns with the popular method of using traditional human surveys for various activities as highlighted in some of the previous questions. Seeking customer satisfaction using government websites is not as common as using traditional surveys and other online platforms such as social media.

The majority of responses regarding the utilisation of the data captured from the surveys mentioned supporting the development of annual reports, setting performance indicators as well as other uses by both HICs and LMICs as outlined in Figure 40 below. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.



Note: 1 = Which platform do you use to conduct those satisfaction surveys?, 2 = How do you utilise the output of those surveys?

Figure 40: Breakdown of Q8 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.3.2.1. *WHICH PLATFORM DO YOU USE TO CONDUCT THOSE SATISFACTION SURVEYS?*

Government websites

Some organisations seek feedback through their government website, but this is one the least popular regarding the number of responses from countries, indicating government websites are not the most used method for receiving road user feedback.

- **Canada, HIC:** Quebec 511 and departmental websites allow citizens to use an online form available in the "Join Us" section. Questions, comments and suggestions received are addressed and taken into account.
- **China, LMIC:** User satisfaction surveys are carried out through the government website, and improvements are made according to user opinions and issues raised.

Dedicated online platform

Some responses in this category have referred to using their organisations' websites and refer to the category above. Some organisations also mentioned receiving feedback related to pavements and other asset types.

- **Chile, HIC**: OIRS (Office of Information, Complaints and Suggestions MOP).
- **Greece, HIC:** Official website (www.gefyra.gr) where there is a dedicated contact form that users can post questions, provide feedback, suggestions, complaints, etc.

Social media

Some organisations mentioned social media platforms such as Twitter, Facebook and YouTube to communicate with road users and also to receive feedback on provision of services, roadworks and road condition.

- **Malaysia, LMIC:** To detect major road user concerns, complaints and issues on the road network, as well as any issues related to planned or on-going road construction projects. Social media is also used to receive direct input from road users regarding the condition of existing roads so maintenance works can be directed to those locations which require immediate actions.
- **Japan, HIC:** Analyse tweets or comments related to expressways.

Traditional surveys

Traditional surveys were the most popular method used by both HICs and LMICs. Organisations conduct annual surveys or every 4 years to develop a better understanding on road user perception.

- **Belgium, HIC:** Annual surveys are undertaken (online and/or via phone) with an external agency to monitor customer satisfaction. Every 4 years, a similar survey is conducted which targets local governments and other partners (police departments, public transport, cyclist federations and the transport sector).
- **UK, HIC:** The National Highways and Transport (NHT) public satisfaction survey provides annual feedback on customer opinion of services provided. Two-thirds of Local Highway Authorities (LHAs) use this survey approach. Suffolk Highways has also undertaken formal surveys with local residents following completion of works (maintenance and improvement schemes) which was then used to shape future works delivery and communication methods.

Bespoke / tailored research

The outcome of the responses for bespoke research was similar to the responses provided by traditional surveys although they are not conducted with the same frequency.

- **Russian Federation, LMIC:** The multipurpose think tank NAFI conducted a nationwide survey on estimating regional and local roads quality, dynamics of road quality change and recognisability level of the SHQR in 2019. According to its results the SHQR is the most recognisable among all National Projects.
- **UK, HIC:** Using a variant of the NHT survey, surveys were directed solely at councillors (county, district, borough, town and parish) to gauge opinion on the services provided resulting in service changes.

Other

All of the responses in this category were from HICs and mostly from urban countries. Some countries mentioned responding to road user inquiries via phone calls, emails and letters.

- **Norway, HIC:** Net/QuestBack for Customer satisfaction on maintenance and operation of pedestrian and cycle paths (Research program BEVEGELSE).
- **UK, HIC:** Some LHAs are using on-street 'pop-up surveys' to gain a more localised understanding of public satisfaction.

4.3.2.2. *HOW DO YOU UTILISE THE OUTPUT OF THOSE SURVEYS?*

Setting Performance Indicators

There was only one detailed response for this category as outline below.

- **Japan, HIC:** Performance indicators are one of the outcome indicators of road management by government agency, as well as the Index of internal performance evaluation.

Informing investment decisions

Organisations who selected this sub-question did not provide any examples.

Informing engineering options (design / construction / operation / maintenance)

Organisations who selected this sub-question did not provide any examples.

Developing annual reports

Out of the limited responses for this category, one organisation mentioned that they release information through annual reports.

- **China, LMIC:** The annual status of the road network is shared through annual reports which also includes the status of maintenance works and the use of funding available.

Other

Responses showed that countries use road user feedback to move to a customer centric approach through various communication channels such as satisfaction surveys, emails, etc.

- **Belgium, HIC:** Feedback is used as a driver for internal change towards a more customer centric approach. Budgets are fixed and cannot be altered; however, customer feedback can be used to evaluate (and alter) ways of communication, approach and ways of addressing and channelling the expectations from partners and customers.

- **Chile, HIC:** This initiative is new and in the testing stage. Initially, the aim is to obtain useful data to develop a better understanding of the sectors and where user satisfaction declines.

4.3.3. Q9: HAVE YOU CONDUCTED ANY RESEARCH OR FIELD TRIALS ON THE BENEFITS OR USE OF CONNECTED AND AUTONOMOUS VEHICLES (CAVS)?

A total of 20 countries across 27 organisations responded to Question 9 (Q9) which is less than half of all survey responses. There were 26 countries who did not respond to this question. Participants had the option to select and provide examples for any of the following sub-questions:

- CAV data opportunities for road network management
- CAV data opportunities for road network operations
- CAV data opportunities for user experience
- Other

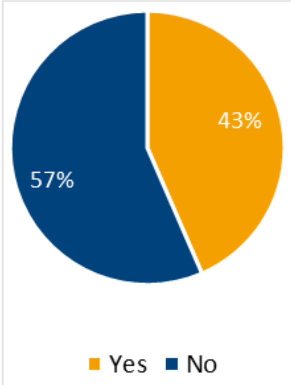


Figure 41: Q9 split of responses

Tables 25 and 26, and Figures 41, 42 and 43 provide a breakdown of each of the three classifications across the countries who responded to Q9.

Table 25: Number of responses by income level for Q9

High	Upper Middle	Lower Middle	Low
19	1	0	0

Table 26: Number of responses across geographical regions for Q9

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
13	1	4	2	0	0	0

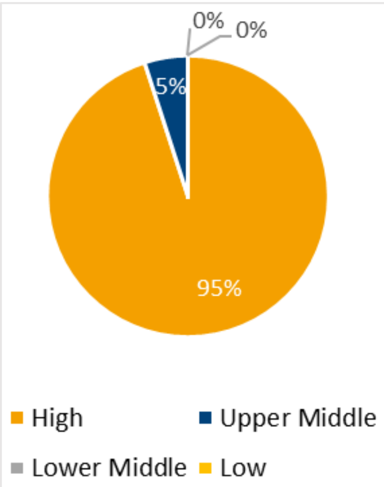


Figure 42: Proportion of responses by income level for Q9

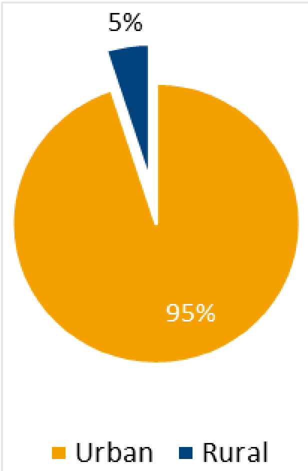


Figure 43: Proportion of responses for urban/rural countries for Q9

Out of the 43% of responses (20 countries), all countries were HICs apart from one and 65% of all responses were from Europe and Central Asia in this question. The majority of countries responded with examples of using CAVs for network operations, network management and improving user experience.

This response rate generally shows that most LMICs who responded to the survey have no plans to use CAVs for collecting road data yet. The low overall response rate also shows that the use of CAVs is still growing across HICs and LMICs in all geographical regions. Figure 44 provides further details on the level of response for each sub-question. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

Figure 44: Breakdown of Q9 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively.

4.3.3.1. *CAV DATA OPPORTUNITIES FOR ROAD NETWORK MANAGEMENT*

The responses mainly discussed the use of CAVs data for capturing vehicle speeds, conducting trials with roadside sensors and real-time incident data affecting road safety.

- **Austria, HIC:** To prepare road infrastructure with specific affordable adaptations and support it with new models and tools to accommodate for the stepwise introduction of automated vehicles.
- **Spain, HIC:** Real-time connection of incidents affecting road safety within the Data Task Force.

4.3.3.2. *CAV DATA OPPORTUNITIES FOR ROAD NETWORK OPERATIONS*

This sub-question received the highest number of responses in Q9, all of which were from HICs. For network operations, some organisations mentioned using CAVs to collect data related to the condition of road pavements and other asset types. Some organisations mentioned implementing pilot trials and schemes, and are working with car manufacturers to improve safety of tunnels.

- **Canada, HIC:** The MTQ participates in various pilot projects of autonomous shuttles on the public road network. The aim of its projects is to enable the Department to develop policies related to CAVs and to acquire knowledge in the field of CAV and V2I (Vehicle to Infrastructure) systems. ACTIVE-AURORA Connected Vehicle Testbed Network – Collaboration between three levels of government and the University of Alberta (www.necavsummit.com/wp-content/uploads/2019/02/Dan-Baxter-Michelle-Orfield-Stantec-Presentation-Low-Res.pdf).
- **Norway, HIC:** Pilots for footway and bicycle lane winter maintenance.

4.3.3.3. *CAV DATA OPPORTUNITIES FOR USER EXPERIENCE*

There were insufficient details provided from the responses on how data collected from CAVs can be used to improve the overall experience of road users.

- **Austria, HIC:** Part of the C-Roads platform (www.c-roads.eu) as well as doing pilots on CAVs (www.inframix.eu and www.ict4cart.eu). Also running national activities (www.alp-lab.at and www.testregion-digitrans.at) and involved in the European CCAM platform.
- **Canada, HIC:** The MTQ is currently experimenting with the various V2I technologies for exchanging information with VAC (traffic light status, SPaT, map, user information, etc.). The Department's objective in this area is to establish standards to ensure the quality and interoperability of V2I systems implemented on its network.

4.3.3.4. *OTHER*

In this sub-question, organisations provided additional information on the wider uses and activities associated with CAVs in their countries.

- **Greece, HIC:** Participated in a work group and provided geographical locations for the DSRC Toll Plazas to implement a Protected Zone Database and reduce ETC interference caused by CAVs.
- **United States, HIC:** FHWA and the ITS Joint Program Office conduct significant research on connected vehicles and automated vehicles. The most reliable sources of information related to this are the following websites: www.its.dot.gov and www.highways.dot.gov/automation.

4.3.4. Q10: DO YOU EXCHANGE/SHARE ANY ROAD RELATED DATA WITH THIRD PARTIES OR OTHER NATIONAL/GLOBAL STAKEHOLDERS?

A total of 39 countries across 57 organisations responded to Question 10 (Q10) which is 85% of all survey responses. A total of 7 countries did not respond to this question. Participants had the option to select and provide examples for any of the following sub-questions:

- Mobile phone network providers
- Satellite navigation providers
- Local road operators (traffic cameras, etc.)
- Road sector organisations
- Private companies
- Insurance companies
- Social media
- Open data sources
- Other

Tables 27 and 28, and Figures 45, 46 and 47 provide a breakdown of each of the three classifications across the countries who responded to Q10.

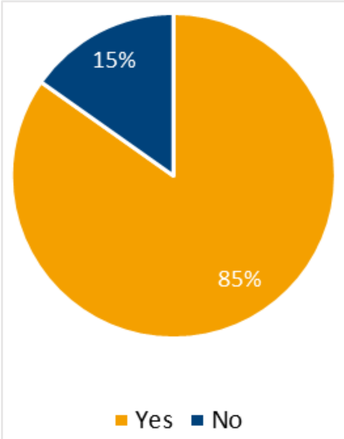


Figure 45: Q10 split of responses

Table 27: Number of responses by income level for Q10

High	Upper Middle	Lower Middle	Low
24	10	4	1

Table 28: Number of responses across geographical regions for Q10

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
19	5	6	2	1	5	1

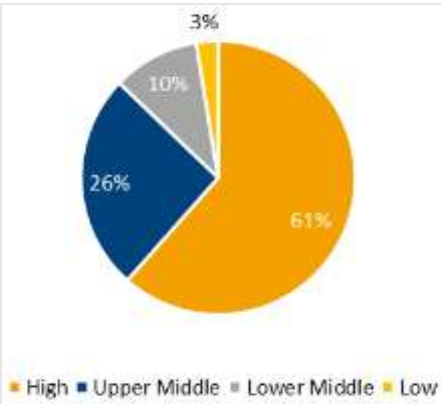


Figure 46: Proportion of responses by income level for Q10

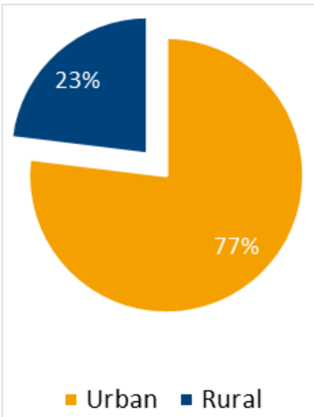


Figure 47: Proportion of responses for urban/rural countries for Q10

Of the 85% of countries who responded to Q10, two thirds of responses were from HICs and 77% were urban countries. LMICs responses followed a similar trend to HICs in their responses to this question related to exchanging road related data with third parties. The majority of responses referred to exchanging road related data with road sector organisations, road operators, private companies and open data sources. Fewer responses were focused on sharing data on social media, with insurance companies and with mobile phone providers. Figure 48 provides further details on the level of response for each sub-question. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

Figure 48: Breakdown of Q10 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.3.4.1. *MOBILE PHONE NETWORK PROVIDERS*

This sub-question had the fewest number of responses in Q10, and almost equal number of responses from HICs and LMICs. The responses varied and some organisations referred to travel times and transport surveys.

- **Argentina, LMIC**: Transit Survey for Survey Adjustment through Big Data.
- **Australia, HIC:** Bluetooth travel time monitoring.

4.3.4.2. *SATELLITE NAVIGATION PROVIDERS*

The responses showed that some organisations have contracts with third parties and share data with them to provide information on road closures and diversion routes. It was also mentioned that third parties provide information to input into the organisations' journey time system.

- **UK, HIC:** Share data with satellite navigation providers (have a contract with INRIX to provide their dataset which forms the basis of the organisation's journey time system).
- **Spain, HIC:** Reach the final driver through these devices. In particular, the TN-ITS project shares static road information such as speed limits and restrictions.

4.3.4.3. *LOCAL ROAD OPERATORS (TRAFFIC CAMERAS, ETC.)*

This sub-question received the second highest number of responses in Q10, mostly from HICs and urban regions. Responses showed that information is shared with local road operators for traffic management, evaluating road safety and improving road condition.

- **Japan, HIC:** Road traffic information and camera images are exchanged in order to provide seamless traffic information between road managers.
- **Czech Republic, HIC:** Data from local road operators are shared based on DATEX II (data exchange standard).

4.3.4.4. *ROAD SECTOR ORGANISATIONS*

This sub-question received the highest number of responses in Q10 with an almost equal number of responses from HICs and LMICs. Responses showed that information shared with road sector organisations includes CCTV videos, real-time traffic information and information on road condition.

- **Bangladesh, LMIC:** With the help of the official website of this Department and the RMMS Database system, Road length, Road conditions, LRP chainage and Traffic data are provided.
- **Japan, HIC:** Transmit traffic information data in real-time to the Japan Road Traffic Information Center that controls the provision of real-time road traffic information.

4.3.4.5. *PRIVATE COMPANIES*

Responses showed that information shared with private companies includes mapping information, traffic restrictions, roadworks and incident data for research purposes and to provide construction and investment planning information.

- **Australia, HIC:** TomTom supports planning for local road design such as large-scale private developments, airport planning, etc.
- **Chile, HIC:** Chilean Chamber of Construction (projects, studies and investments).

4.3.4.6. *INSURANCE COMPANIES*

There were very few responses in this sub-question all of which were from urban countries and mostly from HICs. The responses showed that this information includes photographic evidence and accident data to support insurance claims.

- **UK, HIC:** Digital highway inspection records photographic evidence (pre- and post-repair) for insurance claims.
- **Andorra, HIC:** Viewing traffic cameras to investigate vehicle accidents.

4.3.4.7. *SOCIAL MEDIA*

Some organisations use social media channels to disseminate information on road closures, road incidents and information on any campaign. Almost all responses were from urban regions and mostly from HICs.

- **Mexico, LMIC:** Dissemination of information related to road work programmes, road events and other road network information.
- **UK, HIC:** Traffic Scotland social media platforms are used to share up to date information on road related matters such as roadworks, incidents and campaign information to ensure all road users obtain the knowledge they require when travelling in Scotland.

4.3.4.8. *OPEN DATA SOURCES*

Some organisations share information related to pavements and other asset types with third parties through open sources. This information generally includes traffic volumes and restrictions and in some cases, this information is used to support accident prevention policies.

- **Lithuania, HIC:** Open data (datasets and web services) are created to provide static data (road network, pavement, etc.) and dynamic data (road weather, traffic volume, restrictions, EV charging points, road condition, etc.).
- **Switzerland, HIC:** sharing traffic data with third parties based on the principles of “conditional open data”. The data are freely accessible and anyone can obtain them, but they should also supply data themselves if a business model is being operated with the obtained data. The expanded data are then available to everyone again and can be used for new applications.

4.3.4.9. *OTHER*

Other examples of organisations sharing information with third parties include exchanging information with academia, national authorities and neighbouring countries. Some information is shared via radio broadcasters, newspapers and through service providers.

- **Slovak Republic, HIC:** Exchange/share any road related data with third parties (in limited version for privacy policy reasons) via www.odoprave.info.
- **United States, HIC:** FHWA makes available to the general public most of its data via various agency outlets and websites including social media.

4.4. ECONOMIC, ENVIRONMENTAL AND SOCIAL CONTEXT

4.4.1. Q11: DO YOU HAVE ANY METHODS IN PLACE TO MEASURE AIR QUALITY, TRANSPORT EMISSIONS, NOISE LEVELS OR ANY OTHER ENVIRONMENTAL ASPECTS RELATED TO ROAD INFRASTRUCTURE?

A total of 31 countries across 49 organisations responded to Question 11 (Q11) which is over two thirds of all survey responses. 15 countries did not respond to this question. Participants had the option to select and provide examples for any of the following sub-questions:

- Data from sensors or monitoring equipment
- Data from environmental agencies
- Data from health agencies
- Other

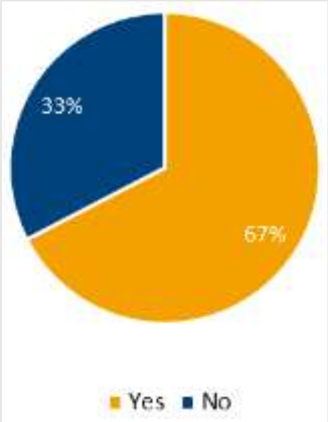


Figure 49: Q11 split of responses

Tables 29 and 30, and Figures 49, 50 and 51 provide a breakdown of each of the three classifications across the countries who responded to Q11.

