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INNOVATIVE APPROACHES TO ASSET MANAGEMENT

TECHNICAL COMMITTEE D.1 *ASSET MANAGEMENT*

WORLD ROAD ASSOCIATION
MONDIALE DE LA ROUTE
AIPCR PIARC

STATEMENTS

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

The study that is the subject of this report was defined in the PIARC Strategic Plan 2016– 2019and 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 don't necessarily reflect the views of their parent organizations or agencies.

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EXECUTIVE SUMMARY

2019R19EN

INNOVATIVE APPROACHES TO ASSET MANAGEMENT

“Asset Management” as defined in ISO standards 55000ff, aims to enable an organization to obtain value from assets. They offer a structured approach to asset management by focusing on implementation of “risk-based, information-driven, planning and decision-making processes and activities that transform organizational objectives into asset management plans”. In the context of road infrastructure, the organizational objectives are closely aligned with asset management objectives, which are to ensure optimum service to road users. Following the need to establish “risk-based, information driven, planning and decision-making processes” the work of the Technical Committee (TC) D1 “Asset Management” focused on innovative methods and techniques that allow managers to obtain high-quality information and on innovative approaches that use this information in risk-based decision-making.

Every decision-making approach is based on the model of reality, which is stored in a database in most organizations. The level of sophistication and versatility of this model, i.e. a “digital twin of road infrastructure”, depends on one side on the organizational requirements and on the other side on the technical, organizational and financial capabilities to collect, record and process the necessary data. The level of versatility ranges from a simple list of inventory to a 3D semantically rich geometric representation e.g. Building Information Modelling (BIM). In this report, two chapters address the methods used to collect data necessary to create the “digital twin of road infrastructure” following the usual paradigm to distinguish between the inventory and condition (including risk) data.

The existence of the “digital twin of road infrastructure” that includes all types of damage, observed or monitored symptoms of deterioration processes, traffic data, data on natural hazards and deficiencies related to performance goals or regulatory requirements allow for robust decision making on maintenance and improvement interventions. Current practice in most countries distinguishes between decision process for maintenance, which is mostly condition-based, and improvement that is mostly risk-based or driven by the regulations that are based on risk considerations, but the distinctions are inconsistent and arbitrary. Therefore, the innovative approaches to decision making are described in two separate chapters, one for maintenance and the other one for improvement. However, the trend toward unified decision process for maintenance and improvement is clearly outlined in both chapters.

Deterioration modelling is an essential component of asset management as it enables forecasting the deterioration and performance of road infrastructure - or rather its “digital twin” - over time. While academic research is actively seeking to improve modelling, the impact of recent initiatives has been moderate but expected to grow significantly as new technology is developed and applied. The chapter on maintenance includes a review of deterioration models and some relevant innovations are described.

Asset Management also includes the communication of current performance goals, condition of infrastructure, intervention planning, financial needs, etc. to owners, authorities and general public. This topic is addressed in a separate chapter. The digital revolution has opened new opportunities to access and use road infrastructure and service data. Providing easy access to information is in the best interest of road organizations as it helps both authorities and the general public to understand and appreciate the importance of readily available road infrastructure to society.

This report does not focus on the organisational aspects despite their importance. The possible organizational forms such as public-private partnerships, which include several interfaces in business processes, are not analysed in this report. However, in discussion some organizational aspects surfaced, and these are documented in the penultimate chapter.

In summary, it seems that the release of ISO55000ff has triggered the transformation of asset management processes, which together with the digital revolution have generated numerous innovations. This process of change now has significant momentum. It is already foreseeable that the innovations in future will be characterized by the integration of BIM with existing Asset Management Systems.

CONTENTS

1. INTRODUCTION

1.1. Importance of the Road Infrastructure

“Roads are essential foundations of our society and economy”, “roads are an indispensable prerequisite for economic prosperity” or similar expressions are commonplace in many publications on road or transportation infrastructure. Indeed, there is broad, seemingly unanimous consensus that the importance of road infrastructure for society cannot be overestimated. This importance is often quantified by the enormous investments that were necessary to build a road infrastructure. It should be noted that investment in road infrastructure, as any investment, merely raises the growth potential of a national economy. It is through the efficient utilization of the road infrastructure that this potential is realized.

The effect of road infrastructure or more generally of transportation infrastructure on economic prosperity was already recognized in the 18th century by Adam Smith [1]. He correctly identifies the division of labour or specialisation as a key productivity driver and therefore essential for economic prosperity. In [1] one reads:

> *“The greatest improvements in the productive powers of labour, and the greater part of the skill, dexterity, and judgment, with which it is anywhere directed, or applied, seem to have been the effects of the division of labour”* and further *“Men are much more likely to discover easier and readier methods of attaining any object, when the whole attention of their minds is directed towards that single object, than when it is dissipated among a great variety of things.”*

It is evident that the division of labour leads to production beyond the needs of the producer and the surplus achieved needs to be traded for other products. Adam Smith states that:

> *“it is the power of exchanging that gives occasion to the division of labour, so the extent of this division must always be limited by the extent of that power, or, in other words, by the extent of the market.”*

He further explains that:

> *“when the market is very small, no person can have any encouragement to dedicate himself entirely to one employment, for want of the power to exchange all that surplus part of the produce of his own labour, which is over and above his own consumption, for such parts of the produce of other men's labour as he has occasion for.”*

It was obvious to Adam Smith that the extent of the market is governed by the ability to transport products. Characterized by the epoch he lived in, he sees in water transport a vehicle to increase the extent of the market:

> *“As by means of water-carriage, a more extensive market is opened to every sort of industry than what land-carriage alone can afford it, so it is upon the sea-coast, and along the banks of navigable rivers, that industry of every kind naturally begins to subdivide and improve itself, and it is frequently not till a long time after that those improvements extend themselves to the inland parts of the country.”*

In book V of [1], Adam Smith advocates that public institutions have a duty to facilitate commerce in addition to the defence of the society, the administration of justice and the education. To this end the *“erection and maintenance of the public works which facilitate the commerce of any country, such as good roads, bridges, navigable canals, harbours, etc.” is necessary.* He also realizes the relationship between the "increase in annual produce" and "expenses of making and maintaining public roads".

Efficient utilization of transportation infrastructure allows for increase of market extension and enhances division of labour. Affordable transportation of goods allows the concentration of production facilities and therefore higher productivity. It also increases the demand for niche products that require further specialization and in consequence increase productivity. These effects unfold slowly as the economy adapts to enhanced transportation capabilities. However, increased productivity is enabled and fostered by many factors such as technological innovation, education and political stability in addition to the effects of readily available transportation infrastructure. It is therefore that the long-term benefit of transportation infrastructure – like the benefit of education and political stability - cannot be accurately evaluated.

The lower limit of annual macroeconomic benefit of road traffic can be estimated by the contribution of road traffic to the Gross Domestic Product (GDP). It lies between 4% [2] and 10% [3] and [4], of Gross Domestic Product (GDP). The inconsistency in the contribution of road transportation to GDP stems from the differences in financing and accounting practices in different countries, as discussed in [5] . Apart from purely economic benefit, road infrastructure enables road users to be involved in various activities that yield other private, public, and social benefits [6] and [7]. In addition to these beneficial externalities, the road traffic and indirectly the road infrastructure also have negative health, societal and environmental impact (e. g. accidents, noise, pollution), which is mostly difficult to ponder against the benefits. Nevertheless, the detrimental externalities – although very important – don't significantly diminish the overall benefit of mobility and, therefore, of road infrastructure to the society. The objective of asset management is to maintain and enhance this benefit.

1.2. CONTENTS OF THE REPORT

Road organizations throughout the world explore different ways to maintain and enhance the benefit of the transportation infrastructure or – to use a more familiar term for asset managers – to increase the performance of road infrastructure. PIARC Technical Committee D.1 organized a survey to explore the current agency approaches and to identify those that are regarded as innovative. Some of these are sophisticated and some of them are simple. Responses were submitted by 64 road organizations (37 countries). The related answers were a basis to select 21 face-to-face interviews (15 countries), in which some of the approaches and techniques are discussed in detail. In addition to the information obtained by survey and interviews, relevant information from other sources such as technical papers, reports and books has also been compiled in this report.

Based on the available information sources, it appears that efforts to enhance asset management target different levels of its activities:

- The conceptual level i.e. specification, overarching goals and related indicators
- The technological level i.e. tools and techniques to measure and improve performance of road infrastructure
- The organizational level i.e. distribution of responsibilities between road authorities, private operators, concessionaires, contractors, etc. and specification of business processes within the road organizations

Innovation occurs on all three levels and they are all addressed in this report. The focus is primarily on the second then first and then third level. The report covers all steps of asset management i.e. the decision-making process.

The basis for asset management decision making is the asset information. Asset management information comprises the quasi-permanent data related to location, type, composition, etc. of assets and the transient data related to observations (visual or measured) that are relevant to the performance of assets, asset operations, maintenance or improvement activities. The core information is commonly referred to as inventory. In **chapter 2** the innovative approaches to collect and store the inventory information are presented. The trend from storing purely alphanumeric representation of inventory toward more geographical and 3-dimensional representation of infrastructure is outlined. In particular, the importance of Building Information Modelling (BIM) for asset management is addressed. In **chapter 3** asset management in road organizations is put in context of international standard ISO 55000 on Asset Management. The objectives of asset management are investigated and conceptional approaches are discussed. All conceptional approaches reflect the pivotal importance of asset condition information. In **chapter 4** methods and techniques to diagnose as-is condition of asset are presented. The quality of this data determines the accuracy of condition forecasts that are pivotal to trigger right intervention at the right time. In chapter 4, forecast modelling is also addressed. The interventions that target part or fully restoration to the as-new condition are treated in **chapter 5**. These are commonly referred to as maintenance interventions and the decision processes that lead to them. Distinct from maintenance interventions the goal of improvement intervention is to meet new requirements regarding traffic demand, environmental protection and natural hazards. Planning of these interventions is the topic of the **chapter 6**. In **chapter 7** innovative approaches on communication practices and service level reporting between road agencies and stakeholders are reviewed. In **chapter 8** some general principles regarding the organization of asset management within the agencies are outlined.

Originally, in the light of the increased privatization of road infrastructure a chapter on insurance was planned. The idea was to address liability insurance, and also insurance against natural hazards, which is quite common in building sector. However, we were not able to obtain any sufficient relevant information on current insurance practices. It seems also that private organizations either don’t have any insurance contracts or are not willing to share the information about them. For this reason, the original idea to include a chapter on insurance was abandoned.

1.3. THE SURVEY

The core of the work was the structuring and dissemination of the survey and analysing the responses. The interactive on-line survey was structured in a free “Jot Form” platform, and is included in the appendix. The survey consists of 10 parts and there are total of 76 questions:

- General information (15 questions, G1-G14)
- Inventory data, (7 questions, fields I1-I5)
- Traffic data, (4 questions, fields T1- T1.4)
- Accident data, (3 questions, fields A1- A1.3)
- Condition data, (16 questions, fields C1- C5)
- Hazard data, (6 questions, fields H1- H1.5)
- Additional data, (3 questions, fields Ad1- Ad2.1)

- Routine maintenance, (3 questions, fields R1- R2)
- Repair & Rehabilitation, (15 questions, fields RR1- RR7)
- Additional information, (4 questions, fields Ai1- Ai4)

The questions were free-text, multiple choice and single choice. All questions, with the exception of those with free text, were mandatory (at least one answer for multiple choice questions) but there was the option to respond "not applicable" i.e. N/A. By choosing the latter option in some questions, the respondents were able to skip the entire part/group of related questions (e.g. if an agency does not collect/use hazard data, then this topic was not further elaborated). Also, if an option within a question was checked true, there were additional questions asked to investigate the related topic in more detail. For example, this was the case in the part on Inventory data (question I1.1), where agencies which indicated that they use BIM were asked to give more details and in the part on Repair and Rehabilitation (question RR2) for the agencies which indicated that they apply performance indicators in their decision making. Also, in the part Repair & Rehabilitation, the question RR1 was on the general type of decision making. This was a single choice question to distinguish which agencies are already on the level of risk-based decision making. Those respondents who answered that their decisions on maintenance actions were condition-based were subsequently asked on the prioritization procedure (question RR1.1). However, for the latter, they were not asked to elaborate on risk/vulnerability assessment if any applied in prioritization.