Table 29: Number of responses by income level for Q11

High	Upper Middle	Lower Middle	Low
23	8	0	0

Table 30: Number of responses across geographical regions for Q11

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
18	3	7	2	1	0	0

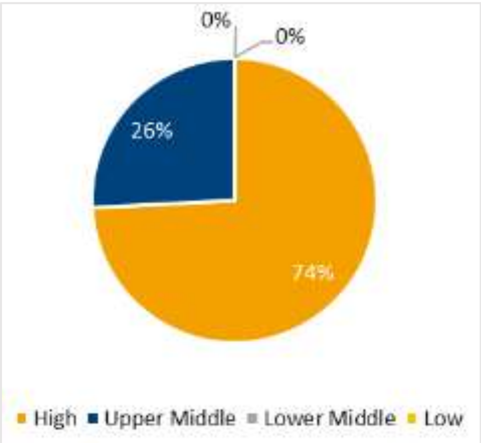


Figure 51: Proportion of responses by income level for Q11

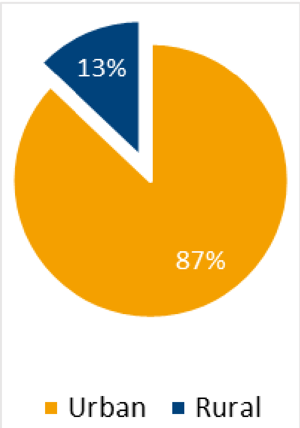


Figure 50: Proportion of responses for urban/rural countries for Q11

From the 67% of countries responded to this question, almost three quarters were HICs and 87% were urban countries. There were no responses from Lower Middle or Low Income countries for this question. Countries mostly responded to the sub-question of using 'data from sensors or monitoring equipment' to measure air quality. There were more responses in the 'Other' sub-question than the data from environmental or health agencies.

LMICs did follow a similar trend but there were significantly fewer responses from LMICs to draw any major conclusions from the results. There were no responses from LMICs for data from health agencies. Figure 52 provides further details on the level of response for each sub-question. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

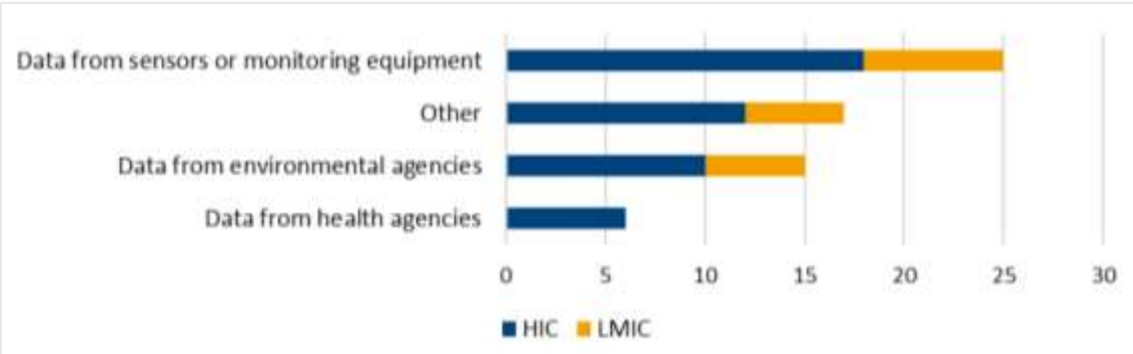


Figure 52: Breakdown of Q11 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.4.1.1. *DATA FROM SENSORS OR MONITORING EQUIPMENT*

Methods to capture data from sensors included using equipment to collect noise levels, air quality (mostly in tunnels) and water pollution. Some organisations who capture this data, mentioned that they either use permanently installed sensors or portable equipment. Other organisations receive data from transport agencies or regional authorities.

- **Colombia, LMIC:** A platform is already in place for capturing and monitoring wildlife information related to road infrastructure, developed by the National Roads Institute; an application called SUKUBUN is used by road managers. The information seeks to identify "hot spots" where there is greater impact on wildlife. In the future, it is hoped to generate tools to mitigate the problem of wildlife abuse.

- **Mexico, LMIC:** The Mexican Transport Institute (IMT) monitors noise levels on some roads in the country through direct measurements with portable equipment. The use of information is for research purposes in order to establish public policies that allow adequate levels of noise to be maintained on the roads in accordance with international standards.

4.4.1.2. *DATA FROM ENVIRONMENTAL AGENCIES*

The majority of responses showed that the data sought from environment agencies is related to air quality. All responses were from urban countries and mostly HICs.

- **Mexico, LMIC:** Air quality information is estimated through models that are part of the national inventories carried out by the Secretariat of Environment and Natural Resources (SEMARNAT) of the federal government, with the support of the National Institute of Ecology and Climate Change (INECC). Major cities have air quality monitoring networks.

- **UK, HIC:** For Air Quality, the Scottish Environment Protection Agency provide a modelling service known as the National Modelling Framework, which is outlined at the following website *www.scottishairquality.scot/lez/*. An example of the output of NMF can be found at the following website *www.connectingedinburgh.com/downloads/file/3/air-quality-evidence-report-edinburgh*.

4.4.1.3. *DATA FROM HEALTH AGENCIES*

This sub-question had the fewest number of responses from Q11. All responses were from HICs and mostly from urban countries. Responses mostly included names of the websites or health agencies the data is received from.

- **Czech Republic, HIC:** Regional hygienic stations mainly use portable devices to measure noise and air quality by accredited measurement methods.
- **Canada, HIC:** The Ministry of Environment and Climate Change (MELCC).

4.4.1.4. *OTHER*

This sub-question had the second highest number of responses for Q11. Some countries have responded with tools used to calculate noise from construction activities, air quality calculations and produce air quality maps. Some organisations also mentioned that some of the data is collected by third parties.

- **New Zealand, HIC:** Air Quality Map can be found at the following website: *www.nzta.govt.nz/roads-and-rail/highways-information-portal/tools/air-quality-map/.* This interactive map shows background air quality concentrations across New Zealand for two key pollutants – PM10 and NO2. The values shown exclude the contribution of nearby roadways and can be used with other tools such as the NZ Transport Agency screening model to assess the cumulative air quality effects of road projects. Suitable data may already be available from regional councils, the Transport Agency or research organisations. However, road projects with a high air quality risk, typically large projects in major urban centres, may require a dedicated monitoring campaign to better understand background air quality.

4.4.2. Q12: DO YOU GATHER ANY DATA ON THE BENEFITS/IMPACTS OF THE ROAD NETWORK RELATED TO SOCIAL OR ECONOMIC FACTORS (E.G. HEALTH AND WELLBEING OF THE PUBLIC, PROSPERITY OF LOCAL COMMUNITIES, ETC.)

A total of 24 countries across 33 organisations responded to Q12 which is 52% of all countries responded to the survey. 22 countries did not respond to this question. Participants had the option to select and provide examples for any of the following sub-questions:

- Government agencies for Health/Economy
- Commercial organisations
- Industrial organisations
- Local organisations
- Public consultations
- Social media
- Other

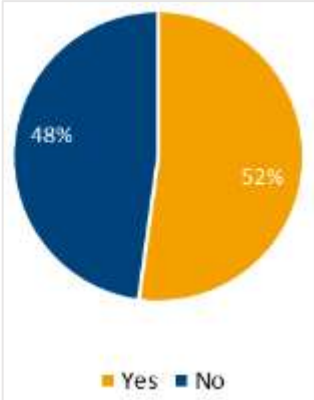


Figure 53: Q12 split of responses

Tables 31 and 32, and Figures 53, 54 and 55 provide a breakdown of each of the three classifications across the countries who responded to Q12.

Table 31: Number of responses by income level for Q12

High	Upper Middle	Lower Middle	Low
16	5	3	0

Table 32: Number of responses across geographical regions for Q12

Europe & Central Asia	Latin America & Caribbean	East Asia & Pacific	North America	Middle East & North Africa	Sub-Saharan Africa	South Asia
11	3	5	1	1	2	1

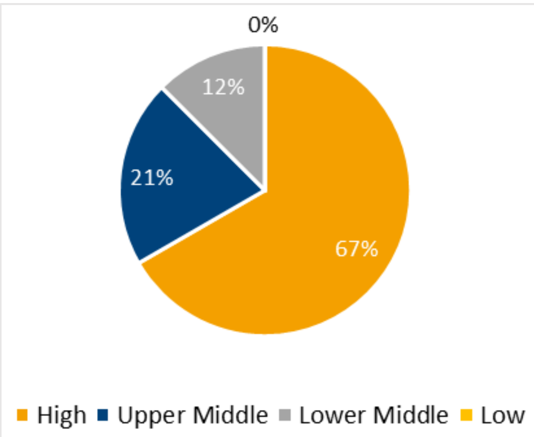


Figure 54: Proportion of responses by income level for Q12

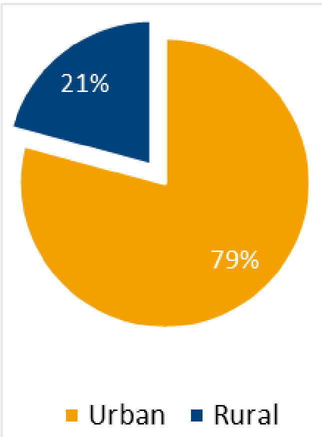


Figure 55: Proportion of responses for urban/rural countries for Q12

As with all the responses from the questionnaire, there was a high proportion of HICs responses at 67%, and 33% from Upper-Middle and Lower-Middle income levels combined with no responses from Low income countries. Almost 80% of responses were from urban countries and mostly from Europe and Central Asia. Figure 56 shows that HICs and LMICs followed the same trend across all sub-questions apart from the 'Social media' sub-question where only HICs who mentioned using social media to gather data related to the benefits and impacts on the road network. The responses for 'other' sub-question had an overall higher response level than most of the other sub-questions. Appendix C shows the total number of responses for HIC/LMIC as well as for urban/rural countries for all sub-questions.

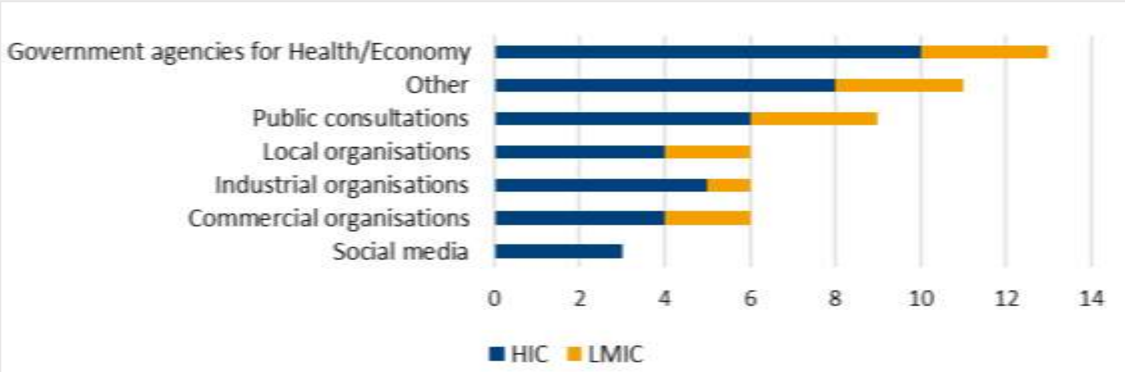


Figure 56: Breakdown of Q12 responses by income level

Some of the examples received in the response for each sub-question are listed under each sub-heading respectively while stating the purpose and/or use of each data type, collection method or technology.

4.4.2.1. GOVERNMENT AGENCIES FOR HEALTH/ECONOMY

This sub-question had the highest number of responses in Q12, with most responses from HICs and urban countries. Some organisations stated that the information provided by government agencies is related to the effects on the road network, traffic speeds, accident rates, employment rates and other social aspects.

- **Japan, HIC:** Reductions in CO_2, NO_x, and SPM emissions are estimated as a benefit of the construction of new expressways and are report to the Ministry of the Environment based on the traffic data and speed data measured. Benefits of expressway construction are also calculated based on the decrease in traffic accidents rate reported by the police, the number of foreign tourists and the amount of industrial shipments reported by the Ministry of Economy, Trade and Industry.
- **Malaysia, LMIC:** To identify Highway Network Development Plan (HNDP) for Malaysia, and to conduct Outcome Based Assessment (OBA) to study the outcome of road project after completion. Information of committed development plans are also provided for the purpose of economic evaluation.

4.4.2.2. COMMERCIAL ORGANISATIONS

There were few detailed responses on data from commercial organisations. All responses were from HICs and from urban countries. The following examples provide details on how the information is used to better understand the impact of investments on the transport system and on the private sector:

- **Japan, HIC:** Statistics and indicators to capture the impact of expressways, although data from governmental organisation are mainly used instead.
- **Chile, HIC:** Impacts on the urban transport system. Improvements in the accessibility, parking and profitability of investments for the private sector.

4.4.2.3. *INDUSTRIAL ORGANISATIONS*

Similar to the previous sub-question, 'industrial organisations' had few detailed responses, all of which were from HICs and urban countries. Most of the responses for 'industrial organisations' were similar to the responses provided for 'commercial organisations'. The following example shows how Japan uses a reduction in travel time as a proxy to understand the benefits to the road network:

- **Japan, HIC:** The reduction in travel time is calculated as a benefit of new highway construction projects and is calculated based on the speed data measured. Surveys related to increases in capital investment, the number of employees, production, and sales are also conducted using dedicated companies.

4.4.2.4. *LOCAL ORGANISATIONS*

As with the previous two sub-questions, 'local organisations' also received few detailed responses. Some responses were from LMICs and included a response from a rural country. Responses generally showed that some data provided by local organisations is used to calculate or understand the benefits to the road network.

- **Malaysia, LMIC:** Provide information on the existing numbers of population and committed residential and commercial development plans for the purpose of social evaluation and trip generation data.
- **Japan, HIC:** Understand the effects of expressway development in each area and the trends in each sector.

4.4.2.5. *PUBLIC CONSULTATIONS*

Responses showed that public consultations are used to communicate road schemes and changes to existing road infrastructure, to help the public understand the changes and how it can impact them. Some organisations also mentioned using information collected from public consultations to develop an understanding on the current condition and usage of the road network.

- **UK, HIC:** Public consultations are undertaken through all aspects of our work; the most recent consultation that included economic factors was the National Transport Strategy (NTS). The NTS sets out the focus and aspirations for Transport Scotland over the next 20 years.
- **Canada, HIC:** The Manitoba government recently opened a public engagement portal (EngageMB) that is used for specific projects but is likely to be harnessed in the future to gather such data for the whole road network.

4.4.2.6. *SOCIAL MEDIA*

Due to the very limited responses received for this sub-question, it is not possible to draw significant conclusions from how social media is used to better understand the benefits/impacts of the road network in relation to social and economic factors.

- **Japan, HIC:** For performance evaluation purposes. A quantitative approach is being tested to capture public opinions through social media.

4.4.2.7. *OTHER*

The responses in the 'other' sub-question varied in each response where countries reflected on the impacts on journey times, and the cost savings benefits to the road user. It was mentioned that some of this data is publicly available through open statistical data sources and is used to forecast outcomes of investments.

- **Switzerland, HIC:** Only costs for congestion and indirect impact on the economy through longer driving times and thus higher travel costs.

- **Mexico, LMIC:** The National Council for the Evaluation of Social Development Policy (CONEVAL) is a body that assesses well-being and social prosperity. In relation to roads, it assesses the degree of road accessibility which is an indicator used to determine the existence of paved roads and other aspects that allow society to access the road network all year round. It also shows the level of isolation that a population could experience to access basic services.

4.5. SUMMARY AND RECOMMENDATIONS

4.5.1. SUMMARY OF FINDINGS

Road Network

Overall, there was a higher proportion of responses from HICs, from Europe and Central Asia and from urban countries across the three themes of the survey.

The first theme of the Road Network covered six questions on collecting, using and analysing road related data for the management and improvement of the network. Across all questions in this theme, countries mostly responded to the sub-questions on Asset Management Systems (software) and the use of GIS mapping tools, most of which were from HICs. This indicates that these countries are more inclined to use Asset Management Systems and datasets with geographical referencing systems to manage their data and use it to assist with the management and operation on the road network as to facilitate the decision-making process.

There was high response rate from both HICs and LMICs regarding the use of dedicated sensors to capture inventory and condition data of road infrastructure assets, and weather sensors to effectively prepare for natural/man-made disasters.

In the context of this theme, it can be concluded that road administrations are not often using up-to-date technologies in collecting inventory and condition data as Q1 responses showed fewer examples of using Vehicle Telematics, CAVs, AI, Machine Learning and Computer Vision techniques.

Road User/Data sharing

The Road User/Data Sharing theme covered four questions related to the exchange of information with road users and third parties, and also related to conducting research or field trials on CAVs. The demographics of responses were similar to the responses under the road network with a higher proportion of responses from HICs, from Europe and Central Asia and from urban countries.

Countries and organisations were willingly sharing information related to road traffic and accidents through means of social media channels and websites to communicate the necessary information to road users and also for research purposes.

Interestingly, using traditional surveys to collect road data was a common approach amongst both HICs and LMICs which was also trending in questions 1 and 2 in the Road Network theme. This indicates that countries regardless of their income level, are still relying on traditional human surveys during the slow but increased use of state-of-the-art technology across their organisations.

The question related to exploring the benefits and use of CAVs received the fewest number of responses throughout the survey with a response rate less than 50% of the total number of countries who responded to the survey. There was also insufficient number of examples provided as part of the responses received. Moreover, no responses were received from Lower-Middle or Low income countries. Therefore, further research is still required to develop a broader understanding on the potential use of CAVs globally.

Economic, environmental and social context

This theme covered the benefits and impacts of the road network in relation to the economic, social and environmental factors. Increasing focus on climate change is adding more pressures on all transport organisations to ensure their transport network is performing sustainably. Responses showed examples of using sensors, monitoring equipment and data from environmental agencies to monitor air quality and develop a better understanding on how it changes. Having this information allows road administrations to adapt their road management approach and make any necessary changes as required.

The data collected on traffic volumes, traffic speed and noise levels can allow road administrations to identify the social and environmental benefits and impacts on road users and the public, as well as supporting the decision-making process in relation to network accessibility and future investments.

4.5.2. OPPORTUNITIES AND CHALLENGES FOR THE ROAD SECTOR

CAVs along with machine learning and AI are an emerging technology which are growing especially in HICs. However, the survey responses showed insufficient examples around those topics which suggests that they are still not used widely in those countries who formed part of the survey. On the other hand, traditional human surveys are still widely used in both HICs and LMICs. Hence, there is a good opportunity to expand the implementation of pilot schemes on the use of new and emerging technologies, allowing a reduction in the use of human surveys while delivering efficiencies.

Use of the transport network is ever-changing, which makes it more challenging to adapt to meet the needs of the diverse range of road users. Using social media, data from third parties and data from other sources can assist in providing a deeper insight of how road users perceive and use the network.

Generally, there was a limited number of responses from LMICs in comparison to HICs throughout the survey. More responses across a range of countries from different income levels and geographical regions may provide a better understanding on where the similarities and differences lie across countries and regions. This can facilitate sharing of existing methodologies, approaches and technologies used to collect, analyse and utilise road related data across road administrations globally.

4.5.3. RECOMMENDATIONS FOR ROAD ADMINISTRATIONS

R2. Learn from the online survey, then act and improve:

- Undertake a high-level review of the findings to understand the range of topics covered and the different approaches being implemented globally.
- Carry out a detailed review to focus on current and future practices which address local priorities, and identify opportunities to introduce or improve applications of data.
- Based on the documented findings of the survey, develop an action plan for the implementation of improvements related to data, and engage and collaborate with other PIARC members where appropriate.
- Consider further surveys in the future to collect updated information on the use of road-related data, especially around take-up of evolving technology, processes and systems.

5. BUSINESS MODELS FROM A ROAD ADMINSTRATION PRESPECTIVE

5.1. INTRODUCTION

The term "business models" is used here to represent how road administrations can arrange their ways of working to either develop their approach to utilising data in the delivery of services or to support the improvement of existing practices. This section uses a framework structured along the following six themes (Figure 57), which were derived from the key topics highlighted by the POT combined with learning from the earlier stages of the project and the professional experience of the project team:

1. Strategy – sitting at the core of data-related activity;
2. Data Sources – existing data, new data that is collected or new data that is accessed;
3. Organisation and Management Approach – how an organisation can structure its functions;
4. Partnerships – engaging with external organisations or providers;
5. Enablers – people and tools to deliver improved approaches to data; and
6. Making the Case – justifying investment and understanding benefits.

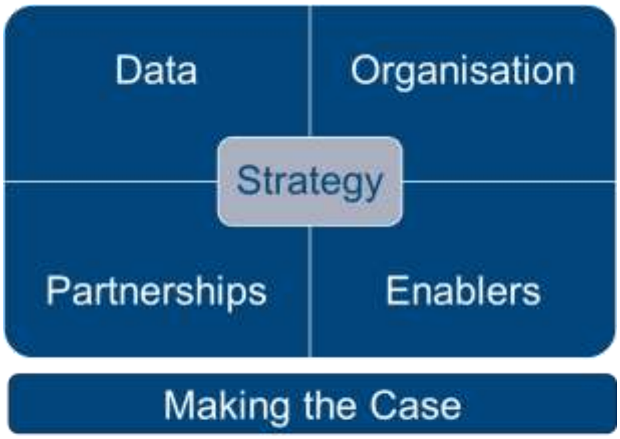


Figure 57: Business Model Themes

Each theme includes a definition of the subject, an outline of different approaches, a set of recommendations for road practitioners to consider implementing within their own administration, and case studies from various organisations, primarily from the deep dives but also supplemented with additional learning from around the world where appropriate.

Whilst this section is primarily aimed at road administrations, the following guidance and recommendations promotes collaboration and engagement with other industry organisations such as research institutions or manufacturers, to ensure that all stakeholders are up-to-date regarding innovative systems and opportunities for better data use.

To inform this framework, the literature review and stakeholder survey produced a significant volume of information on data and associated technologies that are being implemented within road administrations around the world. The learning from these activities was combined with a number of deep dive interviews with organisations from the Netherlands (representing HICs) and South Africa (representing LMICs), using the methodology set out in Section 2:

- **Rijkwaterstaat** – responsible for maintaining and improving the Netherlands' trunk road network.
- **RAI Association** – representing the vehicle industry in the Netherlands with a strong focus on the mobility sector.
- **National Data Warehouse** – the national access point for traffic data in the Netherlands.
- **SANRAL** – the South African National Roads Agency, responsible for management of the national road network.
- **Stellenbosch Smart Mobility Lab** – a research centre within Stellenbosch University in South Africa.
- **ITS** – consultants from South Africa who provide support to SANRAL.

5.2. STRATEGY

5.2.1. DEFINITION

Regardless of the resources available to a road administration, there should be alignment between the high-level objectives of the organisation and the delivery of operations and services to users in order to maximise the value and effectiveness of the use of data. This section covers the importance of strategic planning, and how authorities should either develop or improve in this area to ensure that data is properly integrated into their decision-making process.

5.2.2. APPROACH

Every road administration should have an organisational strategy in place, outlining its vision and approach to meeting high level objectives in line with government policy. This should explain the role of the organisation as well as its objectives, key challenges and priorities. Data should be an integral component of an organisational strategy, as it is the fundamental building block of informed decision making and ultimately delivering a service to its users and stakeholders. Figure 58 below outlines the relationship between infrastructure, the service that it provides, and the end user, which need to be balanced through the development and delivery of a suitable strategy. The figure illustrates that while there are complex interrelationships, data can be used to understand and influence each of these.

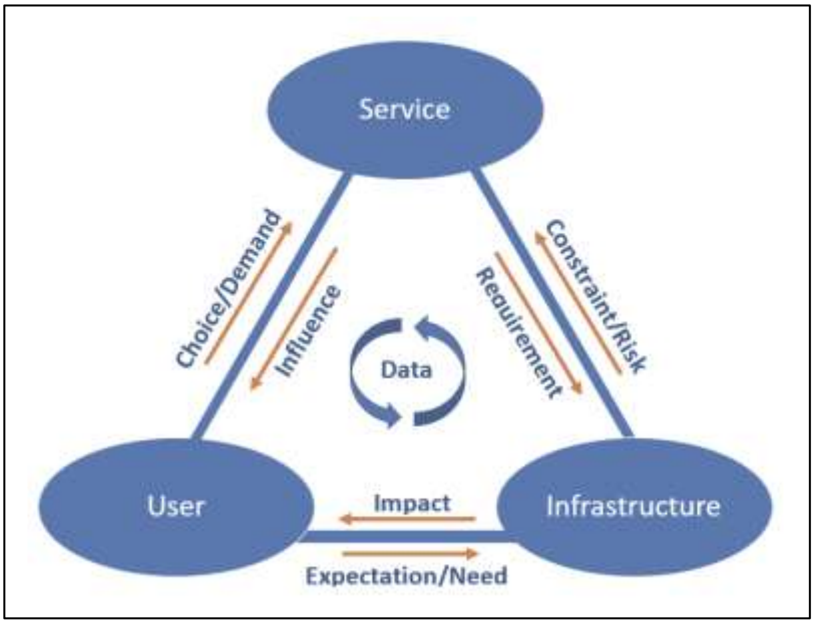


Figure 58: Linkages Between Infrastructure, Service And User

With an organisational strategy in place, and data embedded within it as a key component, a separate data strategy should be developed. This will provide line of sight between the corporate objectives, the road administration’s approach, and how data makes a difference in the decision-making process and the delivery of services. A one-size-fits-all approach is unlikely to work, and flexibility will be required as data needs are driven by local requirements – every administration is different and will have its own challenges to consider. There may be clear differences between HICs and LMICs, due to the local context, environment and resources that are available. However, the core principles should apply to all road administrations, and be implemented to an appropriate depth and scale.

As well as aligning the road data strategy with the organisational level, the OECD's paper *'Enhancing Access to and Sharing of Data: Reconciling Risks and Benefits for Data Re-use across Societies'* (2019) recommends that considering national and sectoral data strategies can also provide significant benefits, including:

- Alignment with required outcomes at a strategic level;
- Coordination of approaches to data collection and management;
- Assurance and guidance related to data protection and ethics;
- Understanding performance across sectors; and
- Supporting the development of user-centric solutions.

Further coordination of activities that rely on data within the administration may support increased effectiveness and efficiency, such as strengthening the link between the data strategy and the asset management strategy. This should provide greater clarity on what the pain points are within the functional elements of the organisation, and thus what practical challenges need to be addressed through the use of data. This top-down approach will ensure that solutions meet high-level objectives, but there are situations where a bottom-up approach (identifying how data can be utilised in a more effective manner) can drive specific innovations.

The case studies in this section illustrate various ways of applying data strategies within different organisations, which reinforce the recommendations below. The subsequent sections of this chapter outline the supporting themes that would make up a strong data strategy. The sections within this chapter should not be considered in isolation and should instead be applied as a whole.

5.2.3. RECOMMENDATIONS FOR ROAD ADMINSTRATIONS

R3. Use a strategic approach, both at organisation level and also in terms of data as a discipline:

- Ensure that the organisational strategy includes data as a core component and enabler, rather than as a separate activity. This will provide line of sight from corporate vision and objectives to operational and wider outcomes, support a more effective and efficient approach to using data, and create a clear recognition of the importance of data collection and analysis as a discipline in itself.
- Develop a data strategy to link the objectives within the organisational strategy to outcomes. This will ensure that data is used to address the genuine needs of the organisation and its users, rather than developing solutions and then searching for applications.
- Align the data strategy with any national government and / or regional initiatives, including sharing of data and analysis across agencies and between roads and other transport modes and networks. This will maximise the benefits outlined in the business model analysis.

R4. Develop an action plan for data using SMART (Specific, Measurable, Achievable, Relevant and Time-bound) principles:

- Develop a SMART action plan to implement the data strategy and embed its principles. This will support real change and creation of value at an organisational level, rather than being limited to aspirational discussions or delivery of individual projects.
- Within the action plan, assign responsibility for delivery of the various components, using a RACI approach (Responsible, Accountable, Consulted and Informed), to specific departments, units or individuals. As the implementation of the data strategy may involve a wide range of stakeholders, this will support ownership, allocation and coordination of effort across the organisation.
- Build in checks to ensure that the deliverables are providing visibility of the expected outcomes, e.g. increased customer satisfaction.

R5. Collaborate, learn and review:

- Collaborate with other road and transport administrations to provide stronger capability, share insights and manage risk. This may be essential to deriving some of the benefits from a data-driven approach.
- Learn from other organisations to gain the benefits of previous work in this area. However, remember that each road administration is different, and requirements will need to be tailored to the specific local context and priorities.
- Review strategies on an ongoing basis to ensure they stay relevant and can adapt to changing circumstances. This should usually be an annual activity, however review periods may increase or decrease depending on the road administration’s data maturity and the speed and extent of change in key parameters.

5.2.4. CASE STUDIES

SANRAL

South Africa

Horizon 2030 is the overarching strategy for SANRAL and is well-embedded having been in place since 2017. It outlines the organisation's context and challenges, its strategic objectives, and plans to deliver on these through the four pillars of roads, road safety, stakeholder and mobility, plus a series of enablers. As part of the strategy document, data has clear links to objectives such as "utilise technology, research and innovation to advance the provision, operation and management of the national road system (meet road user needs)".

Data is also a core component of the Information and Communication Technology (ICT) enabler, with this role no longer seen as simply providing laptops to staff. Instead, "to ensure high levels of user satisfaction, the ICT strategy must be aligned with the business strategy. In a constantly changing environment innovation is of the utmost importance as is the increasing need for information security." Key focus areas of this enabler include:

- Define the ICT maturity level and ensure user satisfaction.
- Drive innovation and smart solutions.
- Enhance information security.
- Increase bandwidth and capacity.
- Create a paperless environment.

As well as global issues such as road safety, SANRAL have been using data to address more contemporary problems such as major drought and COVID-19, plus specific local challenges such as crime on freeways.

Rijkswaterstaat (RWS)

Netherlands

The Rijkswaterstaat Data Strategy 2020 has been adopted by the RWS Board and is subject to annual updates. It aligns with current programmes and projects and is accompanied by an implementation plan with a clear timetable for delivery, ranging from short term actions for year one, plus longer-term objectives. Key issues include the organisation of data, silo mentalities, questions of ownership and constraints to exchange, with the following five main objectives at the core of the strategy:

- Vision and strategy
- Data, information and presentation
- People and organisation
- Process, management, control and finance
- Architecture and infrastructure

These are supported by a set of principles and conditions:

Principles

1. **Ownership of data** – all data has an owner who is responsible and accountable for quality, following the principle: "if the object is yours, the data is also yours".
2. **Apply data conventions and standards** – if there are none, best practices from RWS is used, with the principle "apply or explain".
3. **Core registrations with mandatory use** – core records are kept for the data that is most important to work processes.
4. **Collect once and use multiple times** – where possible, reliable data is used that is available elsewhere.
5. **Data management in one place** – the chain from collecting, managing, to providing and presenting data takes place in a standardized manner for all data flows.

Conditions

6. **Safeguarding data craftsmanship** – it is essential that this is safeguarded throughout the chain.
7. **Data is integrated in work processes** – according to unambiguously agreed quality requirements.
8. **Make strategic choices** – priorities are then set for confirmation by the Board.
9. **One central data platform** – available internally and externally, it is connected to external data nodes so that third parties also have access to data.
10. **Combining expertise** – to apply new data technology and quickly achieve the added value of innovations.

National Data Warehouse

Netherlands

The new organisational strategy has seen the creation of the National Data Portal, to better reflect the role of not only collecting data but also processing and sharing it. As a shared data centre, their aim is to provide data of quality to all their partners for consistency and provide cost efficiency through central procurement. As a portal, they have an active role to communicate data to their partners (private to public and vice versa).

Traffic management is fast becoming a much more data driven sector, which is based not only on government data but also on other third-party data – NDW works closely with service providers such as navigation services companies (Google, TomTom, HERE) and OEMs.

Stellenbosch Smart Mobility Lab (SSML)

South Africa

The SSML is a state-of-the-art research and teaching environment established at Stellenbosch University for the study of Intelligent Transport Systems (ITS), which is the application of technology, communications and data analysis to the transportation engineering arena. The vision of the SSML is the establishment of a Centre of Knowledge to ensure sustainable ITS deployment in the developing country environment, and its main objectives include:

- Create a multidisciplinary research environment for the deployment of technology in the transport environment.
- Provide a “testbed” for product development.
- Provide industry training at all levels to ensure sustainability of the industry.
- Create a stimulating environment to attract students to this field of study.
- Play a leadership and visionary role in ITS deployment within the developing country context.
- Continue to create ITS awareness specifically aimed at implementing agencies.

SSML
STELLENBOSCH SMART MOBILITY LAB

5.3. DATA SOURCES

5.3.1. DEFINITION

With a strategy in place to provide line of sight from organisational objectives through to delivery of services, careful selection and use of data is essential to support decision making and communication. This section outlines the various data types that can be used, either in terms of existing data, newly collected data, or newly accessed data, and the common principles that should apply regardless of their source.

5.3.2. APPROACHES

The findings of the research showed significant activity across all respondent road administrations (both in the online survey and the subsequent deep dive interviews) in terms of utilising data to manage their network. This included a wide range of innovative approaches to improve how data is currently being used as well as new approaches for gathering or accessing data.

An important factor when assessing data for potential use within a road administration is to ensure that this aligns with the data strategy, what challenges need to be addressed, how that supports the organisation's objectives, and thus what the actual data needs are. This will ensure that time, cost and effort are directed to working with data that provides genuine value to the road service and its customers.

A lesson learnt from some road administrations is that although data has been collected in the past, some of it has served little purpose or was hardly used. To address this, and before any work is undertaken for new data collection, it is essential that road administrations review their existing data and consider making best use of this data first. This could be done through a set of principles known as FAIR (Findable, Accessible, Interoperable, Reusable) which are described below:

- Findable – a single source of the truth should be used, which will avoid data silos, and ensure that data can be coordinated and found easily for use.
- Accessible – this requires a balance between the need for access with ownership and security.
- Interoperable – this is more challenging as it requires integration across datasets and tools / processes, but provides an opportunity to create much greater value across multiple datasets, i.e. "the whole is greater than the sum of the parts."
- Reusable – once data is collected / secured, it should be used to its full potential value over time and via multiple applications, for efficiency and consistency.

If there is still a valid need for new data to be introduced, then the FAIR principles should be applied to this too (GO FAIR, 2020). More information is available online www.go-fair.org/fair-principles.

Where additional data is required, two main options are available to road administrations; either collecting new data or accessing existing data from outside the organisations. Numerous examples of both options are covered in the results of the survey conducted as part of this project and in the case studies covered below in this section. To collect new data, this may be delivered either in-house within the organisation or through the use of specialist suppliers. The latter option may be necessary when state-of-the-art technology is being used which the road administration does not have the relevant hardware, software or human resource to collect the required data, or where the supplier is able to deliver their service more efficiently due to their existing dedicated resources, commercial model and / or economies of scale.

Alternatively, the use of "unconventional data", such as data from social media, APIs or other external sources, provides road administrations with a different way of working that has some risks that need to be managed, but also significant potential benefits which could be realised. The first and most apparent benefit is that if the data is already being collected by someone else, it is likely to be more efficient to access that rather than duplicate effort to capture it again separately. Also, the nature of the data may provide a different perspective, such as moving from having a snapshot of road condition via traditional surveys, to having an ongoing stream of data which provides a slightly less detailed picture of the network but makes up for this with having a much greater coverage in almost real-time.

The survey results and case studies provide a range of examples of these type of applications, and the Partnerships section below provides further information on the arrangements to secure such access. For example, the European Union Open Data Portal (EU ODP) provides access to open data published by EU institutions and bodies, which is catalogued and freely available online (https://data.europa.eu/euodp/en/home) for use and reuse for either commercial or non-commercial purposes.

Other sources of open data that may provide value to road administrations that need to address gaps, understand a problem from a different perspective or benchmark performance, include datasets released by global bodies such as the United Nations or Organisation for Economic Cooperation and Development (OECD), development banks such as the World Bank, and regional groups such as the European Union.

5.3.3. RECOMMENDATIONS FOR ROAD ADMINSTRATIONS

R6. Treat data as a valuable asset:

- Data should be recognised as being a core asset within a road administration, alongside built infrastructure, digital infrastructure and people. Like these other elements, it should be planned, designed and managed properly and with a clear view of the ultimate outcomes.
- Assessment of data options should not only consider collection but also the management of data throughout its lifecycle, such as storage, capacity, quality assurance, sharing, update policies, retention periods and disposal. This will ensure that fully informed decisions are made regarding data.
- Security of data and its application is a key concern in an increasingly digital society, and this must follow local legislation covering issues such as data protection, privacy and cybersecurity. Specific guidance on these issues should be sought from specialist sources.

R7. Make better use of existing resources:

- Review existing data and tools before investing in collecting new data or implementing new technology, and make better use where possible. This will avoid duplication of effort and wasted resources.
- Map out the data that is already held within the organisation and develop a "single source of truth". This will support the need to regulate and control data to ensure consistency, common understanding and aligned use across agencies and departments.

- Standardise data formats and approaches to using data. This will increase the ease with which the data can be identified, shared and employed within the wider organisation and avoid risks of duplication, inconsistency or inefficiency.

R8. Consider access to existing external data before collecting more primary data:

- Understand what existing relevant data sources are available via external organisations such as app developers or via open data, and the potential arrangements that could make this available to a road administration. This will inform a cost-benefit analysis to decide whether it is more appropriate to develop a data partnership with an external organisation or to collect new primary data on behalf of the road administration.
- When collecting new primary data, review options of using either in-house resources or procuring services from specialist suppliers. Factors which should be considered include, but are not limited to, experience and availability of staff, access to specialist services and technologies, and potential economies of scale in delivery.
- Manage risks related to external data that are outside the direct control of the road administration, e.g. ownership, access, and assurance. Refer to further guidance within the Partnerships section of the business model analysis.

5.3.4. CASE STUDIES

Rijkswaterstaat (RWS)

Netherlands

Through a review of past data practices, RWS identified a number of lessons learnt that needed to be addressed:

- Ambiguity regarding source systems is for the storage of which asset information, which can lead to a lack of consistency.
- Data definitions were sometimes unclear and could lead to different interpretations and thus to errors.
- Data was regularly transferred manually between systems, which can also result in errors.
- Different systems were synchronised at different times, producing misalignments.
- Discrepancies in asset registrations between different registration systems.

As a result, a series of improvements have been planned and implemented through the Data Strategy.

Data Standards

In order to be able to use and combine data, it should be created, stored, managed and subsequently made accessible in a similar way. To this end, standards and conventions (frameworks) are drawn up and established by the CIO. The procedure is followed as described in the Data Strategy. Until a new framework has become commonplace, guidance is needed in its application, and the use of the framework is monitored.

Standards are laid down in the “RWS guide”, including the RIVA (Rijkswaterstaat Information Provision of Connection Conditions). In drawing up and establishing standards, RWS actively contributes to national and international consultation, such as the further development of the key registers under the responsibility of the Ministry of the Interior and Kingdom Relations. In addition, the following RWS standards are being developed: role model, Master Data Management for determining core registrations, OTL for data definitions, a data quality system and standards for accessing and exchanging data. The coherent system of data standards is described in the Target architecture data.