The TC members contacted road agencies in both public and private sectors and obtained 64 responses in total from 37 countries, mostly from Europe (Figure 1.1). The survey was available for dissemination in English (53 responses), Spanish (7 responses), French (2 responses) and Portuguese (2 responses). Unfortunately, some efforts were not successful as a dozen agencies did not respond to multiple reminders or failed to provide requested information within a year.

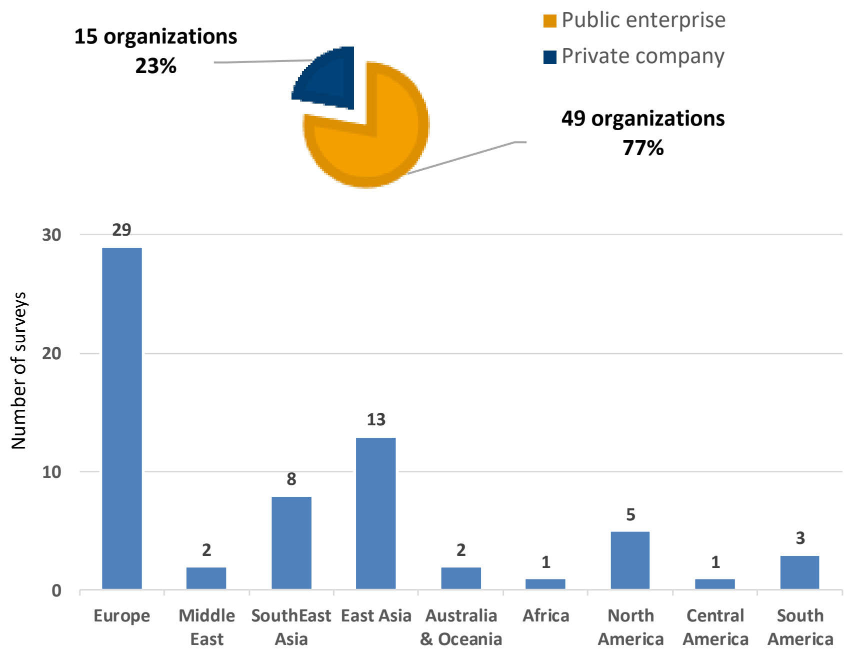


Figure 1.1 The survey coverage by type of organization (upper chart) and by region/continent (lower chart).

The answers to the questions related to number of employees in departments, type of surface on roads in a network and asset numbers were not statistically reviewed in the report, but are available per respondent in the appendix.

Due to the diversity of survey questions, it was expected that the responses would be required from several persons within an agency. However, a lack of details in some free text questions suggest that this was not always the case. Also, it must be noted that a few agencies (East Nippon Expressway Company in Japan, Highway Management (City) in the UK, Rijkswaterstaat in Netherlands and New Zealand Transport Agency) filled in an off-line survey i.e. a list of questions were provided to them in Word format. These respondents were advised to look for the hints and explanations given in the on-line version. All provided answers have been accounted for in the survey analysis, with an exception of the information provided by New Zealand Transport Agency (NZTA) in Word format, which was too detailed, and therefore, this entry was regarded as an interview.

1.4. The Interview

The interview was a follow-up on the survey for the agencies that have provided the most detailed responses. Also, it was an opportunity to establish a contact with the agencies which were not considered in the survey dissemination or did not respond to the survey. The interview was structured as a list of 56 free text questions in English and divided in 8 parts (see appendix):

- Data on Inventory, (9 questions)
- Traffic data, (3 questions)
- Accident data, (5 questions)
- Condition data, (9 questions)
- Hazard data, (4 questions)
- Routine maintenance, (2 questions)
- Major maintenance, (14 questions)
- ISO 55000, Performance, Quality (10 questions)

The total of 21 interviews from 15 countries were conducted in person or remotely by TC members (Figure 1.2). Among these agencies, 15 were those that have had already responded to the survey. Similarly as in the survey, it was desirable that several people from an agency take part in the interview for the sake of completeness and obtaining detailed answers. The respondents were encouraged to provide also relevant figures, tables and snapshots of their asset management systems, to be used later as examples within this report. However, interviews show a variety in the quality of provided information. Also, in some cases, the detailed information on topics is lacking (e.g. responses from China) or it is not complete (e.g. South Korea).

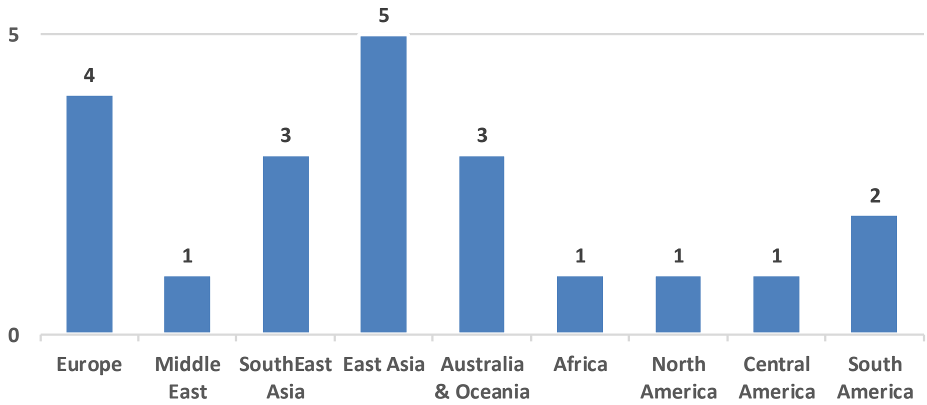


Figure 1.2 The interview coverage by region/continent.

2. INVENTORY

2.1. Introduction

The Asset Management information is a comprehensive inventory database of all essential components of a road network. The structure, the quality and the completeness of the data must be related to the requirements of Asset Management and any other process or system also dependent on the information, e.g. traffic regulatory activity. The main objectives for a road operator are usually to ensure asset availability, safety (operational and structural safety) and economic efficiency (short and long-term) in an adequate balance. Therefore, an Asset Management inventory database system should facilitate the following tasks:

- management of key data of structures and pavement,
- inspection activity,
- assessment of the condition,
    - road
    - structures
    - roadside facilities (signs, road markings, retaining systems, ITS facilities, etc.)
    - electromechanical equipment
- monitoring of structures,
- prioritisation of treatments for structures and sections,
- definition of treatments for refurbishment, improvement or replacement,
- prognosis of condition development,
- calculation of budget scenarios, and
- determination of key performance indicators (KPIs).

For asset management, operating a database system with high-quality data is crucial task. It is critical that the data model structure has an effective relationship between all data types. This is becoming especially important to accommodate new technologies such as high-resolution photos, videos, 3D models, etc. and to relate customer service or performance to infrastructure. If the data are not properly structured, it is more difficult to assess cause and effect relationships and determine the impact of interventions against expectations. This hamper asset managers work and reduces the reliability of decisions. Thus, asset management information systems are established to ensure that inventory data is:

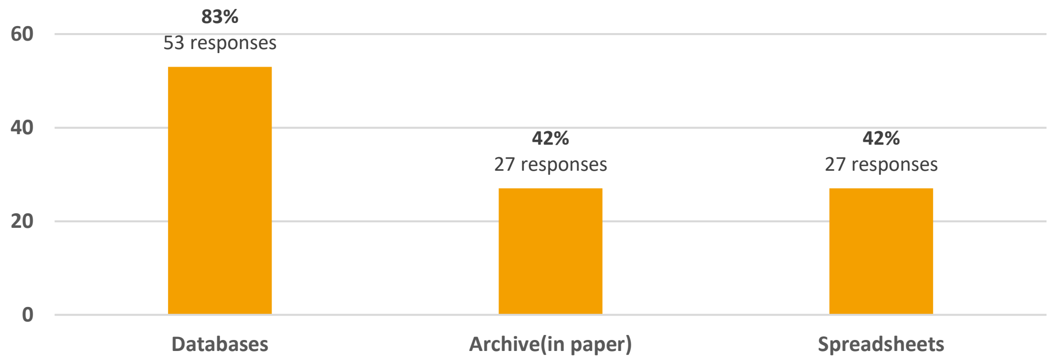
- single sourced,
- easily accessible to a user (e.g. throughout various platforms and devices),
- consumable for internal and external use (the right aggregation/visualisation of data), and
- efficient i.e. once it is stored, it can be used multiple times.

The existence of such an information system provides credibility to a road agency, makes data transparent and increases their accountability.

2.2. Inventory data systems

2.2.1. Data types, their storage and structure

According to the responses in the survey, storing inventory data in databases is a common approach (Figure 2.1). Regarding some asset classes, spreadsheets are also used by a few agencies as well as paper archives. Drawings and reports related to structures exist in paper, digital or semi digital form (i.e. scanned). With regard to reporting capabilities, the agencies mostly use in conjunction photos, drawings, spreadsheets, graphs and geographic information system (GIS) data. GIS is not used in some inventories, while a few agencies indicated to use only alphanumeric/spreadsheet formats (Figure 2.1). Additionally, a few agencies reported that they store above all, sophisticated data formats such as LIDAR data and 360-view videos and photos, which is discussed further in chapter 4.



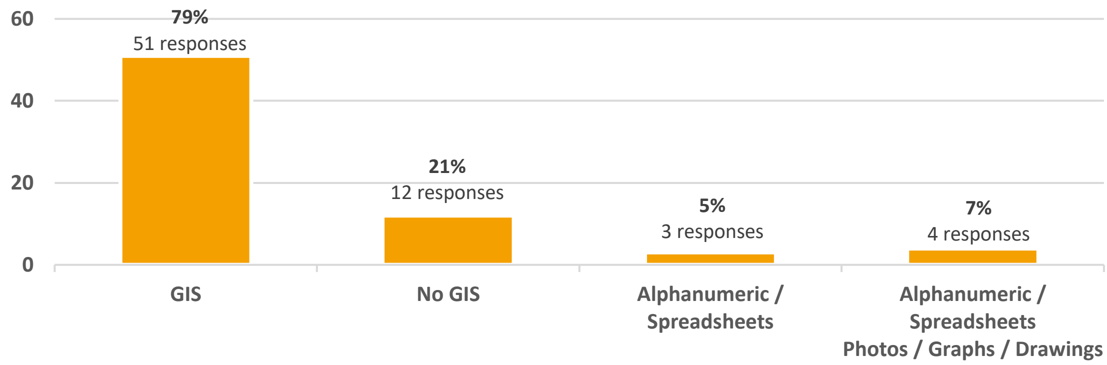


Figure 2.1. Frequency of reported types of data storing (upper chart) & frequency of prevailing reporting capabilities in practice (lower chart); survey questions I1. & I3. - 64 responses.

According to survey information, the following data (here grouped by an asset class) are usually collected and stored in inventory databases:

- Linear assets
    - pavement, drainage systems, road markings, road restraint systems, noise barriers
- Punctiform assets:
    - Bridges, gantries and signboards, retaining walls, anchored structures, culverts, protective structures (natural hazards),
- Punctiform assets with linear asset information data:
    - Tunnels, galleries and long retaining walls

Linear assets are an asset class whose characteristics may be defined related to a section of a road. Between a defined start and endpoint, the characteristics are the same. The properties of punctiform assets have to be declared by an object orientated data structure, which reflects the type of structure and its sub parts. Punctiform structures may also have length, height and width, but these values are only attributes in the data structure. Punctiform assets with linear asset information data are a mixture of two previously mentioned classes. The related data structure is object orientated, but for some sub-parts of structure, characteristics are stored as a linear link. In general, the electro-mechanical and safety equipment can be both regarded as a linear asset and a punctiform asset.

Handling of paper documents is still important for many road operators (Figure 2.2). In general, a lot of inventory data may exist in paper only and scanning of paper documents is considered only if it facilitates the work of engineers i.e. if this scanned data can be used multiple times and for various purposes. Alternatively, electronic archive systems may support the handling of paper documents. This archive system works like a database for libraries. It provides the status of availability of documents and the location of storage. This system may also provide an interlink between digital inventory database and paper documents. Electronic documents as CAD drawings, reports and other technical documents maybe stored in a document management system instead of storing on a file server. The benefit of this approach is, that this document can be interlinked with the inventory database and a GIS system.

Figure 2.2 Paperwork archive with RFID, tags and electronic archive database; ASFINAG, Austria.

An object-oriented data structure is commonly applied for an asset management information system (e.g. Figure 2.3). The main characteristic of this structure is the definition of a unique ID to which every data of an asset is linked. The assigned data must be grouped according to its structure. For example, if one wants to store key data of parts of an asset which may repeat in different number for each different asset, an additional table for this data is to be created. This new table has a 1:n relationship to the original table. Another example is the inspection data. The inspection events repeat periodically, therefore its data should be stored in a 1:n linked sub-table, where every inspection event is one dataset. In general, the creation rules for relational databases apply.