Data Car Wash

Achieving a uniform, standardised data production process “from collection to access” is not automatic. To achieve this, a Data Car Wash is being set up. This concerns both the introduction of “Data by design” in order to properly arrange new developments, and to get the quality of existing data sets in order.

In the first year (innovation phase) this concept is operationalised by applying it to an initial number of datasets. A plan for the standardisation phase is drawn up on the basis of these learning experiences, and it also identifies the capacity and budget needed to scale this up. The vision for the future is that more and more datasets will be passed through the Data Car Wash, while at the same time the necessary training and the assurance of the management are being arranged so that improvement can be achieved. In combination with the working method

Rijkswaterstaat (RWS)

Netherlands

“demonstrate, participate, do it yourself”, more and more employees within RWS can apply the frameworks and this requires less and less support.

Thanks to clear frameworks, support and monitoring of use, and the standardization of data production, RWS can rely on its data and support working as one organisation. By ensuring that the frameworks are applied immediately in new developments and by applying them step-by-step to existing data, the existing problems surrounding data are becoming increasingly limited in scope. This increases the ease of use of data.

Rijkswaterstaat (RWS) and RAI Vereniging

Netherlands

The Netherlands has been investigating and implementing the use of connected vehicle data for a range of uses to improve the management of the network and user experience. This is based on the fundamental principle that data that is important for vehicles is likely to be important for roads too.

Sensors in cars and Light Goods Vehicles (LGVs) are providing huge sets of data that can be used for the development of apps and services, such as road condition / deterioration, speed, temperature etc. Sensor data related to multiple skidding incidents or even a single airbag deployment can highlight locations of interest to road administrations. A notable example was the use of data from NIRA dynamics (responsible for tyre pressure monitoring systems) to identify the precise location and cause of problems on a specific section of the network, and thus successfully repair the underlying issue. Potential value has also been added to winter maintenance, through better quality of information related to de-icing performance.

This can provide significant benefits, but also challenges related to who has access to the data and who can use it. Vehicle data is owned by the OEM, not RWS or NDW – and OEMs value their data. While legislation is in place for the sharing of safety-related data, it is for short term storage only and subject to regular legal checks. Issues related to privacy can be mitigated by requesting access to aggregated information rather than granular data. Other issues related to OEM data are the requirements for its secure handling plus potential latency from point of collection to point of use.

The innovation centre in Helmond is researching the potential uses of social network data, including the identification of road defects via access to Twitter location – however, potential safety concerns related to distracted drivers should also be considered. Whilst new and unconventional data sources are being used and seen as the future of road management, RWS consider it is essential to retain historical approaches and data (for example induction loops) during the transition to new ways of working to manage risks.

National Data Warehouse (NDW)

Netherlands

NDW considers unconventional data sources to be new data sources that are available and could be used to get more information for traffic management. They are used for real-time operations, but also to do back-analysis related to users, preferences etc.

This includes probe vehicle data, where the key challenge (and benefit) is in transforming the data to information, and from that to knowledge such as an actual event on the road. Cellular data based on the location of mobile phones is currently providing information on traffic flow, speed, and origin / destination of journeys. Other App data includes linkage with Strava to analyse people and demographics of users and use of apps to incentivise active travel behaviour such as bicycle usage, with benefits including reduced congestion and health improvements. Cyclist interaction with 'smart traffic lights' also allows users to engage with infrastructure, for example a group of cyclists riding together using a certain app will be given priority. Those apps are frequently partnered with NDW.

Smart infrastructure is also providing some developments in the area of traffic data, such as identifying traffic congestion using vibration from fibre glass sensors, weight-in-motion detection for HGVs, and potential replacement of induction loops.

An area of potential future development is that of social media, which is not currently used as a data gathering source in itself, but instead primarily used as a communication tool to provide information to the public, for example to re-route travellers when there is an incident.

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On the current FMS system, data is collected using radar sensors as well as probe data from on-board devices (cell phones and GPS's). The radar devices are located between interchanges and collect classified vehicle counts, speeds and occupancies. From the collected data as well as information from the probe devices, average link speeds are determined. The latter is used to report on traffic conditions and to calculate travel times. The travel times are posted on Variable Message Signs as information to drivers.

The FMS management centres also use the probe and speed data for detection of incidents. A further element assisting the TMC's with detection is the Waze social media app. Whenever an incident is logged via Waze, the TMC operators are notified about the incident. The primary source of incidents in the TMC's are from operators manually scanning the network using the CCTV footage. Most of the time incidents are detected via the manual CCTV scanning process. It is seldom that the automated methods (speed monitoring through radar devices and probe vehicles, or social media apps) provides a faster detection method, than manual scanning of CCTV feeds.

Road users are informed about road conditions and incidents through on-road Variable Message Signs, mobile text messages (if subscribed) and social media (Twitter and Facebook), call-in services and radio stations. The radio stations and the call centre operators mostly get the information from the TMC via the social media platforms.

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The Advanced Transport Management System (ATMS) included a data warehouse and a data visualization engine. The SANRAL ITS DBOM programme is amongst the richest and most complete sources of incident and traffic data for the network. The data warehouse makes data easily accessible in near real time by transport management professionals, in municipal and provincial partner organizations as well as other key transport partners such the Airports Company of South Africa (ACSA) and the Road Traffic Management Corporation (RTMC). Additionally, the data can be readily accessed by educational institutions, i.e. universities and the Council for Scientific and Industrial Research (CSIR) for advanced research and development which is aligned with SANRAL's 2030 strategic objectives.

This data warehouse is accompanied by a powerful data visualization platform utilizing the commercial program, Tableau. Using customizable dashboards, transport planners, engineers, and technicians will be able to rapidly glean insights on key transportation parameters such as critical incident hot spots correlated with variables such as weather and day of week, and network flow and speeds. These tools are expected to provide the rich ITS DBOM dataset to a broad network of transport professionals to improve network operations, planning and design.

The National Advanced Traffic Information system (ATIS) web-based website is accessible to road users to subscribe and receive traffic related notifications in the three Provinces. Still- images of the critical road sections are refreshed every 60 seconds. Also access to all the incident data information for third party service providers is possible via an API. The latter requires approval from the client.

Pilot studies have been undertaken to investigate the use of computer vision to improve the effectiveness of pedestrian crossings, by modelling desire lines and numbers, plus the automatic detection of pedestrians and feedback to control systems.

Various data sources are utilised by SANRAL for asset management throughout the full lifecycle. The SA road design system uses data to enhance the testing of materials, reducing human error and providing grading information for future analysis. Asset data collection is driven by need and used for asset valuation (in accordance with IFRS) and road network planning (using HDM-4). Machine learning and artificial intelligence are being used by providers to process data related to road cracking. Data has also been used innovatively on routine road maintenance contracts, as software developed by SANRAL is linked to mobile devices / workflows, has been used for assurance of quantities.

The use of floating vehicle data has been investigated with SSML, to identify hotspots on the network, understand causes of problems, and generate potential solutions. Historical data supports modelling the pre-intervention scenario for comparison and evaluation against post-upgrade, providing inputs to cost-benefit analysis. Other unconventional data sources under consideration include TomTom satellite navigation, and Tracker, a car tracking company, is actively engaging with the road sector using an understanding of "g force events" via sensors, the balance of scale of network coverage compared to more traditional survey resolution, detection of incidents, monitoring of traffic flow, and capacity planning.

5.4. ORGANISATION AND MANAGEMENT APPROACH

5.4.1. DEFINITION

To deliver better use of data within a road administration, it is essential that resources are deployed in a way that will ensure sufficient capacity and capability are available for the required functions. This section outlines the different structures that can be used to deliver a data-driven approach within a road administration, how resources can be managed, and how performance is monitored.

5.4.2. APPROACHES

A wide range of organisational models are available for road administrations to consider when structuring their data functions, with the three main variants outlined below along with the pros and cons that each are associated with (Theuwissen, 2019).

Centralised model – this approach uses a centralised team that leads on overall data activity within the organisation and supports other parts of the business in delivering this.

Table 33: Pros and Cons of Centralised Model for Data Functions

Pros	Cons
Clearly defines data as a specialism in its own right.	May result in a silo approach, as skills and data culture are not distributed throughout the organisation.
Data is prioritised and managed separately to the day-to-day running of the service.	The road administration may become reliant on the central team with limits on capacity and capability acting as constraints to the wider organisation.
Promotes consistency and control of data, with all the benefits this would bring.	Communication across different parts of business can be restricted.

Embedded Model – this model is based upon data professionals being embedded throughout delivery teams, providing a de-centralised approach.

Table 34: Pros and Cons of Embedded Model for Data Functions

Pros	Cons
Supports the application of data skills in line with the discipline and / or function of the specific team.	May be perceived as diluting specialist skills and leadership within teams.
Provides a better understanding of "local needs" and the dynamics / people / objectives within the team.	Risk of a lack of standardisation across the business.
Can be more resilient due to the broader distribution of data resources across the road administration.	Potential challenges in delivering and embedding an organisational vision to data across all teams.

Hybrid Model – with this option, a central data team is supported by data professionals who are embedded within functional teams throughout the organisation.

Table 35: Pros and Cons of Hybrid Model for Data Functions

Pros	Cons
Provides a balance of understanding local needs but with central leadership and guidance to all.	The complexity of this arrangement can pose management issues.
Can support a more collaborative approach across the road administration.	Requires attention to design a suitable organisation structure with an appropriate balance of central and embedded resources.
Helps to foster a sense of purpose for data resources.	Some advice suggests that this is better suited to organisations with a more enhanced level of data maturity, than organisations that are earlier in their development.

With a structure in place and under review over time, a further challenge exists relating to resourcing within the road administration. Whilst some organisations may historically tend to cover all staff requirements in-house, the emerging skills required to maximise gains with data combined with availability (or lack) of suitably competent roads professionals, means that inevitably other options will need to be considered. This may include setting up commercial arrangements for suppliers to provide consultants / contractor being brought in to fulfil roles. Alternatively, partnering with either other road administrations or road-related institutes may provide opportunities for sharing of resources.

Performance of the data functions within road administrations should be set, monitored and evaluated using the same principles (and ideally performance management framework) as used for the rest of the organisation. To cover this, road administrations should refer to work undertaken by PIARC Technical Committee 1.1 – Performance of Transport Administrations and its predecessors, to understand the latest good practice in this area and existing reports that are available on the PIARC website.

5.4.3. RECOMMENDATIONS FOR ROAD ADMINSTRATIONS

R9. Understand the different organisational model options to deliver data functions and use the most appropriate for the road administration:

- Review the options covered within the business model analysis section. These options include a centralised model (where a core team is responsible within the organisation), an embedded model (where data functions are spread across the wider organisation via functional teams) and a hybrid model (a combination of centralised and embedded models).
- Consider the pros and cons for each model option, within the local context and objectives, before implementing. The business model section contains more detail for each of these.
- Monitor how the organisation and its approach to data matures over time, and how the current model for data functions is operating. As certain capabilities and / or requirements change over time, then the model used within the road administration may also need to change to provide greatest benefit.

R10. Maintain a flexible approach to accessing staff resources:

- Ensure that resourcing for data collection and analysis within a road administration can be accessed from a combination of both in-house staff and contracted supplier(s). This will support the need to build capacity and capability in the area of data, whilst acknowledging that access to the specialist skills needed may be limited due to demand from other sectors.
- Options for employing external resources may be either secondments into the road administration, contracting to deliver specific work packages or data collection associated with specific studies. This will depend on the capacity and nature of the road administration's requirements at the time.
- Road administrations should always retain ownership of the responsibility to develop policy. Whilst external resources may advise and support this area of work, the overall capacity to act on data and make decisions should not be contracted out.

R11. Monitor performance and apply continuous improvement:

- Monitor performance of the road network and of the road administration on an ongoing basis, reporting to organisational leaders in sufficient and proportionate detail, and through effective reporting formats, to allow them to make appropriate strategic and operational decisions.
- Set suitable performance targets that link into the objectives laid out in the organisational strategy and ensure adequate cause-effect understanding and data to track progress.
- Drive improvement in performance through internal review of lessons learnt and good practice, plus benchmarking with external organisations and other road administrations. Consider the recommendations of this Special Project within the context of the work which PIARC has previously done on organisational performance management.

5.4.4. CASE STUDIES

Rijkswaterstaat (RWS)

Netherlands

In order to support data-driven working within RWS, it is important that suitable capacity and capability is in place within the organisation, along with accessibility of data. To achieve this, two important resources are the RWS Datalab and the Central Access Point Data (CTD).

The Datalab has been set up in recent years to make the possibilities of data with modern technology visible. This should now be given a permanent place as the core of the data science capacity within our organisation. This core provides 'proof of concepts' for innovative solutions with data, which ensures that the Datalab is used in a more targeted manner. Individual initiatives here and there within RWS are combined and concentrated at the Datalab. The same applies to the bundling of specialisms required for this, because knowledge and capacity are scarce. Remote sensing is one of the technologies for which a modern basic service is set up. An impact analysis will be carried out, and at the same time, the directors of operations will be asked to draw up a financing proposal. Approval by the board of this proposal and formalising the Datalab into a fully-fledged department within RWS (with structural financing, clear basic services and structured governance), will support continuity of approach and further development. This will ensure that new techniques such as Machine Learning and Artificial Intelligence are made available to RWS to deliver improved service for users of the network and create added social value.

The CTD is being developed to make data easy to find, understandable and accessible for everyone in the same way. This platform is not just a "webshop" where users can find, interpret and reuse all data relevant to RWS. It is also a reliable source for dashboards and analyses, and it makes data quality transparent – it is not just a technical aid. The CTD contributes to the management and responsibilities within data-driven working becoming more transparent, so that employees can acquire greater knowledge of data. The CTD supports the standardised production process with unambiguous access to all RWS data.

A business case has been drawn up for the CTD. After approval of this business case by the board, a program of requirements will first be drawn up, describing which (technical and functional) requirements the CTD should meet. The functional requirements are determined with the help of core projects, with which the CTD program is broken up into smaller manageable chunks, each of which adds direct value for the organisation. Subsequently a review will be undertaken of technical requirements and whether the CTD can be developed from existing RWS building blocks. A detailed description can be found in the business case of the CTD. It also includes an overview of products that the CTD program will deliver. Depending on the final content of the schedule of requirements, the following products are provided:

- The building blocks selection and implementation of the core of the CTD (first version).
- A data architecture for working with Business intelligence products.
- Implementing changes in work processes to ensure that data deliveries remain structurally in order in the future.
- The actual recording of the data in the technical heart of the CTD.
- Guiding the users in using the CTD.

National Data Warehouse (NDW)

Netherlands

The NDW is publicly funded, and its creation was a financial decision, as it was understood to be more efficient to have a single organisation collecting the data and sharing it for the benefit of the roads sector.

Its role has evolved from being simply a data bank, to one that now provides more context, as service providers want information rather than data. To support this requirement, data is processed to provide traffic information, plus data sources are fused to generate more information on issues such as accidents. NDW also publishes open data for wider use.

Big data analytics is carried out in-house and is mainly derived from public data. This data is then potentially used for policy making, so there is little case to move this to the private sector.

Other internal resourcing covers management of frameworks and data architects, with development teams hired from external partners. NDW has a contract with six partners (private data science companies), where tasks are assigned to these to combine data sources and work together on new developments and technical challenges.

The future of NDW will need to consider the balance between the public sector and the private sector delivering services for road administrations. Does traffic management need to be done by the public sector or could it be done privately? Why would public organisations want to do traffic management themselves if there are private sector companies that could be doing it? This would be a particularly attractive option if it could address the skills challenge and delivery improved efficiencies.

SANRAL

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The use of road related data within SANRAL is funded through various projects, including but not limited to, Freeway Management System (FMS), Integrated Transportation Information System (ITIS), Road Incident Management System (RIMS), Open Road Tolling (ORT) etc.

Most of SANRAL's data warehousing and analyses are done through the ITIS system (mostly for road-related strategic planning, design and implementation). ITIS has modules on Linear Viewer, Pavement, Projects, Land, Structures Traffic and Routine Road Maintenance. Each module has a report function with custom reports. All data are georeferenced and viewable on maps, with dashboards providing high level views on all data.

Monthly traffic data (extracted from ITIS) from all toll plazas is used to develop traffic and revenue forecasts for the toll portfolio funding models. ANPR data from the ORT systems and traffic count data are used to re-calibrate traffic models of the freeway network.

Data is made available to stakeholders through the use of visualisation tools, such as BI reports in Tableau / Power BI. There are clear benefits in moving from Excel monthly reports, as these are now automated in Power BI and offer further queries. Open internal versions of Power BI are

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available, but accessibility is controlled through the use of restricted versions too. There is always a risk of misinterpretation of data, if visualisation is utilised without understanding. For instance, an uninformed user may not understand that drops in reported data may have been due to a power cut or IT failure, rather than any changes to operation of the network.

Stellenbosch Smart Mobility Lab (SSML)

South Africa

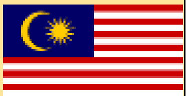
The SSML had, as a first objective, the development of a data rich environment, particularly for data related to all transport and mobility activities. SSML research activities relate to both to the immediate City road network as well as the wider regional freeway environment. Within the Stellenbosch Municipality context, a testbed environment is being created through a partnership between the Stellenbosch Municipality, the Stellenbosch University and the various industry partners of the SSML.

A network model has been developed in VISUM as part of the PTV suite. This allows for a traffic data warehouse environment, whilst it is also interfacing with the demand modelling, microsimulation modelling as well as real time operational features of the software suite. The SSML collaborates with the Stellenbosch Municipality and share available data. Data sources available, some of which were collected through a number of research projects, include (i) on-campus mobility collected through blue tooth sensors, (ii) floating car data obtained from the TomTom traffic data platform, (iii) traffic detector data obtained from various intersections (on all approaches), and (iv) public transport data.

Further to the above, the SSML is in partnership with SANRAL and has access to the Freeway Management System (FMS) within the Western Cape by virtue of software installation that is associated with a traffic monitoring operator workstation. The FMS “desk” is also linked to a video wall display also provided by SANRAL.

Continuous research is performed, utilising the various data and technology in order to work towards an enhanced mobility experience within the larger Stellenbosch area.

Malaysian Highway Authority (MHA)



Malaysia

In line with the implementation of the Intelligent Transport System application, Malaysia Highway Authority (MHA) has established a Traffic Management Center (TMC) to integrate the traffic control and surveillance functions of all privatised highway networks in Malaysia at national level. All field equipment is provided and managed by concessionaires.

TMC also serves to disseminate information to road users , which includes making the current status and traffic flow on the highway available to all users for travel planning facilities. Traffic and Incident management are concessionaires' responsibilities while TMC (MHA) monitors their operation and acts as second call centre.

MHA has a range of valuable data that can be analysed to help make predictions and improve the performance of the highway services. Currently MHA is in the planning stages of implementing Big Data Analytics (BDA) to bring together various types of data sources such as data from internal systems, data from external sources as well as social media that are then aggregated into one data stream. This combined data can be used to generate predictions and expectations that can help improve services. The targeted outcomes of this BDA are made up of 3 components:

- Revenue driven
- Business operation efficiencies
- Meeting highway user expectation

Business case proposals for incorporation in the BDA include improvements to highway traffic management, quality of rest & service areas, highway patrol services, advertisement management efficiency and incident management.

5.5. PARTNERSHIPS

5.5.1. DEFINITION

Road administrations should not expect to deliver services on their own, and should make best use of partnerships with a range of potential organisations. This may include options to generate added value for public services, to potentially monetise data or to release open data for use by external parties. This section provides insight into the issues around partnering with such organisations, including who may be involved and how it may be facilitated.

5.5.2. APPROACHES

The research identified a range of different partnership types, including with other road administrations (national and local), universities and research institutes, and private sector organisations. In setting up partnerships, the main models tend to be either commercial or mandatory arrangements, with the use of open data also providing massive potential. The case studies in this section provide examples of how different types of partnership have been applied, and this is supplemented by further guidance and good practice below.

The OECD (2019) report *Enhancing Access to and Sharing of Data : Reconciling Risks and Benefits for Data Re-use across Societies* outlines a number of factors that should be considered when setting up a commercial arrangement, which are based on experience in North America and Europe.

These include, but are not limited to, the following:

- **Ownership** – who is responsible for the data and its usage.
- **Collection, Access and Control** – what additional controls are in place to regulate usage.
- **Notice** – how / when the owner should be informed regarding usage.
- **Transparency and Consistency** – what purpose will the data be collected and used for, and who will have access to the data that the product or service creates.
- **Disclosure, Use and Sale Limitation** – restrictions on further use of the data beyond the original agreement scope, including commercialisation.
- **Data Retention and Availability** – confirmation of policies and procedures for the handling of data, from receipt through to secure disposal.
- **Unlawful or Anti-Competitive Activities** – restrictions on the use of data for such activities.
- **Liability and Security Safeguards** – clear terms of liability, along with protection against risks such as loss or unauthorised access, destruction, use, modification or disclosure, plus policies for notification and response in the event of a breach.
- **Shared value creation** – recognition that where data is generated as a by-product of using a product or service, multiple parties may have contributed to creating this data.
- **Respect for each other's commercial interests** – coverage of the need to protect both the commercial interests and private information of data holders and data users.
- **Ensure undistorted competition** – particularly when exchanging commercially sensitive data.

A slightly different approach is the use of data partnerships within the private sector and / or between the private and public sector. These can be formed through the use of open data or via incentivisation through research-related funding. Alternatively, public bodies such as road administrations may act as an independent trusted third party or engage directly with the private sector via public private partnerships.

Mandatory data sharing is an approach primarily used for “data of public interest”, and how this is applied depends on the locality and specific arrangement. An example where this has been used to great effect has been the European Commission, that is examining data sharing between the private and public sector in order to guide policy making and improve public services. The case study below from the Netherlands outlines how this has worked in relation to connected vehicle data and its application to improve both management of the road network and the customer journey.

Further advice and guidance from Europe (European Commission, 2020) provides more detail around Business-to-Government (B2G) data sharing around three areas – while these have been designed for adoption by members of the EU, the lessons and principles covered should be considered by other road administrations too for transferrable knowledge:

- Governance of B2G data sharing;
- Transparency, citizen engagement and ethics; and
- Operational models, structures and technical tools.

Open data has been mentioned earlier in the report, and the experience of organisations such as Transport for London and the National Data Warehouse provide firm evidence of the potential benefits. This is reinforced by the OECD reporting of a general trend related to the setup of open data portals within all its member countries (OECD, 2019).

5.5.3. RECOMMENDATIONS FOR ROAD ADMINSTRATIONS

R12. Engage with other road organisations and the private sector to identify opportunities to develop partnership arrangements for the shared collection and use of data:

- Consider partnering with other road administrations within the country (e.g. municipal authorities) with neighbouring countries and / or organisations managing other transport networks. Whilst this should have lower risks and concerns than partnering with private sector organisations, this could still be set up formally via an arrangement such as a Memorandum of Understanding.
- Use the most appropriate form of partnering arrangement when engaging with the private sector. For example, the research identified examples of both mandatory sharing of data (through legislation and regulation) and commercial arrangements (through the use of contracts, terms and conditions).
- Review good practice from governments and professional institutes to use the latest thinking when developing partnering models. This is a fast-moving area, and significant work is being undertaken to produce templates and advice that can help inform road administrations in this area.

R13. Understand the difference between information and data:

- Acknowledge that information is key as this provides the basis for sound decision making and ultimately knowledge, based on the data available.
- Consider when information is required rather than raw data when partnering with external providers. For instance, accessing information instead of data will minimise volumes of content to be transferred, processed and stored from the data supplier. However, raw data will be essential if increased granularity and further types of analysis are required by the road administration.
- Use aggregated data where possible and where granularity is not required, to minimise data protection risks.

R14. Recognise the opportunities and value that open data can provide:

- Gain efficiencies related to data collection through the use of appropriate open data (which is freely available data that may be used without restriction), and also create insights that are not normally easily available through traditional sources. For example, this may include information on user behaviours.
- Identify where value may come from the internal use of open data from external organisations, when responding to emerging or escalating issues. This is due to the nature of some datasets providing significant geographical and historical coverage which may be accessible at short notice.
- Consider releasing certain data held by the road administration into the public domain in a structured fashion with accompanying guidance and oversight. This has been proven to generate benefits for users and wider society, but any data should be reviewed thoroughly prior to release to ensure that this will not create any risks for either the road administration or end-users.

5.5.4. CASE STUDIES

Rijkswaterstaat (RWS) and RAI Vereniging

Netherlands

RWS and RAI have very different perspectives and priorities. However, due to European regulations related to Safety-Related Traffic Information (SRTI) (No 886/2013), sharing of safety critical data is mandated, and pilots are being trialled across five nations with multiple OEMs and contexts.

It is acknowledged that due to OEM business models, there would be no sharing of data without the regulatory impact. Although there is no current profitable model for OEMs to use this data, they are protective around future value that may be realised.

The benefits of shared data would be enhanced by greater OEM involvement, as more data will provide a better picture. Also, there are challenges related to a lack of standardisation between OEMs and models, an example being one OEM who was supplying data over a period of time, but changed format without providing adequate communications to all parties. The transfer of data is also an issue, given the huge volumes of data being continually produced by connected vehicles, which is mitigated by companies aggregating data and combining against locations.

A strategic alliance is being developed between road administrations (including RWS working with provinces and municipalities in the Netherlands to extend coverage), OEMs and PIARC, which intends to work to overcome these challenges and maximise benefits.

More information on the Data Task Force and programme of work that generated this can be found online at (www.dataforroadsafety.eu), which includes full details on membership across multiple road administrations and OEMs, latest report from October 2020 including key recommendations, and documentation such as the multi-party agreement used to support the collaborative efforts.

National Data Warehouse (NDW)

Netherlands

NDW does not directly provide services from public data, but does process and combine data sources, then shares information to and from the private / public sectors. The model in the Netherlands could be used in other countries. The basis of NDW is efficiency in collecting, processing and sharing data. It stimulates traffic management developments and enables different companies to come together, providing the link between the data source and the final user of the data.

A lot of the new developments are initiated by the public sector, for example work with government and navigation companies to avoid school zones at certain times of the day. Intelligence of the market is also used to create services, and shared intellectual property helps stimulate the market.

Data is purchased from private partners including communication companies, navigation apps, and Floating Car Data. Commercial arrangements on how data is purchased can vary. and some two-way sharing arrangements are particularly of interest. Agreements are also in place to share raw data from both sides that is not public.

There is some resistance with new data / information, as there are challenges due to the different partners involved, where each partner has different interests and drivers. This includes private companies that are very traditional and because it involves new risks. In particular, technological challenges and commercial issues can act as barriers to private partnerships

Responsibility for shared data is a key area for attention, for example the potential for something going wrong due to data provided. With open data there is no legal requirement for any level of quality – data is shared, but it is up to the user to check quality. However, when NDW procure data, a quality check is carried out and a certain level of quality is expected. The responsibility is then shared by NDW and the data provider, with reliability and quality included in the contract. This is a change to previous arrangements when NDW just delivered open data, as now there is more of a relationship with the service providers.

Legal requirements may be a barrier in developing new tools, as there is always a risk for private companies if they have responsibility for incidents caused by the services they provided that were based on inadequate data.

SANRAL

South Africa

SANRAL shares data via intergovernmental partnerships, such as the FMS project's links with local and provincial authorities. Data is also made available for academic purposes, through partnerships with the University of Cape Town Research Centre, SSML and Data Science Academy – valid reasons for access are required, and data is anonymised before being released. Agreements are in place with tracking companies for Floating Car Data, including TomTom, Waze, Altech Netstar, plus potential future arrangements with vehicle fleets. Data from TomTom is anonymised at a granular level, but this does not impact on the analysis of trends. As with all data sharing, concerns regarding data protection and privacy must be addressed in line with local legislation (POPIA).

SANRAL provide a range of Value-Added Services (VAS), where data is used to support court cases, address insurance claims, and promote improved mobility / public transport. Business models for generation of formal revenue are still at conceptual stage, with review underway of income sources. There are barriers to setting up commercial arrangements with third parties, due to procurement regulations. However, API links are freely made available for service providers, to support third party app development. Also, hackathons have been delivered, such as a pilot with Uber to better understand Cape Town freeways – locations were identified, predictive models were built for incidents, traffic, weather etc, and then interventions were planned whilst being able to model contributary factors such as geometry.

SANRAL's ORT Transaction Clearing House (TCH) processes payments related to toll roads, including concessions. All toll roads on National Roads operate through one-tag-one account. The system was developed under contract. Toll road concessions are paid through this TCH and additional Value-Added Services are under development, including a mobility card that will be piloted on various forms of public transport, including the minibus taxi. Open road tolling data captures approximately 70 million vehicle movements per month, and uses Automatic Number Plate Recognition (ANPR) to detect cloning of plates and create a Vehicles of Special Interest (VOSI) list shared with police and traffic enforcement.

Stellenbosch Smart Mobility Lab (SSML)

South Africa

The SSML has a number of partnerships, both private and public sector. These include:

- TomTom – provision of historic and real time data.
- PTV Group – access to state-of-the-art transportation planning, management and operational software.
- Syntell – provision of traffic controllers for class displays.
- Stellenbosch municipality – support of local testbed, funding of student research, funding and collaboration of testbed environment.
- SANRAL – provision of video wall and ATMS/ATIS software; access to Freeway Management System software for exposure training and research opportunities to students.
- National Department of Transport – student bursaries, provision of some equipment.
- ITS South Africa – awareness and support.

COVID-19 Mobility Impacts

Global

Analysts from Atkins analysed the impact of COVID-19 measures around the world using a range of open data sources such as Google, Apple and TomTom, together with data about COVID-19 spread as aggregated from the Our World in Data. Data was visualised using Power BI dashboards, and has been used to inform some of the work by the PIARC COVID-19 Response Team. It should be noted that these datasets were produced specifically to help authorities monitor the effects of lockdowns and travel restrictions, and it remains to be seen whether they will continue to be produced after the pandemic, either freely available or as paid resources.

More information on some of the data sources and a global snapshot visualisation are outlined below:

The **TomTom Congestion Index** represents the relative difference of average congestion levels in 2020 from standard congestion levels in 2019. Daily and weekly differences are based on weighted averages derived from hourly data. Each week starts on Monday and ends on Sunday. The daily standard congestion level for each weekday represents the daily average for that weekday over 2019. The weekly standard congestion level represents the mean of average weekly congestion levels in 2019. The values range from -1 to 1, more information can be found on **TomTom Traffic Index (**www.tomtom.com/en_gb/traffic-index**)**

Google Mobility Indexes from **Google Community Reports** show how visitors to (or time spent in) categorized places change compared to our baseline days. A baseline day represents a normal value for that day of the week. The baseline day is the median value from the 5-week period Jan 3 – Feb 6, 2020. More information can be found on **Community Mobility Reports, Google (**www.google.com/covid19/mobility/**)**

The Government Stringency Response Index records the number and strictness of government policies. The index is published in the Oxford COVID-19 Government Response Tracker and is

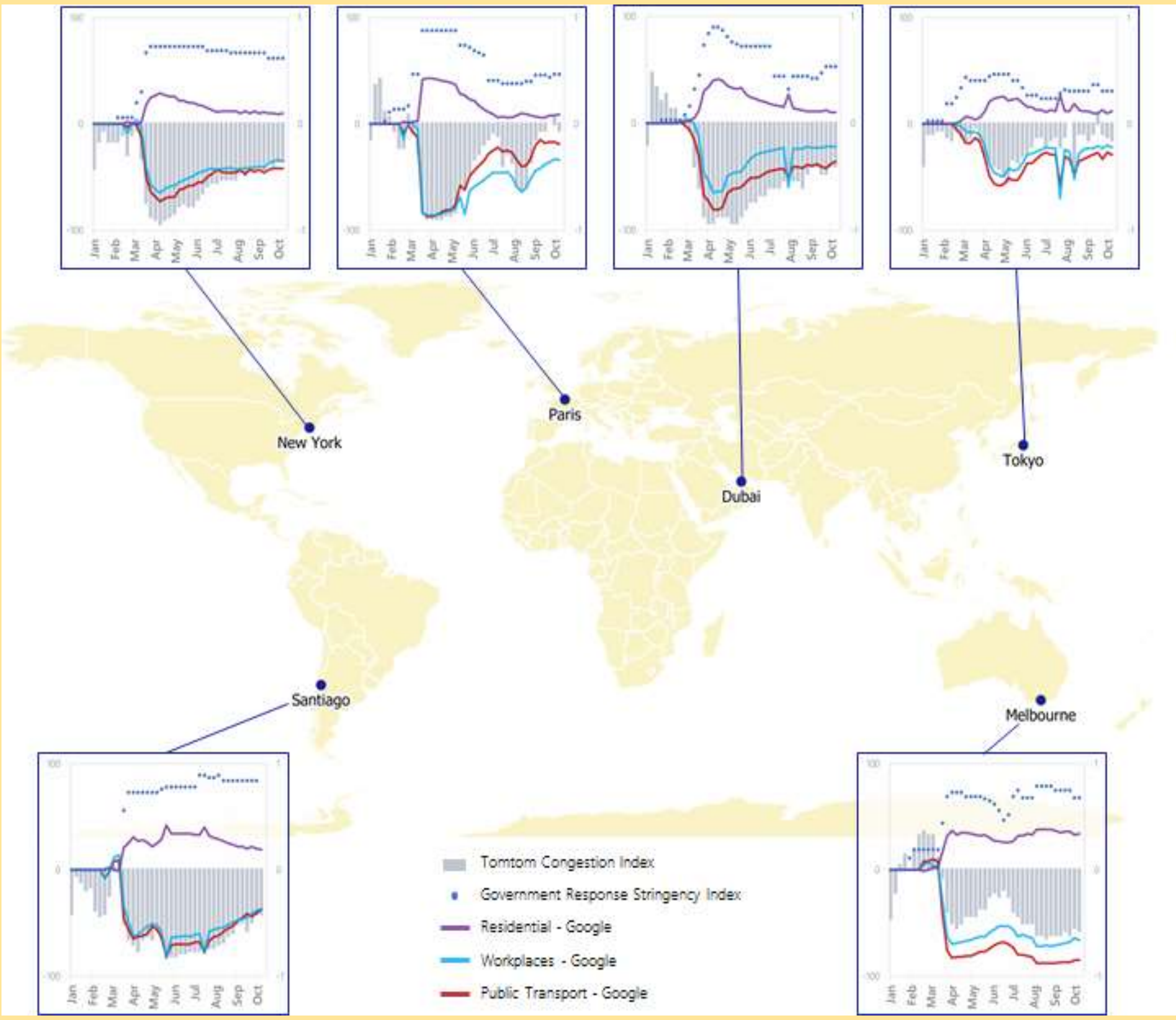
COVID-19 Mobility Impacts

Global

calculated using publicly available information on 17 indicators of government responses. Eight of the policy indicators (C1-C8) record information on containment and closure policies, such as school closures and restrictions in movement. Four of the indicators (E1-E4) record economic policies, such as income support to citizens or provision of foreign aid. Five of the indicators (H1-H5) record health system policies such as the COVID-19 testing regime or emergency investments into healthcare.

More information on **Coronavirus Government Response Tracker** can be found here (www.bsg.ox.ac.uk).

Global Snapshot



Open Data Institute (ODI)

UK-based, International

The ODI (theodi.org) was co-founded in 2012 by the inventor of the web Sir Tim Berners-Lee and artificial intelligence expert Sir Nigel Shadbolt to show the value of open data, and to advocate for the innovative use of open data to affect positive change across the globe:

It works with companies and governments to build an open, trustworthy data ecosystem and to bring about sustainable behaviour change, via three key activities:

- Sector programmes – coordinating organisations to tackle a social or economic problem with data and an open approach.
- Practical advocacy – working as a critical friend with businesses and government and creating products they can use to support change.
- Peer networks – bringing together peers in similar situations to learn together.

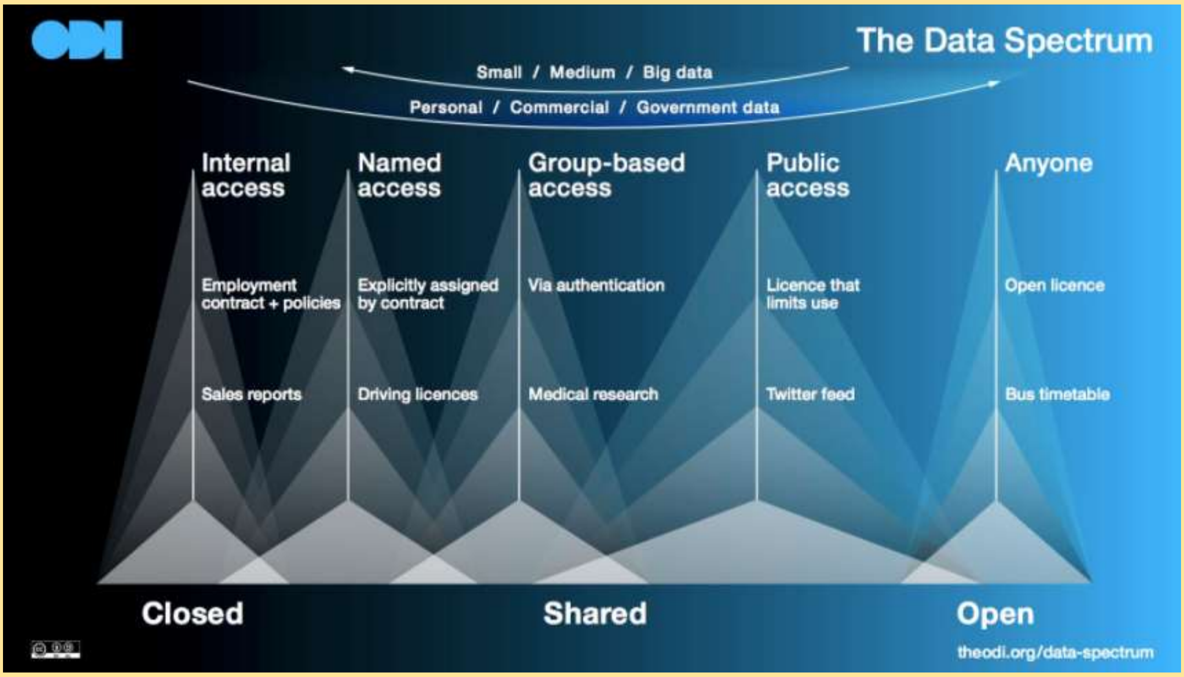
The ODI advocates for and support practices that increase trust and trustworthiness: building ethical considerations into how data is collected, managed and used; ensuring equity around who can access and use data; engaging widely with affected people and organisations. It can help practitioners identify and address how open data can be used effectively in their sector to improve decision making and processes, deliver more efficient and effective services and products, and fuel economic growth and productivity.

The ODI is an independent, non-profit, non-partisan organisation, and offers the following:

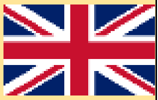
- Strategic advice – identifying how data can help to achieve programme goals and how to measure success.
- Policy development and guidance – scrutinising the interaction between general data governance practices and sector norms.
- Technology development – creating appropriate data standards and the tools needed to support them.
- Research – from creating case studies of the role of data in the sector to rigorous impact evaluation.
- Training – including blended learning packages that combine face-to-face, e-learning and webinars.
- Running competitions and acceleration programmes – to foster innovation in the sector.
- Building communities within the sector – and communicating clearly with them.