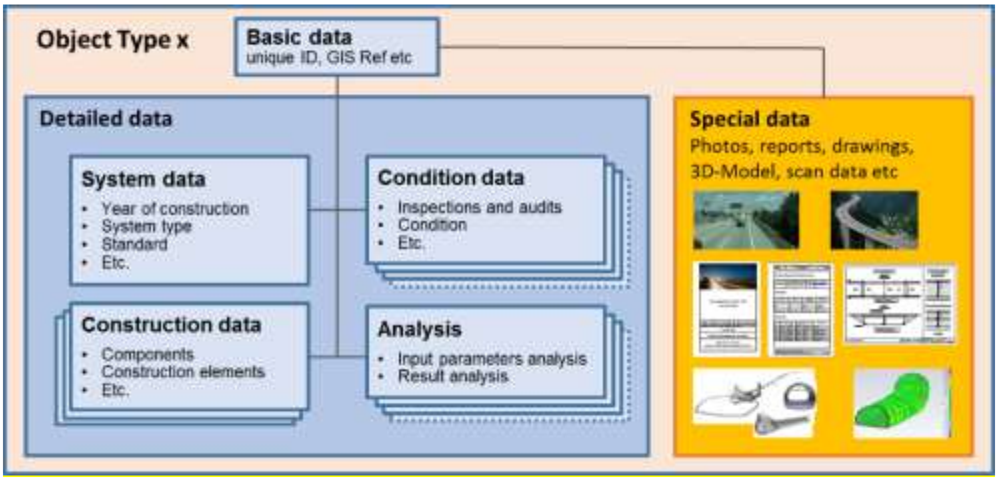


Figure 2.3 An example of a generic data model for engineering objects; ASFINAG, Austria.

The location of linear assets such as pavements can be managed using a location referencing system such as ”Datex II” (a data exchange standard developed by European Committee for Standardization), with the individual pavement segments being referenced as uniquely identified objects. All linear assets are geo-located related to their position on the network map. There are many ways of doing this, for example, one can define equidistant sections and store aggregated characteristics and condition data for them, or define sections with various length but constant characteristics. Alternatively, raw data can maintain as built and the conceptual pavement model is created for management purposes. The location reference is always the position on the network map, which provides the location link to all other infrastructure whether these are linear data such as drainage or punctiform structures.

2.2.1.1. Electromechanical & safety equipment and use of Intelligent Transport Systems (ITS)

The utilization of roads is highly dependent on reliable and judiciously positioned electromechanical and safety equipment. These provide not only basic information (e.g. navigation and regulatory information such as speed limits) on roads, but can also warn and protect users from threats (e.g. hazards, accidents). Additionally, some equipment is used to measure and gather data on traffic and weather, and in combination with Intelligent Transport Systems (ITS), can give crucial information to road users on road availability in real time and also aid asset managers’ decision making for short term and long-term interventions.

In the survey, 42 out of 64 agencies (66%) have shared information on their road equipment inventory (question G13.). The most common for all respondents is a stock of informative, regulatory and warning road traffic signs/gantries. Also reported in inventories are video equipment, traffic lights, light poles/masts, various signalling/sensor devices, emergency telephones and tunnel equipment as well as the feeder pillars which enable necessary electricity supply. Regarding safety equipment, various barriers/wires/ramps, anti-climb fences, road studs and guardrails are mentioned. For hazard protection, a few agencies reported on fire detection systems, weather stations, water pumps and related installations (pipes, drainages, etc.).

Several agencies have also shared detailed information on the Intelligent Transport Systems (ITS) applied in their networks (question G14). These are mostly related to the tolling system, traffic surveillance, vehicle counting stations and devices for accident/hazard warning, etc. In order to store and work with these data, agencies use various types of open and proprietary communication protocols and some additionally report that their ITS systems are externally managed. Some examples of the reported equipment and ITS systems are given in the following paragraphs.

The agencies DARS in Slovenia and ASFINAG in Austria report on the use of safety system in tunnels including a thermal scanner for heavy vehicles in front of a tunnel. They also use weigh in motion systems, cathodic corrosion protection for bridges, sensors to measure salt concentration and temperature and a black ice warning system. Besides height control and speed, these agencies indicate that they can detect vehicles going the wrong way. The latter mentioned practices and equipment are also indicated to be applied by Strassen.NRW in Germany, which additionally reports using load scanners for heavy vehicles in front of some bridges and video control of traffic on special roads and tunnels. The above-mentioned also apply for Swiss Federal Roads Office (FEDRO).

In Chile, the Ministerio de Obras Públicas (Ministry of public works) reports that there are currently automatic counting stations for moving vehicles at approximately 140 locations on their road network. The equipment collects information on the type and weight of each vehicle 24 hours a day, 365 days a year.

In South Australia, the Department of Planning, Transport and Infrastructure (DPTI) reports on the use of various enforcement systems such as safety cameras and red light/speed cameras. Besides CCTV for visual traffic monitoring, automated incident detection is also possible. Here, various communication protocols are reported: traffic signals communicate via “SCATS” which is a proprietary protocol developed by Road & Marine Services, New South Wales Transport Authority, and the majority of the ITS equipment communicates via STREAMS, the proprietary protocol developed by Queensland Government in Australia.

In Canada, the Government of Alberta transportation department reports that ITS data on their network comprise: highway image data, pavement sensor readings, air sensor readings, GPS locations of snowploughs and associated plough sensor data. The road weather information system consists of 112 stations and 660 snowploughs are equipped with automated vehicle location systems. The ITS is managed from a Regional Traffic Management Centre (RTMC) in Calgary. It was also reported that there are Bluetooth detectors in place on some parts of highway network to measure travel times.

Further information on the condition of equipment and frequency of related data collection, are given in sections 4.3 and 4.4, respectively.

2.2.2. Data manipulation and visualisation

In the past, engineers had to access several separate databases and merge the data they needed manually. Because inventories are often large and complex this was usually inefficient, more or less time consuming and error-prone. Nowadays, most road operators are using GIS for viewing interlinked data of their road network. In some cases, GIS is used in combination with tailored tools, which may also integrate other types of data such as video, photos, etc. GIS can represent every data for which geographical coordinates can be defined. In the survey, most respondents indicated that they use linear referencing or 2D terrestrial coordinates for location of their assets (Figure 2.4).

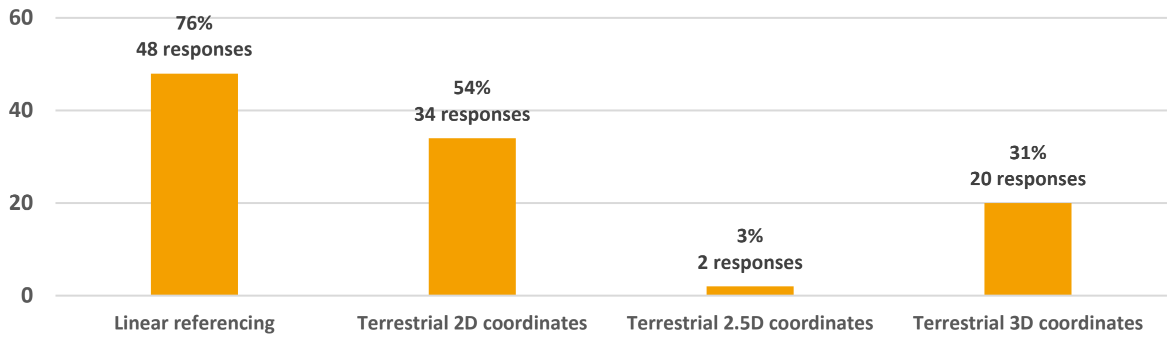


Figure 2.4 Frequency of reported location data referencing; survey question I1.4 - 63 responses.

Viewing assets and related road networks on a map supports the common way of working. For interlinking of data, an object-oriented data structure "behind" the user interface is necessary. For assets like bridges, tunnels, retaining walls and noise barriers one can use unique IDs in the database. These unique IDs can be used as an interlink between different software systems. As an example, a screenshot of the GIS system used in Austria is given in Figure 2.5 .The bridge which is viewed on the GIS map has an interlink to the bridge management system and to the document management system (DOXIS in Austria). With a simple click, the user can easily access these systems. This interlinking of data is also preparation for a modern "one stop shop" user interface. The big challenge for many road administrations is that several databases are currently running in parallel. The aim is to avoid duplication of data and unnecessary interlinking of the data.

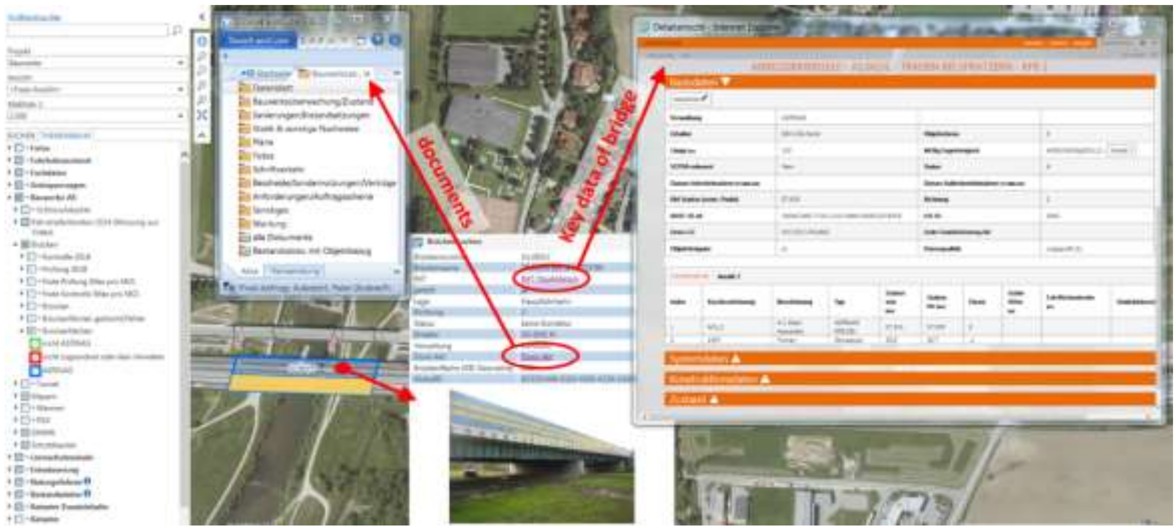


Figure 2.5 An example of a GIS system interlinked with a document management system and bridge management system; ASFINAG, Austria.

An example for a modern user interface is RIMS (road infrastructure management system) which is used by East-NEXCO, Japan (Figure 2.6). RIMS uses a shared memory application programming interface which provides interlinked data. For the graphical user interface, they are using a strip-map approach. It is possible to customize the workspace according to one's own requirements. In Figure 2.6, an example of how you can access bridge information is presented. After selecting the road or a part of a road you can select a section between two intersections. The second route band shows the selected section. In the windows below the route bands you can select a bridge which is situated in this section. Then the key data, available drawings and other documents and photos can be selected for further viewing.

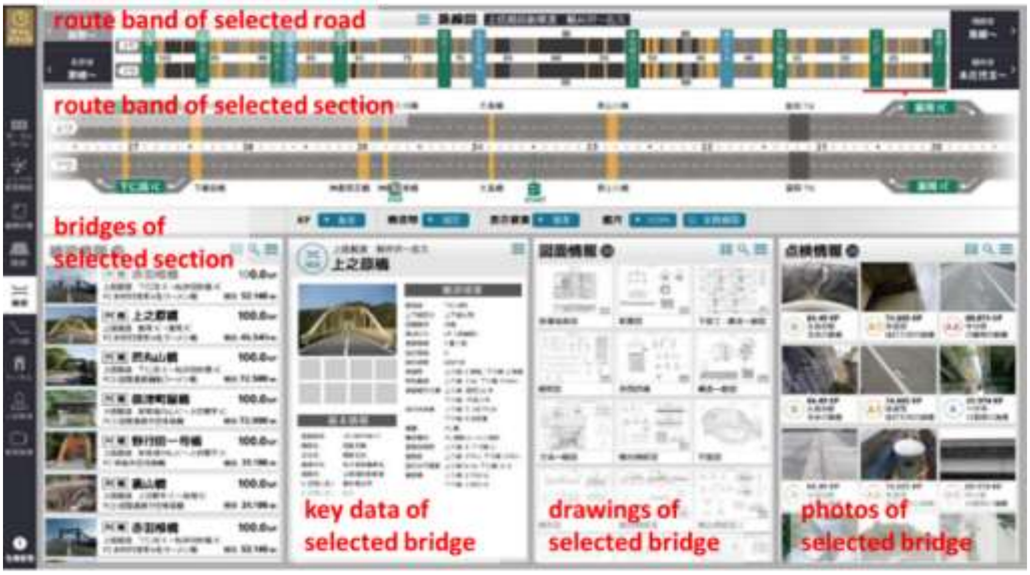


Figure 2.6 RIMS - a road infrastructure management system; NEXCO East, Japan.

This system is flexible and can be customized by the user to the need of actual work. By using large high-resolution touch capable screens, you can easily configure your desktop. By drag and drop you can select the relevant information of interest for a technical discussion in an engineering team (Figure 2.7). By turning the screen to a horizontal position, you can create a kind of discussion table, which may facilitate your technical meeting in a modern and innovative way.

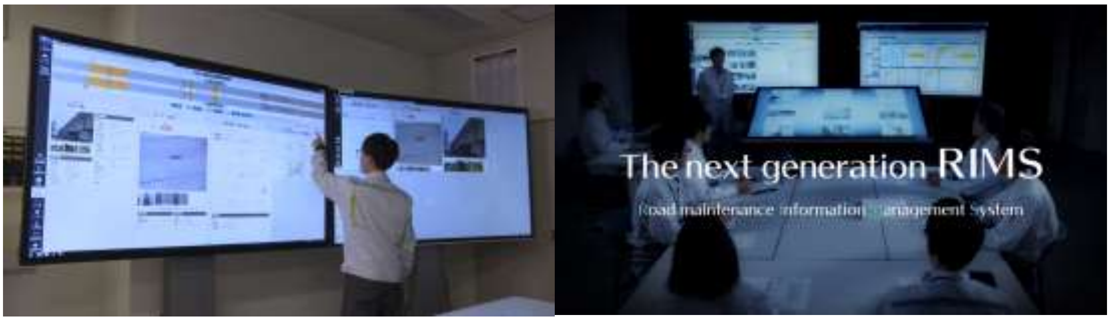


Figure 2.7 Working with RIMS; NEXCO-East, Japan.

In parallel to rapid advances in technology, Business Intelligence (BI) systems have been developed to accommodate decision making. The BI systems in asset management are essentially used as efficient tools to visualize alphanumeric data interactively. The benefit of using BI systems is that they can handle multiple data sources, interlink the related data, and one can easily design specialized analysis sheets where automatic data filtering throughout the graphs/tables is possible (Figure 2.8). These and similar tools can be very useful for preparation of reports for planning and for communication with the general public.

Figure 2.8 An example of a BI analysis sheet; ASFINAG, Austria.

Connecting and using data sources that don't share the same semantics is a challenging problem that need to be solved since some data sources are owned by other agencies or even private companies. There is significant research effort toward tools that allow semantic data transformation [8]. In the near future these tools will allow data fusion and provide useful information.

2.3. DATA ACQUISITION

In order to accommodate novel inspection techniques and associated data, asset inventories are being upgraded and improved. Although deemed expensive, data acquisition from video surveys and/or LIDAR technology using drones and autonomous vehicles, can be a one-time expenditure that provides many benefits to asset management. Here, one of the main improvements to asset inventories are novel methods to communicate and update the data straight from employees and equipment on site to central asset databases (e.g. using smartphones and tablets).

The most relevant innovative approaches related to the aforementioned topics, which are currently being used/developed, and those reported in the survey (question I1.5) and interviews are reviewed in the following sections.

2.3.1. Video/photo and other specific data in inventories

Simultaneously with data acquisition of pavement condition, videos are captured with stereo cameras or multiple cameras mounted on an inspection vehicle (Figure 2.9). The data is used as general information for engineers and as a basis to create 3D models.

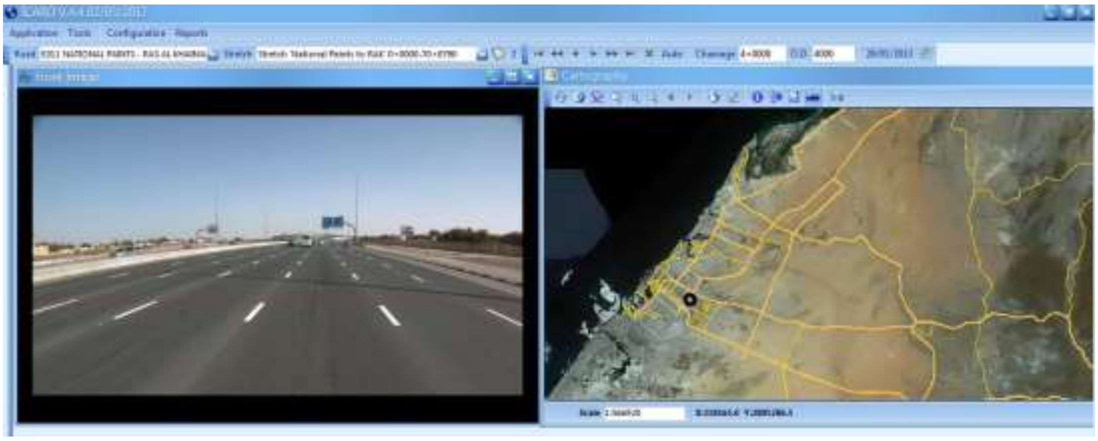


Figure 2.9 A video view of road and a map with geospatial data; the interview with Ministry of Infrastructure Development, UAE.

Transport Scotland reports that it has undertaken a large-scale refresh of the network inventory using a video survey, in which location and specific attributes about assets were collected.

Video data from CCTVs, which are strategically installed along routes, can be specifically useful to gather relevant traffic information. This type of data, for cases of traffic accidents, is reported to be stored within the inventory of the Expressway Cooperation (KEC) in South Korea.

There are systems in use or currently being developed by agencies, based on diverse software platforms, which can combine the information collected directly by employees on the road (video, photos) with modern GIS systems, providing better data visualisation and facilitating inspection.

In Malaysia, a road management company Belati Wangsa (M) Sdn Bhd is developing a system (BeAIMS) for managing inventory capable of collecting data in 3D coordinates with photos (using 360 degrees camera and GPS). In South Australia, DPTI has developed a suite of GIS (based on ESRI platform) and database applications that support asset management. Here, web mapping and videography products are utilized to provide an interactive way to overview and inspect the road asset data. The Government of Alberta province in Canada is developing their own web–based knowledge system to collect, store and analyse data. Within this Transportation Infrastructure Management System (TIMS), various data are collected on: collisions, appurtenances, geometry of pavement/highways, condition, traffic by GPS location and also there are video logs.

2.3.1.1. Use of drones

PIARC has conducted a study [9] to evaluate the actual status of the use of unmanned aerial systems (UAS) to remotely collect data for road infrastructure. It was concluded that many transportation agencies all over the world use UASs, also known as drones, to facilitate:

- data collection (all road assets),
- design and construction of road infrastructure,
- bridge inspection,
- monitoring of roads for avalanche and mudslide dangers,
- identifying flood damage risks in urban areas,
- reconstructing crash scenes, and
- monitoring traffic and road conditions.

The study indicates that the largest benefits of using drones are their low cost, efficiency, quick turnaround and accessibility.

For inventory data, 3D models of assets can be created by photos/videos made using drones. This is not limited to infrastructure itself, but also to adjacent terrains which can be of interest in future planning, hazard analysis, etc. Figure 2.10 shows an example of a mudslide model which can facilitate the evaluation of the extent of a related hazard event.

In the survey and interviews, collection of inventory data with drones is reported by Southland District Council in New Zealand (3D models), Connect Plus Services in UK (videos) and in Jiangsu Ninghu Expressway Corporation in China (a highway survey). The application on the drones for inspection is further covered in chapter 4.6.1.

Figure 2.10 A 3D model of a mud slide; ASFINAG, Austria.

2.3.1.2. LIDAR application

LIDAR (Light Detection and Ranging) is a remote sensing method, usually carried out with the use of a vehicle or an aircraft, which allows laser data to be collected on the surface of objects and simultaneously determine their actual dimensions. The LIDAR is coupled with GPS and the combination of these technologies allows to generate visualizations of the shape of the earth's surface or infrastructure elements in the form of a point cloud with three-dimensional coordinates (latitude, longitude, altitude). The ability to obtain such data allows far-reaching analytics in the field of infrastructure management.

With developments in technology and proliferation in the use of autonomous vehicles, the speed of gathering the LIDAR data will reach its full potential i.e. allow a road administrator a very advanced information about roads and accompanying infrastructure transmitted practically in real time. Recently, the software that accompanies this new technology has begun to develop rapidly. It is now possible to classify infrastructure to individual groups as barriers, signage, ITS equipment and other, which can significantly facilitate and improve the management of all components of road assets. In addition to capturing video, LIDAR is often used to generate 3D models of a streetscape (Figure 2.11).

Several uses of LIDAR have been reported in the survey and interviews. The upgrade of inventory of traffic signs was performed in Slovenia by the road agency DARS, and SANRAL in South Africa, using specific software and photos taken with 360 degrees camera combined with LIDAR data. Additionally, several more agencies indicated the use of these data in inventories: MoID in UAE, Highways England in the UK, Connect Plus Services in UK, Plus Berhard in Malaysia, Delaware Department of Transportation in USA and Lithuanian Road Administration.

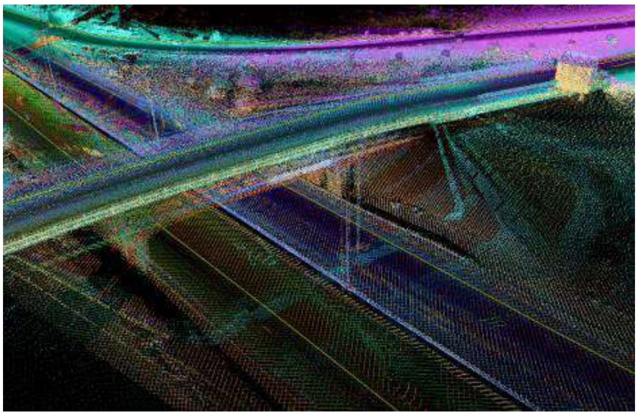


Figure 2.11 An example of data collected by a LIDAR system to establish a 3D model of infrastructure; the interview with Ministry of Infrastructure Development, UAE.

2.3.2. Data fusion

The adequate handover of as-built data from asset construction projects to organizations responsible for maintaining these assets in the operational phase is a crucial step in an asset management process. In the following steps it is of the utmost importance that all entities/parties which are engaged in the process of asset maintenance have all relevant, updated information on the asset.

New Zealand Transport Agency (NZTA) reports on a data warehouse “Corridor management plans” for 30 corridors across the entire network that draws together information at the service level as well as at the intervention planning level. This information was produced in support of the current bid for investment over 2018/21. The data provided thematic maps of infrastructure condition, demand, works, performance etc. in one place. Also, a customer-service-led investment story is provided to better link the need for works to support customer service levels with the activity planned.

In Chile, Dirección de Vialidad - Ministerio de Obras Públicas (MOP), is working on the implementation of the IBM Maximo Asset Management system that will integrate road inventory of paved and unpaved roads, conservation contracts, works contracts, use of resources of the organisation i.e. machinery and personnel and inputs in the tasks of road maintenance. It is also intended to integrate the data on the state of the road network, traffic data and all relevant information for adequately managing the infrastructure.

In France, Ministère de la transition écologique et solidaire en charge des Transports Francais (Directorate of Transport Infrastructure), reported that there is a national database which comprises data from the 14 managers of the non-concession national road network. The managers may have their own databases but they must be able to export the necessary data to the national database.

The agencies in the interviews provided a variety of answers on the policy that is applied to the contractors which deliver the data on inventory after interventions. Depending on the intervention that is provided by contractors, the most agencies ask that the format of the related reports is handed in as a hard copy (i.e. in paper) and/or electronic including spreadsheets, pdfs, text, digital photos and drawings. The data obtained are then recorded in the inventory databases by the agency personnel. However, two agencies reported that their contractors will be obliged to deliver data in a database format (MoID in UAE and Roadcare in Malaysia).

In order to enhance the efficiency of data collection and provide a more user-friendly means of updating data on site, the agencies have been testing (Transport Scotland) or already using web-based inventory collection and condition rating applications (ASTRA in Switzerland, Ministerio de Formento and Communidad de Madrid in Spain).