Open Data Institute (ODI)

UK-based, International



Transport for London (TfL)



United Kingdom

In the UK, TfL is responsible for the city's principal road routes as well as other transport modes, and has been committed to sharing free, accurate and real-time open data for over a decade. Research by Deloitte in 2017 estimated that this approach was providing annual economic benefits and savings of up to £130m a year for London, with wider benefits for both TfL and their customers.

The report indicated that over 80 data feeds were available through the free unified API, which provided data from one system to over 13,000 developers. These included a wide range of professional and amateur developers, ranging from start-ups to global innovators, working to deliver customer-focused applications. Developer guidelines were made available to provide technical information related to how the open data works, its correct use, data refresh rates, branding requirements and terms and conditions of use. At the time of the report, over 600 apps had been developed using TfL's open data, which were being used by almost half of Londoners.

The report found that TfL's open data policy provided the following benefits:

- Time savings for customers worth between £70m and £90m per year.
- Improved journey planning resulting in additional use of the system with a value estimated at up to £20m per year.
- Creating commercial opportunities for third party developers, with economic benefits of between £12m and £15m per year.
- Generating value and savings from partnerships with major customer facing technology platform owners, such as TfL receiving significant data on areas it does not itself collect data (e.g. crowdsourced traffic data).

Examples of the open data sets available include those related to roads, cycling, walking, planning and air quality, with more information on these, the TfL unified API and guidance via tfl.gov.uk.

5.6. ENABLERS

5.6.1. DEFINITION

Road administrations require a range of enablers within their organisation to support the implementation of data-driven practices. This section covers a number of key themes that are essential to successfully deliver a data strategy, including the importance of leadership, skills and behaviours within the organisation, and the tools and processes to allow people to get the most out of data, along with examples of potential support for practitioners.

5.6.2. APPROACHES

Strong leadership is an essential factor behind the success of any element of road administrations, and implementing a Chief Data Officer (CDO) role is an effective way of enhancing the benefits and value added from the use of data and analytics within a road administration. The actual job title itself should not been seen as mandatory, but the scope of the role should be one of ownership of the data strategy, and thus responsibility for data and analytics governance, data literacy among the workforce, and establishing a data-driven culture (Hippold, 2018).

Staff can be engaged with implementing a more data-driven approach by focusing on the potential benefits on a personal and professional level, as well as the benefits for the organisation and users. Being able to use data and suitable tools to reduce the impact of time-consuming, uninspiring and / or repetitive tasks, this will be seen as a good incentive to adopt new approaches and make them a success.

Training is always an obvious option to develop skills within a road administration, and this applies to data too. However, as with all learnt skills, staff must “use it or lose it” – i.e. if there is no opportunity for them to apply their new skills straight after training, then it is likely that they will forget what they have learnt and the training will have been wasted (Waller, 2020).

Staff development may not only consist of formal and informal training, but also learning activities and mentorship are options to develop data capabilities in a cost-effective manner. Organisations have also been able to encourage adoption of data practices by incorporating this into the professional development reviews (appraisals) of staff, creating incentivisation. Enabling staff to actively participate in data analytics through access to tools is also likely to create greater buy-in, as they are exposed more closely to processes and begin to consider data as a part of “business as usual”. Development of communities within an organisation will also reinforce positive behaviours and development of skills across the workforce (tableau, 2019).

The OECD has undertaken many studies into the use of data within and across organisations, and this includes the subject of upskilling the wider sector. Aligning with universities to co-create additional resource in the field of analytics will be beneficial, especially when there is a focus on the application of R&D to address real-life challenges for road administrations. Benefits can also be realised by engaging with tech start-ups and spin-off companies, who can rapidly develop emerging skills and technology, which can be shared with road organisations that would otherwise struggle to cover these types of capabilities. Working with government to develop initiatives for data related skills and competences is a mitigation against the impact of scarce resources of this type, as is support for data analytic and innovation centres (OECD, 2019).

5.6.3. RECOMMENDATIONS FOR ROAD ADMINSTRATIONS

R15. Demonstrate clear leadership both within the road administration and also to the private sector:

- Define a senior role within the road administration to provide direction to the data functions within the organisation and take ownership of strategy and its implementation. This should be an "executive level role" rather than a less-formal "champion", and will ensure that data is seen as important as engineering when delivering road services now and in the future.
- Shape a data- and evidence-led culture of decision making within the road administration and secure buy in from all stakeholders. Executives and other senior staff should lead by example in developing this, regardless of whether their role is data-specific or not.
- Road administrations should act as a leading organisation by stimulating innovation and growth within the private sector. This may take the form of initiatives such as hackathons, innovation competitions or funding opportunities.

R16. Develop more than just data-orientated skills, but also behaviours and culture within the road administration:

- Develop staff via formal training, on-the-job training and online resources. Change should be incentivised, both through the staff development policies of the road administration and also through communicating the personal benefits from a more data-driven approach, for example potential reductions in manual processes leaving more time to focus on value-added work.
- Recruit staff from wider backgrounds, for example with more focus on statistics, digital systems, mathematics and similar experience and skills. This will provide a more diverse set of resources within the business, who are well-prepared to face the challenges from data and complement existing data skills held by more traditional road planning and engineering staff.
- Align with academic institutions to understand and develop the right skills for the future, especially around digital systems, technology and their data collection and analytics potential. This will need to consider how data and technology may need to be employed within a roads context, plus it should also encourage young people into the industry, vitally important given the expected levels of competition from other sectors for data-skilled graduates.

R17. Use the right tools to analyse data and communicate findings:

- Select the right tools for the right job, for example suitable software packages, with the right people in place to use them. There is unlikely to be a one-size-fits-all solution, so will need to be considered on a case by case basis.
- Reduce time, effort and risk of errors through the automation of processes or procedures where possible. This may provide dual benefits of increased quality and reduced costs, but it is critical that such automation is set up correctly and thoroughly tested before full implementation, and then monitored.
- Use data visualisation tools to support the analysis of data, especially when aggregating disparate datasets or understanding implications of how they combine. This is also a powerful way for communicating outputs to both a technical and non-technical audience.

5.6.4. CASE STUDIES

Rijkswaterstaat (RWS)

Netherlands

RWS have access to data scientists within the organisation and also via good relationships with NDW, universities and applied science institutes. However, challenges exist related to recruitment, as this can be hard due to very specific skills. Also, whilst road administrations want cooperation within the contracting sector, for example learn from one another and from one project to another, some road building and maintenance contractors can be very conservative in nature. There is a need to improve behavioural / cultural issues, as sharing with one another is seen as a loss of competitive advantage, and innovation can be seen as a risk rather than a benefit.

As part of the Data Strategy, a key theme is around development of maturity related to collaboration, knowledge and communication. This comprises of three main parts:

- Measures to strengthen internal and external cooperation.
- Measures to increase knowledge and craftsmanship.
- Measures aimed at awareness and communication.

By investing in training, recruitment, awareness and linking supply and demand in the RWS organisation, the maturity level will increase.

Collaboration (internal and external)

A virtual team of departments dealing with Business Intelligence and management information (including NIS) is set up; an action plan is drawn up in connection with the intended core project of the CTD “dashboarding”. Alliance strategy data regarding knowledge and data exchange (other governments, universities, and Europe market) such as input for the update RWS university policies and priorities with regard to EU-projects.

Knowledge and craftsmanship

Data knowledge profile (as part of the knowledge field Digitisation), with a translation into the Strategic Personnel Plans. Specific attention is given here to the positioning of information managers in relation to other functions such as business architects, data scientists and data stewards. Implement the basic course for employees and the (mandatory) one-day training for "data managers" as part of the internal curriculum update. Opportunities to gain a “data passport” or do an internship at the RWS Datalab.

Communication and culture

Initiatives such as “data week” events and publication of newsletters. Monitoring compliance with agreements and frameworks with regards to data.

SANRAL

South Africa

The Technical Innovation Hub (TIH), located in the Western Region, provides an environment for graduates in the fields of electrical, electronic, mechatronic and computer engineering, to explore the application of technology to engineering problems. This innovative work forms part of their practical professional training, and secondments to specialist engineering firms are negotiated to provide candidates with work exposure and training in their fields of interest.

In 2018/19, there were five students at the hub and work progressed on the following pilot projects and feasibility studies:

- Testing the use of drones to perform geotechnical inspection of the stability of cuts at Sir Lowry's Pass.
- Investigation of the benefits of solar road studs on a stretch of the N1.
- Experimental use of a robotic flagger in conditions hazardous to human flaggers.
- Evaluating the use of camera technology to understand patterns of pedestrian movement.

SANRAL also has access to an increased resource pool through SSML introducing ITS skills as part of its educational programmes. The Research Panel also engages with industry / academia to identify and secure suitable skills and staff.

European Data Portal

European Union

The European Data Portal offers a free-to-access e-learning programme, which provides an introduction into concepts of open data, its potential benefits and how it can be applied. It is available online at (www.europeandataportal.eu).

The content is available in a range of languages (English, French, Italian, German, Spanish, Swedish) and 16 modules are available online, covering the following lessons:

1. What is open data?
2. Unlocking value from open data
3. Open data. Agent of change.
4. Why do we need to license?
5. What makes quality open data?
6. Measuring success for open data
7. Why should we worry about sustainability?
8. Getting to grips with platforms
9. Choosing the right format for open data
10. How useful is my data?
11. How to clean your data
12. Finding hidden data on the web
13. Linking up the web of data
14. Open data advocacy
15. Managing change in open data
16. Achieving impact with open data

The site also offers free guidance for Data Managers and Data Holders.

Skills Framework for the Information Age (SFIA)

SFIA Foundation

The SFIA Foundation is a global not-for-profit organisation which oversees the production and use of the Skills Framework for the Information Age, which has been adopted by governments, corporates and individuals in almost 200 countries. SFIA describes skills and competencies required by professionals in roles involved in information and communication technologies, digital transformation and software engineering. It is available in multiple languages (English, German, Spanish, French, Italian, Polish, Portuguese, French [Canada], Arabic, Chinese, Japanese) and can be accessed online at (sfia-online.org).

The key design principles of SFIA are:

- Straightforward, generic and universally applicable – the breadth of coverage is broad and it is designed to be applicable to all sectors.
- An experience-based framework – an individual has a particular competence because they have demonstrated that they have a level of responsibility and have practised a number of skills at the levels required in real world situations. It is not aligned to any qualification or certification; certifications can be aligned to SFIA but qualifications that merely test knowledge do not indicate experience nor a level of responsibility.
- Defines levels of responsibility and skills – it does not define jobs, roles, people, processes or general areas of activity, however important they are.
- Defines the essence of skills – it is descriptive, not prescriptive. It does not define low level tasks nor deliverables.
- Provides an integrated view of competency – it recognises levels of responsibility, professional skills, behaviours or attributes, knowledge and qualifications and certifications. It shows how these fit together and how they complement each other.
- Independent of technology and approach – it does not define technology, methods, approaches or technical knowledge – these change rapidly but the underlying skills are more persistent. So, for instance, Cloud, DevOps, Agile, Big Data and digital roles etc. can be described using a combination of the SFIA skills.
- Updated by real practitioners from the international user base – it is driven by its end users – the content reflects what industry and business want and it is not driven by any single stakeholder group.
- Does not assume or recommend specific organisation structures, job or role designs – the SFIA skills and levels can be configured flexibly to support all organisational types and structures. It works for individuals, small and large teams, whole departments or entire organisations with thousands of employees.

5.7. MAKING THE CASE

5.7.1. DEFINITION

Implementation or improvement plans focused on data may cover the technical aspects robustly, but without a through case for investment, they may well face difficulties in being delivered in reality. This section covers the development of such cases, which should clearly frame the costs involved whilst articulating the potential benefits that can be achieved, plus how related messaging can be communicated and key stakeholders convinced.

5.7.2. APPROACHES

Whilst this report outlines the undoubted potential benefits from adopting improved approaches to the use of data within road administrations, securing support and investment from within organisations or from government will require robust justification. Specific examples of this topic were more limited than the previous themes within the business model, perhaps due to commercial sensitivities around the content or detail of business cases.

However, drawing on feedback received plus other experience within the sector, three types of recommendation have been developed which covers:

- Justification for change – analysis should be undertaken to review and justify the investment of time and resources into such programmes of work.
- Communication and messaging – the detail behind data-related improvements may become complex and heavy with technical information. This is unlikely to be appropriate for an audience of senior decision makers, so should focus on high level principles including, but not limited to, outcomes, risks, costs, and benefits.
- Use of pilot projects – this has been demonstrated across each of the case studies as an excellent way of introducing change and innovation to road administrations, that not only proves concepts and ways of working, but also manages risk and supports buy-in from stakeholders.

5.7.3. RECOMMENDATIONS FOR ROAD ADMINSTRATIONS

R18. Develop an investment case for data, and evaluate improvements and subsequent benefits:

- Base the development of a strong investment case on established good practice, particularly where specific local guidance is available. This is particularly important for data proposals, as the topic may seem unfamiliar or perceived as risky by those responsible for review and approval, so maximum diligence will be required.
- Content may include, but is not limited to, description of the business need, alignment with strategy, options assessed, cost-benefit analysis, risks and opportunities, assumptions, organisational and resource considerations, and timescales.
- Evaluate improvements to data work either in terms of improved service quality, time reduction, cost efficiency or other key performance indicators that align with the organisational strategy.

R19. Communicate in accessible language, with technical detail to support:

- Present information at a level that is suitable for the audience or decision makers and in accessible language for them. This is important as data specialists may be used to communicating in complex technical terms and jargon within their work, however these may not be easily understood by other stakeholders.
- Provide technical detail to support any analysis or business case where needed. This will provide assurance to senior audiences even if they themselves are not able to challenge the detail themselves, plus will support swift engagement with any independent technical reviewers of proposals.
- Ensure that communication is two-way with genuine dialogue, to make use of constructive feedback and lessons from any unsuccessful investment cases. This is essential to support ongoing learning within the organisation.

R20. Consider pilot projects to demonstrate principles and secure interest:

- Use pilot projects for new forms or formats of data collection and analysis where applicable to demonstrate principles, gain confidence, dispel myths, develop procedures and evidence potential benefits. This may include not only the proof of technical concepts but also how new types of data partnering arrangements will work in practice.
- Start small and develop over time, to provide opportunities to “fail fast” without over-committing resources and costs. This should see lessons learnt being shared and acted upon in an open and transparent way.
- Monitor the move from pilot status to implementation or development of new standards closely, to ensure that benefits, risks and other project characteristics do not change along with the scale of work. This will support long-term sustainability of these types of data improvements.

5.7.4. CASE STUDIES

Rijkswaterstaat (RWS)

Netherlands

The concept of connected vehicles suffered from political and commercial issues in the Netherlands, until the first pilot was run in 2016. Whilst this involved only a limited number of vehicles, and didn't result in massive technological advances, it did have a major and lasting impact on key stakeholders. The pilot findings created much greater awareness with politicians and shaped a vision for what could be achieved in future, especially around the benefits of more openness of data. It also convinced OEMs of benefits to their customers to provide a win-win situation.

SANRAL

South Africa

Experience in South Africa has shown that investment in digital infrastructure not only needs justifying in itself, but also needs to consider what is already in place and may be replaced, both in terms of costs accrued and the human buy-in to existing systems.

Improvement in data-driven asset management has required the justification of investment in data collection and information systems. This has been achieved by using lifecycle planning tools to understand the reduction in whole life cost by optimising maintenance prioritisation and moving away from a worst-first approach.

Pilot projects have helped with gaining an understanding of potential costs and impact, but there is a clear need for real-world monitoring over time to validate this.

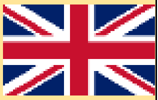
Economic benefits have successfully been predicted, for instance by modelling the value of time saved through the adoption of a potential Traffic Management System.

Non-financial benefits can be measured in quantitative ways, such as the resulting improvement in road response times following investment in data in Gauteng province. This was a particularly strong benefit, as is resulted in a greater number of accidents being attended to within the "golden hour" related to increased chances of survival.

Where the identification of indirect benefits has proven difficult, the value of the data can be measured by considering a scenario where the "switch is thrown off" and resulting impacts to the network or any related service.

Department for Transport, ADEPT & Local Highway Authorities

United Kingdom



The ADEPT SMART Places Live Labs Programme is a two-year, £22.9m project funded by the Department for Transport, that will run until November 2021. Eight local authority-led innovative projects, will develop new smart approaches across communications, materials, energy solutions and mobility. With partners from the private sector, universities and SMEs, the Live Labs trials include gully sensors and drones, behavioural and data analytics, plastic roads, harvesting kinetic energy, and thermal and solar solutions.

At the heart of the Live Labs concept is the acceleration of the adoption of new solutions and technologies to deliver improved outcomes for the local roads sector, both here in the UK and further afield. It is expected that Live Lab partners and their suppliers do not focus only on delivery and associated benefits, but also on the underlying commercial factors that enable success, which is vital for achieving a wider step change. The Live Labs are expected to be collecting the technical, commercial and other supporting data to allow others to construct future business cases for their geographies.

Some examples of the technologies being trialled are outlined below, with further information available on the Live Labs website (www.adeptnet.org.uk).

Buckinghamshire Council – Smart Communication Sensor installation & Control Management System

A number of SMART sensors are being installed in lamp posts that will enable managers to have better control and understanding of the network in real time. These sensors include but are not limited to: traffic type, traffic count, air temp, ground temp, air quality, flood sensors and Bluetooth sensors. The latter in particular is interesting collaboration is planned with the adult and social care department to complement existing care packages. In addition, and in order to manage and control these sensors, a control management system will also be created. This will provide greater remote management of these sensors and will save time and effort for in-field staff.

Reading (Thames Valley Berkshire) – Development of Insights Platform

O2 has developed its insights platform ready for the integration of external data. This has included both historic and real-time capability and an API capability to enable integration of data feeds from other project partners, primarily through discussion with Siemens, which will provide one of the main sources of external data feeds for the project. O2 has also developed the algorithms that will be used to turn O2 mobile network data into insights around people movement, travel behaviours and profiles.

West Midlands – Memorandum of Understanding with West Midlands Police

Through frequent and detailed discussion, we have set up a Memorandum of Understanding (MoU) with West Midlands Police (WMP). This includes a Service Level Agreement (SLA), which extends to WMP's contactor that provides the ANPR (automatic number plate recognition) data. This has meant the Live Lab has access to ANPR cameras without the need to deploy more equipment. It also allows for efficiencies with the greater use of the existing cameras and maintenance of those cameras. The main challenge has been ensuring the data received is of high enough detail to be useful while also complying with privacy laws.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

The research has confirmed that the pressures on road administrations in terms of increasing demand and expectations continue to grow, and current international disruption following the emergence of Covid-19 means that there are likely to be more challenges to deal with in the short-to-medium term. It was clear from the findings that there is great interest and appetite in the potential for data to help with this, and there are already excellent examples of global good practice.

The project objectives outlined in Section 1 have been met through the various elements to this report, both in terms of technical information provided, guidance and recommendation for road administrations and potential activities to support the dissemination and adoption of the report.

The literature review and online survey have provided an extensive overview of the state-of-the-art in road related data, and identified numerous use cases that are intended to help PIARC members review their own practices and learn from colleagues from around the world. This includes the deployment of data and technology across the whole spectrum of activities within road administrations, and the research has demonstrated a range of feasible data applications within all types of organisations, regardless of the size of country, geographical location or income level.