Transport Scotland has been funding in the last two years two trials to improve the efficiency and accuracy of inventory data collection, which also reduce the need for personnel to work in road-space. The first trial is to collect traffic sign and road marking retroreflectivity from a moving vehicle by using Advanced Mobile Asset Collection systems developed in Spain. These vehicles gather data relating to signs and road markings in one pass and are reported to have greater repeatability than current methods used by contractors. The other trial uses electronic tracking of bituminous materials from source to laying. The system records material source, composition and temperature at all stages in the production, transport and laying stages. This is provided in an electronic format and creates a record of compliance with contractual requirements and specifications. The record is planned to be incorporated into the pavement inventory within the Pavement Management System.

2.4. Building Information Modelling (BIM) in asset management

Today, the large majority of road operators and administrations has already shifted from the practice of recording information in paper forms to using benefits of IT. Furthermore, the electronic documents and drawings (file-based) are being stored as digital data in interlinked database systems. Here, the digital data refers to the data stored in a manner that it can be used seamless in all work processes in a lifespan of an infrastructure. For the latter, Building Information Modelling (BIM) can be used to provide structured and unstructured information including various datasets: geospatial, survey, condition monitoring, operational, maintenance, performance and utilization of assets. Thus, BIM is triggering a substantial digital transformation of the infrastructure sector, with development and management of the virtual world which is becoming as important as the physical.

Figure 2.12 BIM applied in asset inventories; survey question I1.1 - 64 responses.

The use of BIM in asset management is not well established at the moment and many agencies are in a trial phase. According to the survey, only a few agencies report on using BIM for various asset management purposes (Figure 2.12) and one has reported an ongoing implementation (Rijkswaterstaat in Netherlands). Also, there is a case that agencies don't have a mature BIM environment but report on using CAD and GIS products (e.g. DPTI in South Australia). However, for almost half of the interviewed agencies (9/21), the use of 3D asset models is limited only to capital projects or these models are not in focus at all. Three agencies reported that they use 3D models based on LIDAR data (Highways England & Connect Plus Services in UK and MoID in UAE) while Korea Expressway Cooperation reported on an ongoing pilot project for establishment of 3D models for several locations in their network. Furthermore, the NZTA reported working on a parameter driven spatial referencing (instead of using available 3D modelling software) that will allow compatible implementation among large and small road agencies through the use of common, open data exchange standards. Currently, there are ongoing initiatives and pilot projects to standardize the use of BIM in planning and construction phases, an example is given in [10], which will be a basis to extend its application in the operation phase. In the following paragraph, a few practical ideas are given on how to start with the implementation of BIM, taking one step at a time.

2.4.1. Example of BIM Model application for management of tunnels

During the planning and construction phase of a tunnel, the information on support and protection system of the cavity as well as the geology and geotechnical indicators (e.g. convergence measurements, hydraulic conditions or special observations during excavation) can be stored in a BIM model in addition to the 3D model of the structure (Figure 2.13). After completion of the construction phase, the geometry of the tunnel can be checked by a 3D model created from a LIDAR survey. This comparison between the planned and built geometry will be the basis for the operation phase. In the operation phase, another 3D model and an orthogonal photo of the tunnel lining with detected cracks can be created (Figure 2.14). This inspection data can be merged in a 3D BIM model with the data from the construction phase, which significantly supports the interpretation of detected defects and damage.

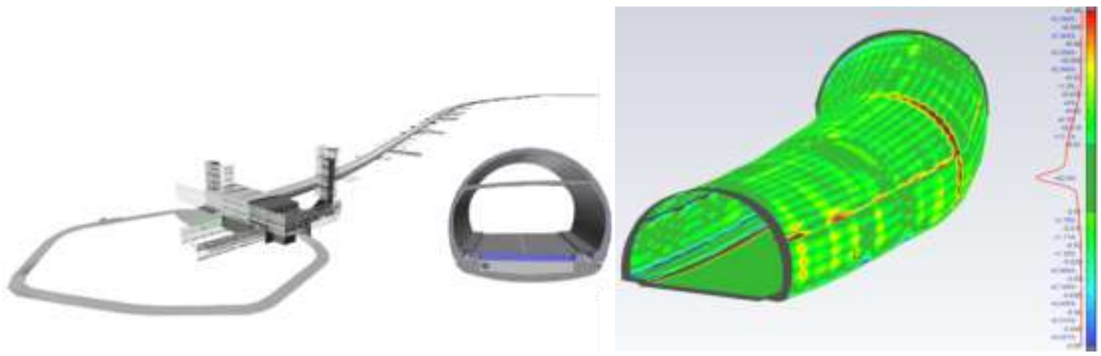


Figure 2.13 An example of a BIM model of a tunnel (left) and the comparison with the 3D-model created by LIDAR (right); ASFINAG, Austria.

Figure 2.14 An example from a photo of tunnel lining projected on to a BIM model (left) and a orthogonal photo with detected cracks (right); ASFINAG, Austria.

During the operation phase, a large amount of data can be collected in inspections, performed interventions and monitoring (e.g. Figure 2.15). Instead of defining a new data structure for storing these data, a BIM model can be used both for snapshot data and for the information that is needed to be stored over time. In such a BIM model, the necessary interventions can be defined which is the basis for the detailed planning phase.

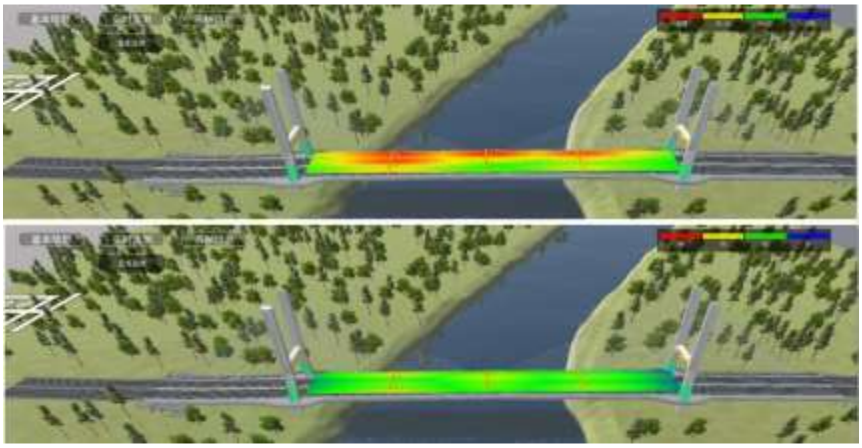


Figure 2.15 Dashengguan bridge life-cycle asset management system. Multi-point real-time monitoring data; Temperature measurement in the main girder (upper snapshot); Strain field in the main girder (lower snapshot); JSTI Group, China.

3. ROAD ASSET MANAGEMENT AND RISK MANAGEMENT

3.1. ISO 55000 AND ROAD ASSET MANAGEMENT

The goal of ISO standards 55000ff is to facilitate an organization achieving its objectives through the effective and efficient management of its assets. The application of an asset management system provides assurance that those objectives can be achieved consistently and sustainably over time. They apply to all types of organization, whereas most of them use assets to provide products and services that generate revenue and, therefore, a value for the organization. The need for assets is governed by a business process that furnishes products and services in order to be available when needed. Everything needed to successfully implement business processes, which means machines, human resources, licenses, patents, space, furniture, etc. are assets. ISO 55000 defines an asset as an item, thing or entity that has potential or actual value to an organization. In the same document, Asset Management is simply defined as the coordinated activity of an organization to realize value from assets. Fundamentally, the standard becomes more concrete as it postulates that:

- Asset management translates the organizational objectives into technical and financial decisions, plans and activities,
- Asset management does not focus on the asset itself, but on the value that the asset can provide to the organization, and
- Asset management implements risk-based, information-driven planning and decision-making processes and activities that transform organizational objectives into asset management plans.

To apply these general principles to road organizations, disregarding whether they are public enterprises or private companies is not quite straightforward. Firstly, it is necessary to define the organizational objectives. The product of a road agency is an infrastructure that can be readily used. The value is generated by the road users based on the macroeconomic principles explained in chapter 1.1 and hence outside the organization. This means that the core business of a road organization is asset management. The processes of asset management can be divided between different organizations, but their final goal is to ensure “value generation” by road users.

This value generation for road users can be endangered by a myriad of issues ranging from deterioration to bad organization of maintenance and from natural hazards to lack of resources. It is, therefore, necessary to implement asset management as “risk-based, information-driven, planning and decision-making processes and activities” that ensure optimum service to road users. This means that all endangering scenarios need to be considered, the likelihood of their occurrence and the associated consequences i.e. risks need to be evaluated either qualitatively or quantitatively. From this viewpoint there is not much difference between risk management and asset management. The major difference lies in delivering infrastructure and projects, in which the asset manager has a supervisory role. However, even the decision making with regard to new infrastructure is a risk or rather an opportunity management task.

In the survey, 14 out of 64 agencies reported that they have basic compliance with ISO 55000 (question Ai.2), while having an asset management policy was confirmed in the interviews by 17 out of 21 agencies. Several answers in the interviews stated that their goal is improvement of current policies rather than just certification to ISO 55000ff.

Highways England is an example of an organization that is on an asset management journey. Recent governance changes have entailed a move from government agency to government owned company subject to performance requirements monitored by government regulator. The licence for the new company includes a requirement for the company to operate ISO 55001 consistent practices and procedures and Highways England is in the process of aligning its practices and procedures to achieve that. In terms of repair and rehabilitation that includes the introduction of lifecycle asset management plans for a 30-year period. Those life cycle asset management plans will be used to inform investment decisions and to feed into detailed 5-year plans alongside bottom up condition-based data. Short term decisions are still condition based but longer-term decisions will be moving towards a performance basis in conjunction with the life cycle asset management plans. The new governance arrangements have also introduced 5-year cycles for maintenance and improvement which provide greater certainty of funding and should remove some of the political elements around funding. However, there has still been some squeeze on maintenance in favour of improvements/projects in the short term. Highways England is coming to the end of its first 5-year cycle (RIS1). When the second five-year cycle (RIS2) commences in 2020 great certainty in funding for maintenance is anticipated.

3.2. INTERNAL RISKS

The value generation for road users can be endangered by inadequate organizational setup or insufficient resources. This can cause the lack of adequate maintenance and improvement and result in disturbance in road traffic either due to traffic jams, unavailability of infrastructure or failures. The expected consequences of jeopardizing scenarios that are predominantly due to inadequate organizational setup or resources are internal risks. Mature road organizations have established processes that mitigate these risks, by streamlining business processes and assesses the human resources needed to perform necessary tasks. Currently, one of the challenges for road organizations is the lack of qualified engineers on the labour market. However, this can be regarded as an external risk.

3.3. EXTERNAL RISKS

Mature road organizations have established processes to minimize external risk. The risk due to deterioration for instance is minimized by introduction of condition rating thresholds at which a risk from deterioration is sufficiently small. The condition rating can be regarded as proxy for risk in case of slowly unfolding, manifest (inspectable) processes.

Similar proxies cannot be found for fast unfolding processes or latent processes. In this case risk assessment needs to be performed and risk reduction interventions need to be applied.

It would be reasonable to treat slowly unfolding, manifest (inspectable) processes in the same manner as fast unfolding processes or latent processes as the only difference is the level of available information. In case of slowly unfolding, manifest (inspectable) processes one can reduce the uncertainty by inspections and monitoring whereas this is not generally possible in case of fast unfolding processes or latent processes. There are some efforts to merge the treatment of two processes, which is also reflected in the survey. However, given that the majority of agencies separate the decision making of these two types of processes, the same is done in this report. The condition-based decision-making is treated separately (chapters 4, 5) from risk-based decision-making (chapter 6).

3.3.1. Risk management - results from survey and interviews

In the survey, only 8 agencies have indicated that they apply risk-based decision making for the repair and rehabilitation actions, and there are two more agencies which reported that they both rely on an evaluation of an asset condition as well as on risk/vulnerability assessments (see Figure 5.1).

When assessing various threats to assets, 5 out of 10 agencies account for only interceptable processes, while other indicated that they consider non-interceptable processes as well. Besides slow processes of degradation (e.g. corrosion, carbonization, rutting, etc.) and traffic demand (volume and loading), half of the agencies indicated that they consider climate change in their assessments (Figure 3.1). For non-interceptable processes, both man-made (e.g. vehicle/ship impact, explosions, fire) and natural hazards (e.g. flood, earthquake, avalanche) are reported. Three agencies reported that they account for fatigue in their assessments (Figure 3.2).

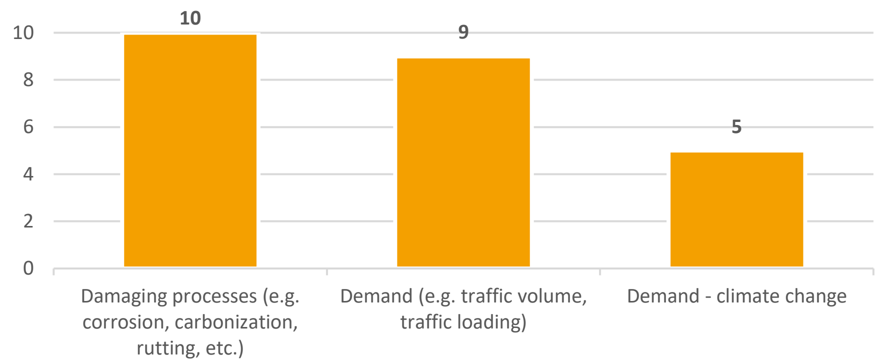


Figure 3.1 Frequency of reported interceptable processes considered in decision making; survey question RR1.2.1 - 10 responses.

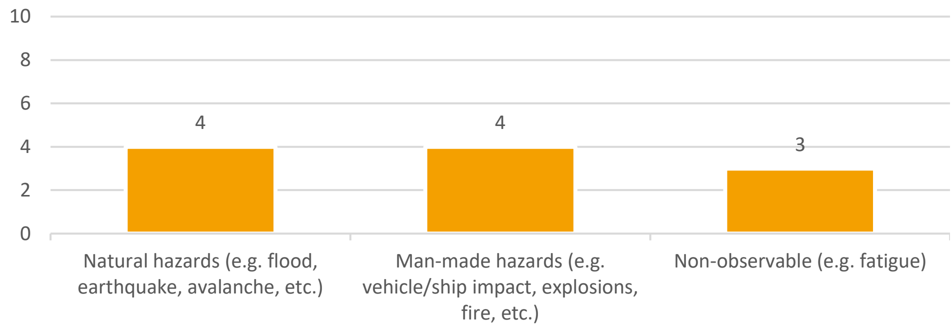


Figure 3.2 Frequency of reported non-interceptable processes considered in decision making; survey question RR1.2.2 - 10 responses.

In the evaluation/assessment of the probabilities of an asset failure, almost all agencies account for infrastructure condition and hazard scenarios. Additionally, 6 consider the statistical analysis of past failures and 6 account for the resistance & robustness of infrastructure (Figure 3.3).

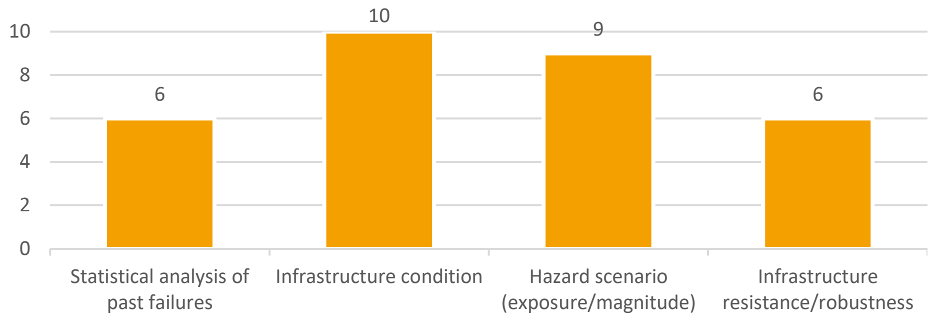


Figure 3.3 Frequency of reported data for evaluation of probabilities of an asset failure; survey question RR1.3 - 10 responses.

In evaluation of consequences of failure, most agencies account for the direct costs of an asset failure i.e. casualties and injuries and repair costs (Figure 3.4). Regarding indirect costs related to road users, 5 account for additional travel time and 5 distinguish vehicle types affected. Interestingly, half of agencies indicated that they consider environmental consequences and also half account for loss of reputation.

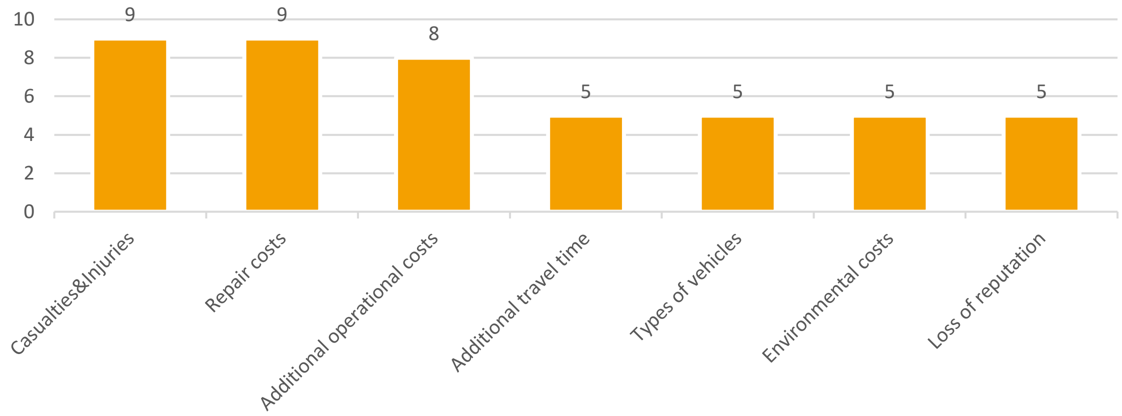


Figure 3.4 Frequency of reported data for evaluation of consequences of an asset failure; survey question RR1.4 - 10 responses.

The number of agencies which reported that they apply risk/vulnerability assessments in decision making is low, but the fact is that many agencies are testing or are in the process of developing risk-based methodologies. These are mostly based on qualitative or semi-quantitative approaches, with a concept of a risk matrix. The first step in these approaches is identification of the relevant scenarios which would lead to failure of specific infrastructure, which is followed by description and grading of probabilities for a failure scenario and estimation of related consequences to stakeholders.

An example of a semi-quantitative risk-based approach has been indicated in the interview by Infraestruturas de Portugal (IP) [11], which is being tested for the last two years. It is briefly presented in the following paragraphs. The relevant scenarios pertinent to asset classes were identified by a panel of experts and grouped in five risk types (Figure 3.5), here mainly based on consequences and the intervention types.

Risk type	Road pavements	Road safety and signalling	Road and Rail bridges	Rail track	Rail Signalling	Rail power systems
R1. Loss of main system			•		•	•
R2. Significant accident		•	•	•	•	•
R3. Major failure Operation impossible			•	•	•	•
R4. Important failure Operation in degraded mode	•		•	•	•	•
R5. Increasing maintenance costs	•		•	•	•	•

Figure 3.5 Asset classes considered when assessing types of risk; [11]

To estimate the failure probabilities for scenarios, two approach types are suggested, depending on the risk type on an asset. The first is expert judgement based on a frequency of occurrence (Figure 3.6). The second is deterioration modelling of relevant asset condition parameter as a random variable using functions of probability and historical data. For the latter, the failures are assumed when certain condition rating thresholds are achieved.

Classification	Qualitative	Probability range	Occurrence
Very likely	The occurrence is almost certain	0.65≤P<1	At least once each 1,5 years
likely	The occurrence is likely to happen	0.35≤P<0,65	Once each 3 years
Possible	The occurrence might happen occasionally	0.15≤P<0,35	Once each 7 years
Unlikely	Remote but likely to take place	0.05≤P<0,15	Once each 20 years
Rare	Occurrence is almost unlikely	0.00<P<0,05	Not predictable

Figure 3.6 An example of the classification for probabilities of failure scenarios; [11]

Similarly, in estimation of the consequences of failure scenarios two approach types are suggested. Expert judgement is the most common approach, which can be related to various consequence categories which cannot be easily monetized: loss of reputation, safety and (un)availability (Figure 3.7). The direct estimation of the expected financial impact is suggested for estimation in the increase in maintenance costs.

Classification	Reputation	Safety	Financial	Unavailability
Extreme	Bad public reputation	Casualties	> EUR 750.000	High-demand routes: 6 Hrs Low-demand: 48 Hrs
Major				
Medium				High-demand routes<2 Hrs Low-demand<24 Hrs
Minor				
Insignificant	No impact	No impact	≤ € 6.000	

Figure 3.7 An example of the classification for consequences of failure scenarios; [11]

Finally, the risk levels are assessed per asset type and all relevant risk types, using a risk matrix and related typical response type (Figure 3.8). This is an input for decision making where different maintenance scenarios can be compared.

Probability	Consequences Insignificant	Minor	Medium	Major	Extreme
Very likely	Moderate	High	High	Very High	Very High
Likely	Moderate	Moderate	High	High	Very High
Possible	Low	Moderate	Moderate	High	High
Unlikely	Low	Low	Moderate	Moderate	High
Rare	Low	Low	Low	Moderate	Moderate

Risk level Qualitative	Risk level Quantitative	Typical response type
Low	≤ 5	Accept
Moderate	≤ 25	Accept; Mitigate
High	≤ 100	Mitigate: Operations at degraded mode; short-term interventions
Very High	> 100	Mitigate: Operation impossible; Immediate actions

Figure 3.8 Proposed risk matrix (upper table) and related response type (lower table) for decision making; [11]

4. CONDITION ASSESSMENT AND DETERIORATION MODELING

4.1. INTRODUCTION

Mobility and transport of goods were the basic needs from the beginning of civilization. With the lengthening of travel and the increase in the value of transported goods, people began to wonder what the journey would look like and would it be safe and comfortable. In the past, the key role of a government was to provide safety & security to all travellers but in time, transport of goods became so lucrative that governments started to take actions to improve other infrastructure performance aspects as well: shorten travel time, improve comfort and, above all, to make the travel less dependent on changing climatic conditions.

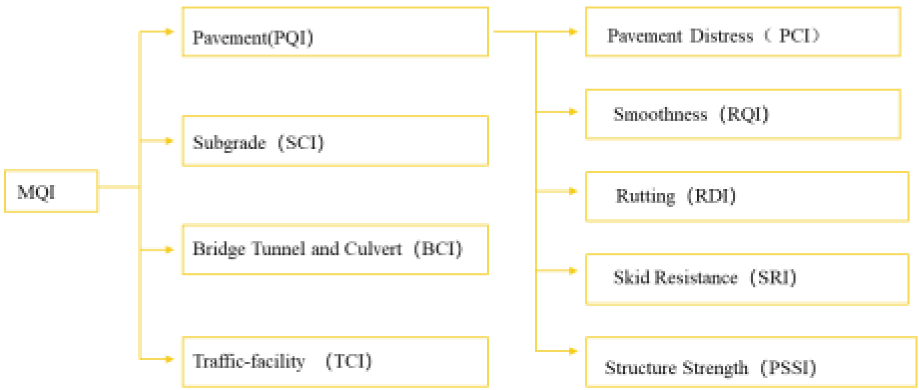
From the beginning, the infrastructure management practice was based on an asset condition assessment, and more recently the prediction of an asset performance over time has become a necessity for optimal maintenance/rehabilitation planning.

4.2. ASSET CONDITION IN QUALITY CONTROL

The quality control of assets is usually prescribed by law and technical regulations in a given country, with a set of requirements (i.e. performance goals) related to infrastructure performance aspects which mirror its fitness for purpose i.e. quality. One of the most commonly used proxies for quality of assets is its condition score, referred also to as condition rating or condition index, and usually estimated based on regular visual inspections/monitoring and engineering judgement. In most cases, only the snapshot of condition (i.e. in a point in time) is considered in decision making. Over years of practice, the latter approach has shown to be insufficient to accommodate quality requirements for many asset types as it allows only for reactive maintenance and fail to account for slow deteriorating processes and sudden events (i.e. hazards).

Technical development in the last 20 years and application of sophisticated equipment for inspections and research in the field of asset management, have led the agencies on a path to improve their quality control and make a step forward from condition assessment. Today, there is a tendency to assess the asset related performance aspects (safety, serviceability, etc.) using a set of qualitative and/or quantitative performance indicators (PIs). The PIs are being gathered in inspections, monitoring or represent a result of a data post-processing. They can be related to any observation/parameter or a distress/damage which in turn can affect an asset quality, as recently discussed for bridges in COST TU1406 [12] and for pavements in COST 354 [13]. It is an imperative that PIs, separately or combined, can be predicted over time and thus give insight on optimum time for maintenance interventions, which is further discussed in chapter 5.5.