The business model research provided a structured guidance and detailed case studies that can help road administrations develop their approach to using data, and improve value of services. This includes setting a strategy and organisational approach to using data, partnership with external parties, and development of new or improved services.

The 20 recommendations below, which are also referenced within the report, provide a clear framework for road administrations to systematically compare their current practices and develop tailored action plans. These also complemented by a further 4 recommendations for PIARC to consider, to supporting member organisations in their journey to deliver better services through smarter use of data.

6.2. RECOMMENDATIONS FOR ROAD ADMINISTRATIONS

6.2.1. RELATED TO THE LITERATURE REVIEW

R1. Learn from the literature review, then act and improve:

- Conduct a high-level review of the findings to understand the range of technical capabilities covered, and identify specific areas of interest.
- Review specific topics and data types in more detail, including the associated state-of-the-art data collection methods, via the content of the report plus the additional literature resources listed separately on the PIARC website.
- Learn from existing technical knowledge, and use this to inform local pilots, trials or applications which will in turn add to the advancing state of knowledge.
- Continue to maintain and update the literature as new technologies, processes and standards evolve along with their potential to collect, analyse and utilise data.

6.2.2. RELATED TO STAKEHOLDER ENGAGEMENT (ONLINE SURVEY)

R2. Learn from the online survey, then act and improve:

- Undertake a high-level review of the findings to understand the range of topics covered and the different approaches being implemented globally.
- Carry out a detailed review to focus on current and future practices which address local priorities, and identify opportunities to introduce or improve applications of data.
- Based on the documented findings of the survey, develop an action plan for the implementation of improvements related to data, and engage and collaborate with other PIARC members where appropriate.
- Consider further surveys in the future to collect updated information on the use of road-related data, especially around take-up of evolving technology, processes and systems.

6.2.3. RELATED TO BUSINESS MODELS FROM A ROAD ADMINSTRATION PERSPECTIVE

THEME – STRATEGY (SEE SECTION 5.2)

R3. Use a strategic approach, both at organisation level and also in terms of data as a discipline:

- Ensure that the organisational strategy includes data as a core component and enabler, rather than as a separate activity. This will provide line of sight from corporate vision and objectives to operational and wider outcomes, support a more effective and efficient approach to using data, and create a clear recognition of the importance of data collection and analysis as a discipline in itself.
- Develop a data strategy to link the objectives within the organisational strategy to outcomes. This will ensure that data is used to address the genuine needs of the organisation and its users, rather than developing solutions and then searching for applications.
- Align the data strategy with any national government and / or regional initiatives, including sharing of data and analysis across agencies and between roads and other transport modes and networks. This will maximise the benefits outlined in the business model analysis.

R4. Develop an action plan for data using SMART (Specific, Measurable, Achievable, Relevant and Time-bound) principles:

- Develop a SMART action plan to implement the data strategy and embed its principles. This will support real change and creation of value at an organisational level, rather than being limited to aspirational discussions or delivery of individual projects.
- Within the action plan, assign responsibility for delivery of the various components, using a RACI approach (Responsible, Accountable, Consulted and Informed), to specific departments, units or individuals. As the implementation of the data strategy may involve a wide range of stakeholders, this will support ownership, allocation and coordination of effort across the organisation.
- Build in checks to ensure that the deliverables are providing visibility of the expected outcomes, e.g. increased customer satisfaction.

R5. Collaborate, learn and review:

- Collaborate with other road and transport administrations to provide stronger capability, share insights and manage risk. This may be essential to deriving some of the benefits from a data-driven approach.
- Learn from other organisations to gain the benefits of previous work in this area. However, remember that each road administration is different, and requirements will need to be tailored to the specific local context and priorities.
- Review strategies on an ongoing basis to ensure they stay relevant and can adapt to changing circumstances. This should usually be an annual activity, however review periods may increase or decrease depending on the road administration's data maturity and the speed and extent of change in key parameters.

THEME – DATA SOURCES (SEE SECTION 5.3)

R6. Treat data as a valuable asset:

- Data should be recognised as being a core asset within a road administration, alongside built infrastructure, digital infrastructure and people. Like these other elements, it should be planned, designed and managed properly and with a clear view of the ultimate outcomes.
- Assessment of data options should not only consider collection but also the management of data throughout its lifecycle, such as storage, capacity, quality assurance, sharing, update policies, retention periods and disposal. This will ensure that fully informed decisions are made regarding data.
- Security of data and its application is a key concern in an increasingly digital society, and this must follow local legislation covering issues such as data protection, privacy and cybersecurity. Specific guidance on these issues should be sought from specialist sources.

R7. Make better use of existing resources:

- Review existing data and tools before investing in collecting new data or implementing new technology, and make better use where possible. This will avoid duplication of effort and wasted resources.
- Map out the data that is already held within the organisation and develop a "single source of truth". This will support the need to regulate and control data to ensure consistency, common understanding and aligned use across agencies and departments.
- Standardise data formats and approaches to using data. This will increase the ease with which the data can be identified, shared and employed within the wider organisation and avoid risks of duplication, inconsistency or inefficiency.

R8. Consider access to existing external data before collecting more primary data:

- Understand what existing relevant data sources are available via external organisations such as app developers or via open data, and the potential arrangements that could make this available to a road administration. This will inform a cost-benefit analysis to decide whether it is more appropriate to develop a data partnership with an external organisation or to collect new primary data on behalf of the road administration.

- When collecting new primary data, review options of using either in-house resources or procuring services from specialist suppliers. Factors which should be considered include, but are not limited to, experience and availability of staff, access to specialist services and technologies, and potential economies of scale in delivery.
- Manage risks related to external data that are outside the direct control of the road administration, e.g. ownership, access, and assurance. Refer to further guidance within the Partnerships section of the business model analysis.

THEME – ORGANISATION AND MANAGEMENT APPROACH (SEE SECTION 5.4)

R9. Understand the different organisational model options to deliver data functions and use the most appropriate for the road administration:

- Review the options covered within the business model analysis section. These options include a centralised model (where a core team is responsible within the organisation), an embedded model (where data functions are spread across the wider organisation via functional teams) and a hybrid model (a combination of centralised and embedded models).
- Consider the pros and cons for each model option, within the local context and objectives, before implementing. The business model section contains more detail for each of these.
- Monitor how the organisation and its approach to data matures over time, and how the current model for data functions is operating. As certain capabilities and / or requirements change over time, then the model used within the road administration may also need to change to provide greatest benefit.

R10. Maintain a flexible approach to accessing staff resources:

- Ensure that resourcing for data collection and analysis within a road administration can be accessed from a combination of both in-house staff and contracted supplier(s). This will support the need to build capacity and capability in the area of data, whilst acknowledging that access to the specialist skills needed may be limited due to demand from other sectors.
- Options for employing external resources may be either secondments into the road administration, contracting to deliver specific work packages or data collection associated with specific studies. This will depend on the capacity and nature of the road administration's requirements at the time.
- Road administrations should always retain ownership of the responsibility to develop policy. Whilst external resources may advise and support this area of work, the overall capacity to act on data and make decisions should not be contracted out.

R11. Monitor performance and apply continuous improvement:

- Monitor performance of the road network and of the road administration on an ongoing basis, reporting to organisational leaders in sufficient and proportionate detail, and through effective reporting formats, to allow them to make appropriate strategic and operational decisions.

- Set suitable performance targets that link into the objectives laid out in the organisational strategy and ensure adequate cause-effect understanding and data to track progress.
- Drive improvement in performance through internal review of lessons learnt and good practice, plus benchmarking with external organisations and other road administrations. Consider the recommendations of this Special Project within the context of the work which PIARC has previously done on organisational performance management.

THEME – PARTNERSHIPS (SEE SECTION 5.5)

R12. Engage with other road organisations and the private sector to identify opportunities to develop partnership arrangements for the shared collection and use of data:

- Consider partnering with other road administrations within the country (e.g. municipal authorities) with neighbouring countries and / or organisations managing other transport networks. Whilst this should have lower risks and concerns than partnering with private sector organisations, this could still be set up formally via an arrangement such as a Memorandum of Understanding.
- Use the most appropriate form of partnering arrangement when engaging with the private sector. For example, the research identified examples of both mandatory sharing of data (through legislation and regulation) and commercial arrangements (through the use of contracts, terms and conditions).
- Review good practice from governments and professional institutes to use the latest thinking when developing partnering models. This is a fast-moving area, and significant work is being undertaken to produce templates and advice that can help inform road administrations in this area.

R13. Understand the difference between information and data:

- Acknowledge that information is key as this provides the basis for sound decision making and ultimately knowledge, based on the data available.
- Consider when information is required rather than raw data when partnering with external providers. For instance, accessing information instead of data will minimise volumes of content to be transferred, processed and stored from the data supplier. However, raw data will be essential if increased granularity and further types of analysis are required by the road administration.
- Use aggregated data where possible and where granularity is not required, to minimise data protection risks.

R14. Recognise the opportunities and value that open data can provide:

- Gain efficiencies related to data collection through the use of appropriate open data (which is freely available data that may be used without restriction), and also create insights that are not normally easily available through traditional sources. For example, this may include information on user behaviours.

- Identify where value may come from the internal use of open data from external organisations, when responding to emerging or escalating issues. This is due to the nature of some datasets providing significant geographical and historical coverage which may be accessible at short notice.
- Consider releasing certain data held by the road administration into the public domain in a structured fashion with accompanying guidance and oversight. This has been proven to generate benefits for users and wider society, but any data should be reviewed thoroughly prior to release to ensure that this will not create any risks for either the road administration or end-users.

THEME – ENABLERS (SEE SECTION 5.6)

R15. Demonstrate clear leadership both within the road administration and also to the private sector:

- Define a senior role within the road administration to provide direction to the data functions within the organisation and take ownership of strategy and its implementation. This should be an "executive level role" rather than a less-formal "champion", and will ensure that data is seen as important as engineering when delivering road services now and in the future.
- Shape a data- and evidence-led culture of decision making within the road administration and secure buy in from all stakeholders. Executives and other senior staff should lead by example in developing this, regardless of whether their role is data-specific or not.
- Road administrations should act as a leading organisation by stimulating innovation and growth within the private sector. This may take the form of initiatives such as hackathons, innovation competitions or funding opportunities.

R16. Develop more than just data-orientated skills, but also behaviours and culture within the road administration:

- Develop staff via formal training, on-the-job training and online resources. Change should be incentivised, both through the staff development policies of the road administration and also through communicating the personal benefits from a more data-driven approach, for example potential reductions in manual processes leaving more time to focus on value-added work.
- Recruit staff from wider backgrounds, for example with more focus on statistics, digital systems, mathematics and similar experience and skills. This will provide a more diverse set of resources within the business, who are well-prepared to face the challenges from data and complement existing data skills held by more traditional road planning and engineering staff.
- Align with academic institutions to understand and develop the right skills for the future, especially around digital systems, technology and their data collection and analytics potential. This will need to consider how data and technology may need to be employed within a roads context, plus it should also encourage young people into the industry, vitally important given the expected levels of competition from other sectors for data-skilled graduates.

R17. Use the right tools to analyse data and communicate findings:

- Select the right tools for the right job, for example suitable software packages, with the right people in place to use them. There is unlikely to be a one-size-fits-all solution, so will need to be considered on a case by case basis.
- Reduce time, effort and risk of errors through the automation of processes or procedures where possible. This may provide dual benefits of increased quality and reduced costs, but it is critical that such automation is set up correctly and thoroughly tested before full implementation, and then monitored.
- Use data visualisation tools to support the analysis of data, especially when aggregating disparate datasets or understanding implications of how they combine. This is also a powerful way for communicating outputs to both a technical and non-technical audience.

<u>THEME – MAKING THE CASE (SEE SECTION 5.7)</u>

R18. Develop an investment case for data, and evaluate improvements and subsequent benefits:

- Base the development of a strong investment case on established good practice, particularly where specific local guidance is available. This is particularly important for data proposals, as the topic may seem unfamiliar or perceived as risky by those responsible for review and approval, so maximum diligence will be required.
- Content may include, but is not limited to, description of the business need, alignment with strategy, options assessed, cost-benefit analysis, risks and opportunities, assumptions, organisational and resource considerations, and timescales.
- Evaluate improvements to data work either in terms of improved service quality, time reduction, cost efficiency or other key performance indicators that align with the organisational strategy.

R19. Communicate in accessible language, with technical detail to support:

- Present information at a level that is suitable for the audience or decision makers and in accessible language for them. This is important as data specialists may be used to communicating in complex technical terms and jargon within their work, however these may not be easily understood by other stakeholders.
- Provide technical detail to support any analysis or business case where needed. This will provide assurance to senior audiences even if they themselves are not able to challenge the detail themselves, plus will support swift engagement with any independent technical reviewers of proposals.
- Ensure that communication is two-way with genuine dialogue, to make use of constructive feedback and lessons from any unsuccessful investment cases. This is essential to support ongoing learning within the organisation.

R20. Consider pilot projects to demonstrate principles and secure interest:

- Use pilot projects for new forms or formats of data collection and analysis where applicable to demonstrate principles, gain confidence, dispel myths, develop procedures and evidence potential benefits. This may include not only the proof of technical concepts but also how new types of data partnering arrangements will work in practice.
- Start small and develop over time, to provide opportunities to “fail fast” without over-committing resources and costs. This should see lessons learnt being shared and acted upon in an open and transparent way.
- Monitor the move from pilot status to implementation or development of new standards closely, to ensure that benefits, risks and other project characteristics do not change along with the scale of work. This will support long-term sustainability of these types of data improvements.

6.3. RECOMMENDATIONS FOR PIARC

6.3.1. RELATED TO NEXT STEPS

Whilst the previous 20 recommendations are aimed at road administrations, the research has also identified a number of further recommendations that should be considered by PIARC, to facilitate the dissemination of the report and its findings, to support improvements within the sector, and to help address challenges related to skills within the industry.

R21. Share learning through networks:

- Disseminate the project findings through the use of a technical webinar and an article in the Routes / Roads magazine.
- Consider the use of peer networks within PIARC to bring together road administrations in reviewing and adopting the report and its recommendations.
- Consider establishing a Task Force or a Technical Committee to support the ongoing investigation of data related issues and opportunities for road administrations.

R22. Help shape common approaches to managing road data:

- Work with road administrations and regional groups to promote closer engagement and collaboration, especially related to work such as the development of common data specifications (to be undertaken outside of the scope of PIARC itself).
- Develop an online register of programmes of work from PIARC member countries that may provide value and learning to road administrations.
- Engage with global organisations to support the development and implementation of data-related initiatives such as BIM and the Digital Twin concept within the roads sector.

R23. Provide greater focus on themes with scope for improvement:

- Promote a greater focus on, and exploration of, data themes that displayed lower levels of current application by road administrations through the online survey, e.g. sustainability and inclusivity.

- Identify strong case studies within the PIARC community to provide encouragement to other road administrations.
- Consider including these themes in future PIARC Strategic Plans and thus through the Technical Committees and Task Forces.

R24. Support the development of new skills within the sector:

- Work with road administrations, technology providers and academia to understand the changing skills requirements for managing data requirements of road networks in the future.
- Coordinate the development and sharing of skills resources such as online training.
- Support the delivery of knowledge exchange, skills transfer and mentoring across PIARC member organisations as part of the Association's core activities.

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8. APPENDICES

APPENDIX A – QUESTIONNAIRE TEMPLATE (ENGLISH)

Survey on Road Related Data and its Usage

Please complete this survey electronically on that form by **Friday 29 May 2020** and send back to Mostafa Massoud at mostafa.massoud@atkinsglobal.com.

If you have any project queries, please contact Miguel Caso Florez, PIARC Technical Director, at miguel.caso-florez@piarc.org.

The collection, processing, integration and management of data is considered the building block of the advanced digital transformation of the road sector. Reliable data provides road owners and operators with the necessary information to help operating and managing the road network whilst taking informed investment decisions.

To this end, Atkins were selected by the World Road Association (PIARC) to undertake a research project on “Road Related Data and How to Use it”. The output of this project will be available free of charge at www.piarc.org and all participants will be notified when the final report is available.

The overall aim of this project is to:

- Provide an overview and compilation of the state-of-the-art technologies related to the collection and analysis of various road related data types generated from different sources (e.g. cameras, sensors, smartphones, connected and autonomous vehicles, social media, etc.).
- Engage with a variety of road administrations and other parties linked to road administrations, in different regions and from different income levels (including Low and Middle income) to provide a better understanding of usage in different contexts;
- Explore how provision of services to road users could be improved using advanced data collection methods; and
- Identifying relevant case studies and implemented projects worldwide.

This survey is formed of 12 main questions falling under three main themes (Road Network, Road User and Context) and should take you around 15 minutes to answer. If you are not able to answer one or more questions, please just complete the survey for the questions you are able to answer.

As far as possible, please include a high-level statement covering the purpose and use of each data type collected or utilised while responding to each question.

Through the questionnaire, please clearly highlight whether any data you mention is already being collected/used or your road administration are looking to potentially collect/use that data in the future.

Any relevant information about case studies, implemented projects or obstacles you faced during the implementation of certain technologies can be sent separately or included in this survey. Please refer to the Case Studies section below.

Please forward this survey to any relevant road operators (concessionaires) and research institutes/laboratories linked to your administration.

Organisation: ……………..   Role of Organisation: …………

Country, City: ……………

Theme 1: Road Network

Q1: Do you collect and analyse inventory data and condition data for road infrastructure assets?

☐ Yes, ☐ No

If yes, please select all the methods and technologies which you are currently using as well as any other innovative technologies you are looking to use. Please specify the purpose and use of each item you select as appropriate.

☐ Smart vehicles with mounted cameras – Purpose/Use: ……………… (Maximum 50 words)

☐ Light Detection and Ranging (LIDAR) – Purpose/Use: ………………

☐ Unmanned Aerial Vehicles (UAVs)/Drones – Purpose/Use: …………

☐ Accelerometers or Smartphones – Purpose/Use: ………………

☐ Road sensors – Purpose/Use: ………………

☐ Machine learning (ML) and Computer Vision (CV) – Purpose/Use: ………………

☐ Artificial Intelligence – Purpose/Use: ………………

☐ Satellite imagery – Purpose/Use: ………………

☐ Multispectral imagery – Purpose/Use: ………………

☐ Connected and Autonomous Vehicles (CAVs) – Purpose/Use: ………………

☐ Vehicle telematics – Purpose/Use: ………………

☐ Asset management system (software) – Purpose/Use: ………………

☐ Cloud-based software and storage systems – Purpose/Use: ………………

☐ Traditional human surveys – Purpose/Use: ………………

☐ Data from third parties or other organisations. Please specify: …………

☐ Other: …………………

Q2: Do you collect and analyse traffic related data?

☐ Yes, ☐ No

If yes, please select all the methods and technologies which you are currently using as well as any other innovative technologies you are looking to use. Please specify the purpose and use of each item you select as appropriate.

☐ Fixed road sensors or inductive loops – Purpose/Use: ……………… (Maximum 50 words)

☐ Acoustics and Radar – Purpose/Use: ………………

☐ Traffic cameras – Purpose/Use: ………………

☐ Laser counters – Purpose/Use: ………………

☐ Probe vehicle: GPS or smartphones real-time information – Purpose/Use: ………………

☐ GPS Satellites – Purpose/Use: ………………

☐ Social media – Purpose/Use: ………………

☐ Traditional human surveys – Purpose/Use: ………………

☐ Data from third parties or other organisations. Please specify: …………

☐ Other: ………………

Q3: Do you collect or use road related data for the management of roadworks and the overall road network?

☐ Yes, ☐ No

If yes, please select all the methods and technologies which you are currently using as well as any other innovative technologies you are looking to use. Please specify the data types as well as the purpose and use for each item you select as appropriate.