According to the interviews, agencies use one number or a letter to express a condition score for their assets. The related scale usually has four to six values, but sometimes can be graded e.g. from 0-100, depending on the applied assessment methodology and the asset. The scores are related to a single asset or their entire stock in a network and given/evaluated based on values of relevant indicators/parameters. Also, depending on an asset complexity (e.g. bridge, tunnel) the asset condition score is often evaluated as a weighted sum of individual condition scores pertinent to the asset elements. As an example, a methodology used in China for evaluation of a condition index for a road section is presented in Figure 4.1.



Grade	Excellent	Good	Fair	Poor	Very poor
MQI	⩾ 90	80-89	70-79	60-69	<60

Figure 4.1 The evaluation of a Maintenance Quality Index in China; provided by JSTI Group, China.

Here, the highway technical condition for a road section is represented with a Maintenance Quality Index (MQI) with a value range of 0-100. It is evaluated per road section, using the following formula:

$$MQI = 0.7 \cdot PQI + 0.08 \cdot SCI + 0.12 \cdot BCI + 0.1 \cdot TCI \qquad (1)$$

In the formula, the indexes used are: Pavement Quality Index (PQI), Subgrade Condition Index (SCI), Bridge, Tunnel and Culvert Index (BCI) and Traffic facility Condition Index (TCI). The indexes, have values from 0 to 100 and are evaluated in semi-quantitative procedures which include weighing factors, modelling parameters, affected lengths/areas, etc. The evaluation of the PQI distinguishes between type of pavement (asphalt, concrete) and requires grading of five indexes that account for various distress/damages (e.g. cracks, potholes), smoothness (IRI included), skid resistance, rutting and strength (Figure 4.1). The SCI accounts for several types of damage to the road subgrade which refer to various defects (e.g. settlements, shoulder damage) and problems with drainage. The TCI accounts for the defects of protective equipment, traffic sign/line defects and poor green maintenance. The BCI values are given based on the condition score of the bridges (5 values), tunnels (3 values) and culverts (5 values). It is to be noted that if a BCI has a value of 0 (the worst value), then the MQI value is set to 0 disregarding values of other indexes.

Similar procedures to evaluate pavement condition ratings are also common in Germany, Austria and Switzerland.

In the interviews, the great majority of agencies (19 of 21) reported that they visualise the condition data using GIS, and here this usually refers to pavement related PIs (Figure 4.2).

Figure 4.2 An example of visualisation of a condition score of pavements in a network, using a set of PIs (roughness, rutting, cracks); the interview with Roadcare, Malaysia.

4.3. POLICIES ON COLLECTION AND STORAGE OF CONDITION DATA

The survey showed that data on the condition of a road network in roughly 60% of cases (38 out of 63) are collected independently by private or public agencies managing road infrastructure in a given country or region (question C1). Only 12 of the surveyed agencies reported that they rely on consultant companies in addition to their own data collection. Interestingly, among private enterprises dealing with road infrastructure management, only a few (four responses) use the support of other private entities (i.e. consultants). Similar answers were obtained for collection of condition data for structures.

For the condition data for electromechanical equipment and ITS, there was an inconsistency in some of the responses, as several agencies did not provide any information on the inventory (question in survey G13) but they provided the information on policies for collection and storage of the related condition data (question C3). The inconsistency may be explained by the fact that more than one person, from different departments within an agency, may have filled responses in the survey. Based on the responses to the survey question C3, the most agencies rely on their own resources or additionally hire private companies for collection of condition data on equipment (32 out of 49). In a few cases, the work is done by a government agency (2 out of 49). Similar percentages are obtained for ITS (survey question C4), where 39 answers were recorded.

The survey showed that in most cases (over 60% of respondents) modern archiving tools such as databases are already in use for keeping records of asset condition. Also, in nearly half of the responses, the use of spreadsheets to store inspection data is reported. About 26% of respondents still store data in paper archives. Here it must be noted that it was found common for the same data to be stored in several different forms, i.e. spreadsheets are source of the data stored in databases and/or data stored in paper archives is transferred in spreadsheets. This is usually the case for road administrators who are public entities, where there are legal regulations binding them to do so. The survey also showed that a few agencies store data simultaneously in a database and paper archives.

4.4. FREQUENCY OF DATA COLLECTION

The majority of responses in the survey indicate that the frequency of data collection on the condition of pavement is either annually or at 1 to 3-year intervals (Figure 4.3). It is reported in several cases that data is collected every 5 years. Interestingly, some of the surveyed organizations indicated that data on the surface condition is collected quarterly (2 organizations), every six months (2 organizations) and much less frequently - every 10 years (2 organizations). The latter are non-standard situations resulting from certain specific features/topology of road network, such as low traffic volume or a rural area.

For bridges, in more than half of the responses, the period of principal inspection varied between 3 and 6 years (Figure 4.4). About a third of all respondents indicated that this period is annual or biennial. The reported periods of inspection for other transportation assets (e.g. tunnels, culverts) resemble the results for bridges (see further responses in the question C2.1).

For electromechanical equipment, the frequency for gathering condition data for about half of respondents (23 of 45) is one year, for 7 agencies this period is up to 5 years and for the rest (12 agencies) it is less than a year (survey questions C3.1).

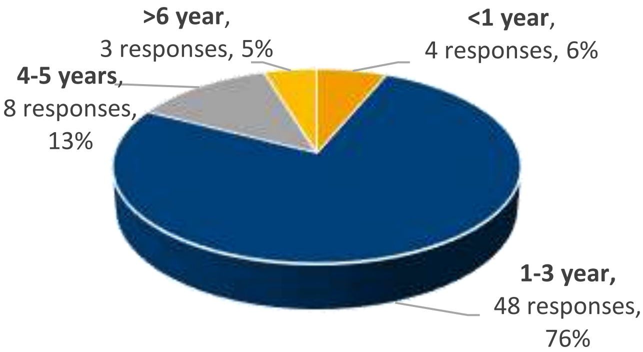


Figure 4.3 Frequency of pavement data collection; survey question C1.1 - 63 responses.

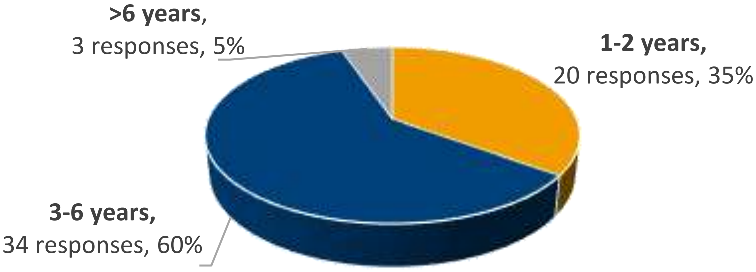


Figure 4.4 Frequency of data collection on bridges; survey question C2.1 - 57 responses.

4.5. SCOPE OF CONDITION DATA COLLECTION

According to the survey, the scope of assessment of the surface condition of road networks varies widely. Some of the respondents indicated that they make basic measurements on a single lane (usually a lane of free traffic), while more than half (36 out of 64) indicated that they tend to conduct a full review of road infrastructure in each year (Figure 4.5). The scope of principal inspections related to other assets (bridges, tunnels, etc.) was not queried in the survey due to complexity of doing so.

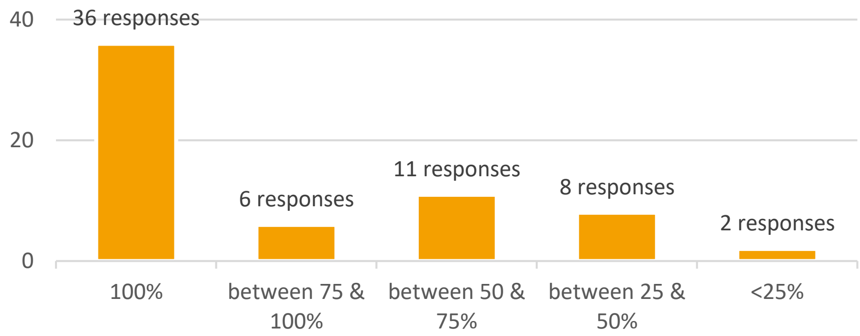


Figure 4.5 Frequency of the answers on the survey question C1.1: The part (%) of infrastructure reviewed in principal inspection; 63 responses.

In the survey (question C1.2), it was indicated that data on the condition of road surfaces are collected using specially equipped vehicles, while a large group of the respondents (26 out of 64) indicated the use of manual methods including visual inspections with the use of data collection vehicles. Several respondents indicated that they use advanced diagnostic equipment for automation of data analysis or they plan to buy such equipment in the future (e.g. Ministry of ecological and solidarity transition, in charge of French transport).

The widespread use of fast-moving vehicles for data collection is also confirmed in the interviews (20 out of 21 agencies). Here the question was additionally aimed at the methods of storing these data and their post processing. The interviewed agencies store their data internally (i.e. in a database format), process it using commercial or in-house software and finally transfer it to a pavement management system (PMS) for further processing and decision making.

Only 14 out of 64 respondents did not provide any data on the scope of principal inspections they perform in their networks (survey question C1.2.1). The rest provided more or less detailed information, and the simultaneous examination of many road parameters/indicators was reported (e.g. roughness, texture, rutting, longitudinal unevenness). In following paragraphs, some of the most interesting answers are presented.

The Connect Roads concessionaire in the UK reports that they perform three types of machine-based surveys on an annual basis:

- Serviceability (TRACS - TRAffic-speed Condition Surveys - focusing on rutting, texture depths, ride quality),
- Safety (SCRIM vehicles– wet skidding resistance), and
- Structural integrity (focusing on deflection measurements and establishment of pavement residual life).

In the Slovak Republic, the Ministry of Transport and Construction stores two types of data in the highway pavement management system - network level data and the individual project data. Parameters which are measured on both levels are: horizontal and longitudinal uneveness, bearing capacity and friction. On the project level, the investigation is performed with more details (for individual traffic lanes) and for shorter sections including visual inspection of a pavement surface.

In Canada, the Yukon Government has 26-years' experience of collecting surface condition of all sealed highways (60% of all roads). For roughly 2,000km of chipseal roads (Bituminous Surface Treatment unique to Northern environments) and 400km of asphalt pavements, the government developed condition indexes. The Pavement index addresses scoring for: ravelling, bleeding, rutting, rippling, wheel track cracking, centreline cracking, edge cracks, transverse cracks, longitudinal in-lane meandering cracks, distortions and ride scores. The Chipseal index measures similar distress signals with the addition of potholes, shoulder disintegration and subgrade failure.

Transport Scotland annually inspects one lane per carriageway with deflectograph (20% of network), with SCANNER (50% of network) and with SCRIM vehicles (100% of network).

In the Netherlands, Rijkswaterstaat reports that ravelling and cracking indicators are measured on all lanes, for the entire length of pavement. The rutting and longitudinal evenness are measured in the heavy traffic lane, for the entire length pavement, as well as the skid resistance but with addition of measurements of approximately 10-15% of the adjacent lane.

In New Zealand, the Southland District Council reports that it performs a 100% review of its entire sealed network every two years. The data on: SCRIM failure, surface condition failure, cross fall failure, and edge break failure are obtained via WDM (wavelength-division multiplexing) high speed technologies. They also gather data on cracks, rutting and potholes, with still photographs for archive reference. They utilise road runner to view photograph and video results for pavement marking, drainage condition, shoulder condition and mowing/spraying.

In the following paragraphs, the example of practice in Poland related to collection of condition data is presented in more detail. The General Directorate for National Roads and Motorways (GDDKiA) in Poland, manages a network of 20,000 km of roads. Measurements on the roads are performed on all lanes of a road and are in accordance with requirements in Polish State regulations. A total of 16 parameters are gathered for control of road condition:

- Deflection indicator - point measurement,
- SCI 300 - point measurement,
- Deflection indicator - continuously measurement,
- SCI 300 - continuously measurement,
- Transversal unevenness (rut depth),
- Longitudinal unevenness (IRI),
- Macro texture (Mean Profile Depth - MPD),
- Transversal profiles indicator,
- Roughness - point measurement,
- Skid resistance continuous measurement,
- Cracking, or any other surface defects for tarmac surface,
- Cracking, or any other surface defects for concrete surface,
- Night-time visibility (dry and wet condition) – RL,
- Daytime visibility (luminance) - Q_d
- Skid resistance – SRT value, and
- Luminance factor – beta.