☐ Intelligent Transport Systems (ITS) – Purpose/Use: ……………… (Maximum 50 words)

☐ Closed-circuit television (CCTV) and video surveillance – Purpose/Use: ………………

☐ Geographic Information System (GIS) mapping – Purpose/Use: ………………

☐ Dedicated software or online interface – Purpose/Use: ………………

☐ Data from third parties or other organisations. Please specify: …………

☐ Other: ………………

Q4: Do you collect or use certain data which can be linked to the development or optimisation of programmes of work for routine maintenance as well as for winter maintenance and operations (including identification of priority routes)?

☐ Yes, ☐ No

If yes, please select all the methods and technologies which you are currently using as well as any other innovative technologies you are looking to use. Please specify the data types as well as the purpose and use for each item you select as appropriate.

☐ Asset management systems (software) – Purpose/Use: ……………… (Maximum 50 words)

☐ Lifecycle planning tools – Purpose/Use: ………………

☐ Route planning tools – Purpose/Use: ………………

☐ Geographic Information System (GIS) mapping – Purpose/Use: ……………….

☐ Data from third parties or other organisations. Please specify: …………

☐ Other: ………………

Q5: Do you collect our use certain data which can be linked to investment planning of road assets and the management of road infrastructure? This includes asset planning, route planning or network wide planning.

☐ Yes, ☐ No

If yes, please select all the methods and technologies which you are currently using as well as any other innovative technologies you are looking to use. Please specify the data types as well as the purpose and use for each item you select as appropriate.

☐ Asset management systems (software) – Purpose/Use: ………………. (Maximum 50 words)

☐ Lifecycle planning tools – Purpose/Use: ……………….

☐ Whole Life Costing tools – Purpose/Use: ……………….

☐ Route planning tools – Purpose/Use: ……………….

☐ Geographic Information System (GIS) mapping – Purpose/Use: ……………….

☐ Data from third parties or other organisations. Please specify: …………

☐ Other: ………………

Q6: Do you have any system(s) in place for effective situation observation or effective response to natural/man-made disasters or emergencies that can affect the road network and its users? (e.g. earthquakes)

☐ Yes, ☐ No

If yes, please list all the methods, technologies and data types which you are currently using as well as any other innovative technologies you are looking to use including their purpose and use as appropriate. Below is an initial list which might be relevant to your road administration.

☐ Weather sensors – Purpose/Use: ………………. (Maximum 50 words)

☐ Road network usage related software – purpose/Use: …………….

☐ Data from third parties such as weather monitoring organisations. Please specify: …………

☐ Other: ………………

(Maximum 100 words)

Theme 2: Road User (Including Data Collected by Other Stakeholders)

Q7: Do you share any data / information with the users of the road network?

☐ Yes, ☐ No

If yes, for the following two questions, please select the relevant data types, platforms or technologies which you are currently using or looking to use. Please specify the purpose and use of each item you select as appropriate.

What kind of data/information do you share with road users?

☐ Traffic volumes – Purpose/Use: ………… (Maximum 50 words)

☐ Traffic information – Purpose/Use: …………

☐ Accidents information – Purpose/Use: …………

☐ Public awareness – Purpose/Use: …………

☐ Maintenance plans and roadworks – Purpose/Use: …………

☐ Diversion routes – Purpose/Use: …………

☐ Traffic volumes – Purpose/Use: …………

☐ Other: ……………

How do you share that data / information with road users?

☐ Government websites – Use: ……………. (Maximum 50 words)

☐ Social media – Use: ……………

☐ Open data sources – Use: ……………

☐ Other: …………….

Q8: Do you actively seek and collect feedback on the satisfaction of road users in a formal method?

☐ Yes, ☐ No

If yes, for the following two questions, please select the relevant items which apply to your road administration. Please specify the use of each item you select as appropriate.

Which platform do you use to conduct those satisfaction surveys?

☐ Government websites – Use: ………….. (Maximum 50 words)

☐ Dedicated online platform – Use: …………

☐ Social media – Use: …………..

☐ Traditional surveys – Use: ……………

☐ Bespoke / tailored research – Use: ………….

☐ Other: ………………….

How do you utilise the output of those surveys?

☐ Setting Performance Indicators

☐ Informing investment decisions

☐ Informing engineering options (design / construction / operation / maintenance)

☐ Developing annual reports

☐ Other: …………….

Q9: Have you conducted any research or field trials on the benefits or use of Connected and Autonomous Vehicles (CAVs)?

☐ Yes, ☐ No

If yes, please select the relevant items where CAVs can potentially be used to collect or utilise useful data. Please specify the data types as well as the purpose and use for each item you select as appropriate.

☐ CAV data opportunities for road network management – Purpose/Use: …………. (Maximum 50 words)

☐ CAV data opportunities for road network operations – Purpose/Use: ………….

☐ CAV data opportunities for user experience – Purpose/Use: ………….

☐ Other: …………………

Q10: Do exchange/share any road related data with third parties or other national/global stakeholders?

☐ Yes, ☐ No

If yes, please select all data types which you are currently using as well as any other data you are looking to use. Please specify the purpose and use of each item you select as appropriate.

☐ Mobile phone network providers – Purpose/Use: …………. (Maximum 50 words)

☐ Satellite navigation providers – Purpose/Use: ………….

☐ Local road operators (traffic cameras, etc.) – Purpose/Use: ………….

☐ Road sector organisations – Purpose/Use: ………….

☐ Private companies – Purpose/Use: ………….

☐ Insurance companies – Purpose/Use: ………….

☐ Social media – Purpose/Use: ………….

☐ Open data sources – Purpose/Use: …………..

☐ Other: …………………..

Theme 3: Context

Q11: Do you have any methods in place to measure air quality, transport emissions, noise levels or any other environmental aspects related to road infrastructure?

☐ Yes, ☐ No

If yes, please list all the methods, technologies and data types which you are currently using as well as any other innovative technologies you are looking to use including their purpose and use as appropriate. Below is an initial list which might be relevant to your road administration.

☐ Data from sensors or monitoring equipment – Purpose/Use: …………. (Maximum 50 words)

☐ Data from environmental agencies – Purpose/Use: ………….

☐ Data from health agencies – Purpose/Use: ………….

☐ Other: …………….

(Maximum 100 words)

Q12: Do you gather any data on the benefits/impacts of the road network related to social or economic factors? (e.g. health and wellbeing of the public, prosperity of local communities, etc.)

☐ Yes, ☐ No

If yes, please list all the methods, technologies and data types which you are currently using as well as any other innovative technologies you are looking to use including their purpose and use as appropriate. Below is an initial list which might be relevant to your road administration.

☐ Government agencies for Health/Economy – Purpose/Use: …………. (Maximum 50 words)

☐ Commercial organisations – Purpose/Use: ………….

☐ Industrial organisations – Purpose/Use: ………….

☐ Local organisations – Purpose/Use: ………….

☐ Public consultations – Purpose/Use: ………….

☐ Social media – Purpose/Use: ………….

☐ Other: …………………

(Maximum 100 words)

Case Studies and Relevant Projects

Please attach any case studies, project information or research you conducted which are related to any of the questions above or which might be useful to the overall aim of this survey. You can also send the case studies separately by email to miguel.caso-florez@piarc.org and mostafa.massoud@atkinsglobal.com by **Friday 5 June 2020**.

Please include any other information or weblinks you would like to add in, particularly to your collection and use of Big Data and Smart Data.

The results of the survey will be publicly available as part of the final project report on PIARC's website and you will get a notification when that is published. Please provide an email address below to get in touch with you if we required further clarifications on your response and to notify you when the project report is published.

Email address: ……………….

Please forward this survey to any relevant road operators (concessionaires) and research institutes/laboratories linked to your administration.

Thank you for your contribution and time spent responding to this survey.

APPENDIX B – ONLINE SURVEY RESPONDENT ORGANISATIONS

Country	Organisation(s)
Andorra	Govern d'Andorra – Conservació i Explotació de Carreteres (COEX)
Argentina	Gestión Integral de las Rutas Nacionales (Planificar, licitar, construir y mantener la Red Nacional de Carreteras)
Australia	Department of Transport and Main Roads
	Australian Department of Infrastructure
	Transport for NSW
	Department of State Growth
Austria	ASFINAG Bau Management GmbH
	ASFINAG, Highway- and Expressway Operator
	AustriaTech
	Motorway operator
Bangladesh	Roads and Highways Department
Belgium	Agency for Road and Traffic
	Agency for Roads and Traffic, regional road administration
	Bruxelles Mobilité
	Service Public de Wallonie Mobilité et Infrastructures
Benin	Ecole Doctorale des Sciences de l'Ingénieur (ED-SDI)
Bulgaria	Road Infrastructure Agency
Canada	Asset Management Branch, City of Ottawa
	Manitoba Infrastructure
	Ministère des Transports du Québec (MTQ)
	Ministère des transports du Québec, Direction de la géotechnique et de la géologie
	Ministry of Alberta Transportation
Chile	Dirección de Vialidad
	Dirección de Vialidad – Ministerio de Obras Públicas de Chile
	Dirección de Vialidad (Ministerio de Obras Públicas)
China	Gansu Province Highway Traffic Construction Group Co., Ltd
	Zhonglu Gaoke Transportation Technology Group Co., Ltd
Colombia	Instituto Nacional de Vías - INVIAS
Czech Republic	Ministry of Transport
	SATRA, spol. s r.o.
France	Météo-France
Germany	Bavarian State Ministry of Housing, Building and Transport – Bavarian Road Administration
	Federal Highway Research Institute (BASt)
	Freie und Hansestadt Hamburg - Landesbetrieb Straßen, Brücken und Gewässer
Greece	GEFYRA S.A. / GEFYRA LITOYRGIA S.A.
India	World Bank
Iran	Road Maintenance and Transport Organization
Italy	Anas SpA – Italian Agency for Roads
	Politecnico di Milano
Côte d'Ivoire	African Development Bank
Japan	East Nippon Expressway Co., Ltd.
	Honshu-Shikoku Bridge Expressway Co., Ltd.
	Metropolitan Expressway Co., Ltd.
	MLIT/HECL/HIDO

Country	Organisation(s)
	West Nippon Expressway Co., Ltd.
Korea, Rep.	Korea Expressway Corporation
	Korea Road Association(under Ministry of Land, Infrastructure and Transport)
Lithuania	Lithuanian Road Administration under the Ministry of Transport and Coomunications
Malaysia	Malaysian Highway Authority (MHA)
	Public Works Department and Highway Planning Division, Ministry of Works Malaysia
Mexico	Dirección General de Servicios Técnicos
	Secretaría de Comunicaciones y Transportes (SCT) / Instituto Mexicano del Transporte (IMT)
Mozambique	National Administration of Roads
Netherlands	Rijkswaterstaat
New Zealand	New Zealand Transport Agency (Pilot Survey)
Norway	Norwegian Public Roads Administration
Paraguay	Comité Nacional PIARC
Poland	General Directorate for National Roads and Motorways
Portugal	Infraestruturas de Portugal (IP)
	LNEC – National Laboratory for Civil Engineering
Romania	National Company of Road Infrastructure Management (C.N.A.I.R.) - Regional Directorate for Roads and Bridges Iasi (D.R.D.P. Iasi)
Russian Federation	Federal Road Agency
	Russian Highways State Company
Senegal	AGEROUTE Sénégal
Singapore	Land Transport Authority
Slovak Republic	Ministry of Transport and Construction of the Slovak Republic
	University of Zilina
Slovenia	DRI Investment Management Ltd
South Africa	SANRAL
Spain	Dirección General de Tráfico
	IECA
	Ministerio de Movilidad, Transportes y Agenda Urbana
	PRINCIPADO DE ASTURIAS
Sweden	Swedish Transport Administration
Switzerland	Federal Roads Office FEDRO
Thailand	Department of Highways, Ministry of Transport
United Kingdom	Suffolk Highways (and, in the wider context, ADEPT members)
	Transport Scotland
United States	Federal Highway Administration (FHWA)
	Minnesota Department of Transportation
	United States Federal Highway Administration, Office of Bridges and Structures
Zambia	Road Development Agency

APPENDIX C – ONLINE SURVEY RESPONSES SUMMARY TABLES

1. Do you collect and analyse inventory data and condition data for road infrastructure assets?

	Organisations	Countries	HIC	LMIC	Urban	Rural
Smart vehicles with mounted cameras	45	**29**	21	8	20	9
Light Detection and Ranging (LIDAR)	28	**21**	15	6	18	3
Unmanned Aerial Vehicles (UAVs)/Drones	33	**22**	15	7	20	2
Accelerometers or Smartphones	24	**21**	12	9	17	4
Road sensors	44	**31**	22	9	25	6
Machine learning (ML) and Computer Vision (CV)	19	**15**	12	3	15	0
Artificial Intelligence	18	**14**	10	4	11	3
Satellite imagery	28	**22**	14	8	19	3
Multispectral imagery	11	**11**	10	1	11	0
Connected and Autonomous Vehicles (CAVs)	16	**13**	9	4	9	4
Vehicle telematics	7	**7**	7	0	6	1
Asset management system (software)	55	**36**	21	15	25	11
Cloud-based software and storage systems	29	**24**	14	10	19	5
Traditional human surveys	45	**32**	20	12	21	11
Data from third parties or other organisations.	32	**26**	18	8	22	4
Other	15	**14**	10	4	13	1

2. Do you collect and analyse traffic related data?

	Organisations	Countries	HIC	LMIC	Urban	Rural
Fixed road sensors or inductive loops	63	**38**	27	11	32	6
Acoustics and Radar	40	**29**	19	10	25	4
Traffic cameras	63	**37**	26	11	32	5
Laser counters	21	**16**	14	2	14	2
Probe vehicle: GPS or smartphones real-time information	28	**23**	16	7	19	4
GPS Satellites	19	**16**	10	6	15	1
Social media	16	**15**	12	3	13	2
Traditional human surveys	46	**31**	19	12	21	10
Data from third parties or other organisations	35	**26**	18	8	22	4
Other	17	**16**	12	4	12	4

3. Do you collect or use road related data for the management of roadworks and the overall road network?

	Organisations	Countries	HIC	LMIC	Urban	Rural
Intelligent Transport Systems (ITS)	48	**34**	25	9	29	5
Closed-circuit television (CCTV) and video surveillance	47	**32**	22	10	28	4
Geographic Information System (GIS) mapping	53	**37**	22	15	29	8
Dedicated software or online interface	38	**30**	21	9	23	7
Data from third parties or other organisations	25	**21**	15	6	18	3
Other	11	**10**	6	4	6	4

4. Do you collect or use certain data which can be linked to the development or optimisation of programmes of work for routine maintenance as well as for winter maintenance and operations (including identification of priority routes)?

	Organisations	Countries	HIC	LMIC	Urban	Rural
Asset management systems (software)	41	**31**	20	11	23	8
Lifecycle planning tools	21	**19**	13	6	15	4
Route planning tools	20	**16**	12	4	12	4
Geographic Information System (GIS) mapping	38	**27**	17	10	21	6
Data from third parties or other organisations	19	**15**	14	1	13	2
Other	12	**11**	8	3	8	3

5. Do you collect our use certain data which can be linked to investment planning of road assets and the management of road infrastructure? This includes asset planning, route planning or network wide planning.

	Organisations	Countries	HIC	LMIC	Urban	Rural
Asset management systems (software)	46	**30**	19	11	23	7
Lifecycle planning tools	30	**23**	15	8	19	4
Whole Life Costing tools	21	**18**	12	6	14	4
Route planning tools	21	**16**	12	4	12	4
Geographic Information System (GIS) mapping	37	**27**	16	11	20	7
Data from third parties or other organisations	8	**8**	6	2	7	1
Other	6	**6**	5	1	6	0

6. Do you have any system(s) in place for effective situation observation or effective response to natural/man-made disasters or emergencies that can affect the road network and its users? (e.g. earthquakes)

	Organisations	Countries	HIC	LMIC	Urban	Rural
Weather sensors	45	**30**	25	5	25	5
Road network usage related software	24	**18**	12	6	13	5
Data from third parties such as weather monitoring organisations	32	**22**	18	4	18	4
Other	22	**17**	13	4	16	1

7. Do you share any data / information with the users of the road network?

		Organisations	Countries	HIC	LMIC	Urban	Rural
1	Traffic volumes	47	**33**	22	11	26	7
	Traffic information	54	**38**	26	12	29	9
	Accidents information	52	**38**	25	13	29	9
	Public awareness	36	**28**	21	7	24	4
	Maintenance plans and roadworks	51	**34**	22	12	26	8
	Diversion routes	42	**29**	21	8	25	4
	Other	16	**14**	8	6	13	1
2	Government websites	52	**35**	24	11	28	7
	Social media	43	**28**	19	9	24	4
	Open data sources	32	**25**	20	5	21	4
	Other	25	**20**	11	9	16	4

8. Do you actively seek and collect feedback on the satisfaction of road users in a formal method?

		Organisations	Countries	HIC	LMIC	Urban	Rural
1	Government websites	13	**10**	6	4	9	1
	Dedicated online platform	14	**11**	9	2	10	1
	Social media	17	**13**	9	4	11	2
	Traditional surveys	28	**21**	15	6	17	4
	Bespoke / tailored research	12	**10**	9	1	9	1
	Other	6	**5**	5	0	4	1
2	Setting Performance Indicators	24	**14**	11	3	13	1
	Informing investment decisions	15	**15**	10	5	11	4
	Informing engineering options (design / construction / operation / maintenance)	17	**14**	10	4	12	2
	Developing annual reports	23	**18**	14	4	16	2
	Other	9	**7**	6	1	7	0

9. Have you conducted any research or field trials on the benefits or use of Connected and Autonomous Vehicles (CAVs)?

	Organisations	Countries	HIC	LMIC	Urban	Rural
CAV data opportunities for road network management	15	**11**	10	1	10	1
CAV data opportunities for road network operations	17	**12**	12	0	11	1
CAV data opportunities for user experience	9	**6**	6	0	5	1
Other	8	**7**	7	0	6	1

10. Do exchange/share any road related data with third parties or other national/global stakeholders?

	Organisations	Countries	HIC	LMIC	Urban	Rural
Mobile phone network providers	11	**10**	6	4	9	1
Satellite navigation providers	14	**12**	10	2	10	2
Local road operators (traffic cameras, etc.)	30	**25**	18	7	20	5
Road sector organisations	35	**27**	15	12	19	8
Private companies	22	**21**	13	8	14	7
Insurance companies	11	**10**	8	2	10	0
Social media	14	**11**	8	3	9	2
Open data sources	24	**19**	16	3	16	3
Other	19	**16**	11	5	13	3

11. Do you have any methods in place to measure air quality, transport emissions, noise levels or any other environmental aspects related to road infrastructure?

	Organisations	Countries	HIC	LMIC	Urban	Rural
Data from sensors or monitoring equipment	42	**25**	18	7	22	3
Data from environmental agencies	19	**15**	10	5	15	0
Data from health agencies	6	**6**	6	0	5	1
Other	19	**17**	12	5	14	3

12. Do you gather any data on the benefits/impacts on the road network related to social or economic factors? (e.g. health and wellbeing of the public, prosperity of local communities, etc.)

	Organisations	Countries	HIC	LMIC	Urban	Rural
Government agencies for Health/Economy	16	**13**	10	3	12	1
Commercial organisations	7	**6**	4	2	6	0
Industrial organisations	8	**6**	5	1	6	0
Local organisations	9	**6**	4	2	5	1
Public consultations	11	**9**	6	3	6	3
Social media	3	**3**	3	0	3	0
Other	12	**11**	8	3	9	2

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