The measurements are performed based on resource (i.e. equipment and personnel) availability. Cycles of measurements of certain parameters don't depend on a road type, but there are certain requirements:

- Longitudinal and transversal profiles of a road measurement and macro texture are performed every year. The related data may not be older than 2 years,

- Deflection measurement is performed on the road sections where longitudinal and transversal profiles or cracking has caused a really poor condition rating (i.e. class C or D according to the internal rating). Generally, these data are gathered annually,
- Cracking assessment measurements are performed every year on certain parts of roads and these data may not be older than three years,
- Roughness is measured every year in a part of a road and these data may not be older than three years, and
- Night-time visibility check should be done at last every two years.

In order to perform these measurements, the GDDKiA uses the following equipment (Figure 4.6):

- Laser Profiler /rut depth, MPD/ (11 pcs.),
- Skid resistance tester /point measurement, SRT/ (12 pcs.),
- Traction Watcher One (TWO) /skid resistance, continuously measurement/ (1 pcs.),
- Falling Weight Deflectometer (FWD) / deflection measurement/ (12 pcs.),
- Road Marking Tester (RMT) /measurement of the night visibility/ (5 pcs.), and
- Laser Crack Measurement System (LCMS^{TM}) /crack measurement/ (2 pcs.)

a) *b)* *c)* *d)*

Figure 4.6 An example of the equipment used for road inspection: a) Skid resistance tester b) Falling weight deflectometer c) road marking tester d) Laser Crack Measurement System; GDDKiA, Poland.

The pavement condition assessment does not only comprise diagnostic/monitoring activities. The wide range of parameters and large amounts of data collected on assets need to be post-processed. Here, the crucial task is to select the most appropriate methods and, if necessary, limit the amount and type of data received to obtain results that represent simple yet comprehensible information on an asset performance. In practice, it is common that the decision-making focuses on the most important parameters, for example, those which are necessary to maintain the safety of users (such as those prescribed within winter maintenance standards in Poland). The latter is the basis for the key performance indicator (KPI) approach, which is discussed in chapter 5.5.

4.6. Innovative approaches in collection of condition data

Today, the use of mobile devices/equipment, robots, drones for inspection is no longer an innovation but their seamless use in situ (offline and/or online) and in the office is not established as a common practice in every transport agency. Challenges still remain in determining what representative feature data will be extracted from the enormous raw data sets to support future decision making without overwhelming data bases with unnecessary details. However, the benefits of using innovative technologies is duly recognized and agencies are working constantly on improving current approaches for inspection data collection/storage/manipulation.

4.6.1. Use of drones

The expansion of highway systems and the related increase in number of infrastructure assets creates a demand for optimal asset maintenance and utilization of human/equipment resources. Many road administrations, under pressure to reduce costs and to be adaptable, are turning to drones as one of the means for improving operations and cutting down costs. The interviews indicate that in several countries there are attempts by agencies (e.g. DPTI in Australia, MoID in the UAE and Roadcare in Malaysia) to use drones for a review of road infrastructure, traffic monitoring, road data collection and inspection of bridge structures. Generally, drones can be used wherever there are difficulties in asset inspection (location, accessibility, etc.) or if personal inspection is too expensive, cumbersome or represents a threat to employees performing it. For the latter case, specifically reported in the survey was the effort of the Norwegian public road administration (Statens Vegvesen) which has used drones on a trial basis for avalanche, rock fall, land slide surveillance and bridge inspection. Here, it is very important to point out that the methods used to collect road data in many countries have been prescribed by local regulations. For example, representatives of Highways England pointed out that the possibilities of conducting inspections with the use of drones are limited, and a liberalization on this point in the related regulations is currently being negotiated.

Drones can carry HD cameras, radar and other equipment and with the assistance of a high precision navigation system and its control system it can become a powerful tool. It can be used for an inspection of bridges where it can aid in timely detecting of damage (cracks, concrete spalling, corrosion, etc.) that can impede bridge performance and shorten service life. Compared with traditional inspection techniques, drones have both advantages and disadvantages. Major advantages include low costs, easy image and video capturing, simple to transport and high mobility. Disadvantages include low stability during flight, necessity for a trained person to operate it and high image distortion in some cases.

Figure 4.7 Inspection of an arch bridge by a drone; ASFINAG, Austria.

For bridges such as the reinforced concrete (RC) arched bridge shown in Figure 4.7, there are many areas which are barely accessible for engineers during an inspection, and drones can significantly facilitate the necessary inspection work. Further, for bridges, orthophotos created by drones are the basis for classification of damage and mapping of cracks, for example, which can be supported by automated crack detection in available software (Figure 4.8). Also, with development of Bridge

Information Models (BrIM), there is a necessity to include damage as separate entities in BrIM. In recent research project it was shown that a photogrammetric mesh of a damaged area can be integrated in BrIM (e.g. Figure 4.9).

The data captured by drones usually have references provided by GPS sensors or a reference to the geometry of a structure. Thus, all photographs and videos and the results of post-processing are available for comparison with future inspections. The atmospheric and lighting conditions as well as type of surfaces being surveyed (e.g. reflective surface coating) have to be duly considered in order to obtain the most useful results while using drones.

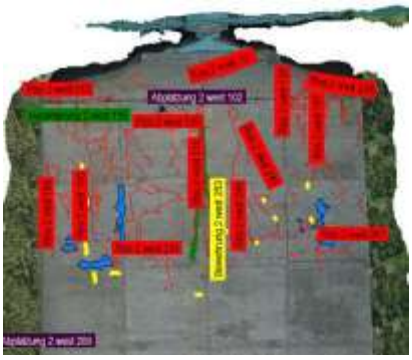


Figure 4.8 An example of crack detection by the use of orthogonal photos created by drones; ASFINAG, Austria.

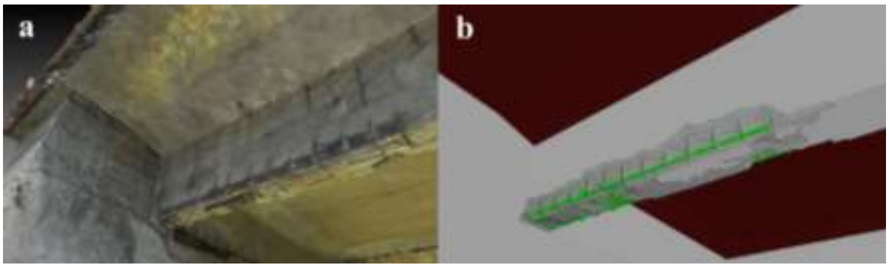


Figure 4.9 An example of damage detection - concrete spalling on a bridge girder: a) photogrammetric mesh, b) Bridge Information Model BrIM; a bridge in Serbia [14]

The use of drones relies on a GPS signal, which is sometimes lost under and inside the bridge. This drawback can be overcome by using visual orientation, i.e. the ability of a drone to orientate and stabilize itself in confined spaces as shown by Robotics and Perception Group of University of Zurich and ETH Zurich (see [15]). The drones use on board cameras and based on pixel-level intensity changes can ensure stable flight and movement within confined spaces. In addition, the drone can fold itself to pass narrow gaps.

4.6.2. Robots for inspection of bridges

An example of an innovative and practical inspection method for cable stayed bridges comes from China, where cable-climbing robots are used (Figure 4.10). This robot can be fitted on cables of different diameters and can record video with four cameras. It has a control panel and data storage. The robot carries a displacement sensor and thus can locate damage/defects precisely. Other important features are:

- It can be operated remotely from a distance of up to 500m,
- the average inspection speed is 10m/m and battery life of eight hours, and

- lightweight (12kg) with good manoeuvrability and easily installed.

Figure 4.10 Inspection of Nanjing 3rd Yangtze River Bridge with Cable-climbing robots; JSTI Group China.

4.6.3. High-speed laser dynamic deflectometers (LDD)

Numerous types of equipment have been developed for non-destructive pavement strength testing, namely Benkelman Beam, Dynaflect, Lacroix Defectograph, Falling Weight Deflectometer (FWD), Heavy FWD, Multi-Depth Deflectometer and the latest is Traffic Speed Deflectometer (TSD). The latter equipment uses a doppler laser measuring instrument, and can measure the deflection of pavement at speeds of 90 km/h. It helps road management agencies to evaluate the structural strength of pavements more quickly and efficiently. The TSD was developed in Europe and has been tested on European road networks in Denmark, UK, New Zealand and Australia. In China, a laser dynamic deflectometer (LDD) measurement system has been developed using a similar technology [16]. It can measure immediate settlement velocity, pressure of vehicles on the road, pavement longitudinal profile, speed, ambient temperature and other information with a high precision. The deflection values under the standard wheel pressure can be calculated. It can measure road deflections consecutively at a speed range of 20 to 90 km/h. Test data analysis shows that it has good repeatability (over 98%) and the correlation between the result compared to Benkelman Beam is over 90%. It was put into application in 2009, and by the end of 2014 there were three LDD systems being used in many provinces in China. JSTI Group has used it on the highways in Jiangsu province to study the applicability of this system under different conditions (Figure 4.11).

Figure 4.11 The LDD system during testing on one of the highways in Jiangsu province; JSTI Group, China.

4.6.4. 3D Ground Penetrating Radar

Based on antenna array technology a 3D Ground Penetrating radar for non-destructive testing has been developed in Norway [17]. Processed 3D scanned images can show colorized cross-section images, 3D vertical cross-sectional images and radar waveform diagrams. Location and extent of distresses can be obtained visually from these images. The distress types and amount of distress can be analysed to evaluate the pavement condition. The pavement research team in JSTI Group, China used 3D-Radar to inspect the conditions of several representative highways in Jiangsu province (Figure 4.12).

Figure 4.12 3D-Radar during inspection (left), and an example of radar image showing reflective cracking (right); JSTI Group, China.

4.6.5. Public participation and pilot projects – the future of data collection

Certain aspects of public participation in the management of road infrastructure are already visible, e.g. via car navigation in which users can add information on location of speed traps, places where congestions are frequent, local traffic limitations or just dangerous spots. The use of smartphones today allows measurements to be made of infrastructure parameters, which was previously reserved for teams carrying out diagnostic measurements and using advanced, very expensive measuring equipment. All over the world, there are pilot projects being conducted to use the car integrated acceleration sensor or the sensors of cellular phones of car users to facilitate the data acquisition of pavement condition (e.g. Figure 4.13). The references for these data are the terrestrial coordinates which are detected by a GPS sensor. All that is needed is to install a specific application on a smartphone and keep it turned on while driving. The relevant information on the road parameters will be automatically transferred to the road administrator via internet connection with the information about their location in GPS format. Some applications have features such as recording photos and video files with tagged geographical coordinates. Others applications can collect data on the efficiency of traffic streams based on the speed of vehicle movement and, thanks to the use of accelerometer sensors within smartphones, data on road roughness, e.g. IRI parameters can be collected, with a satisfactory accuracy in comparison to the data collected with a professional device.

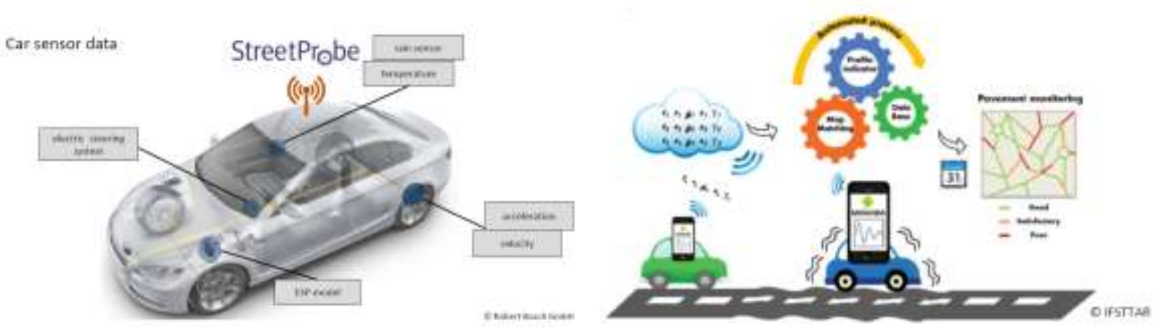


Figure 4.13 Schematic figure for the use of car integrated sensor and cellular phones; the project StreetProbe sponsored by German Federal Ministry for Economic Affairs and Energy (BMWi).

The state-of-the-art approach worldwide is the use of inspection vehicles and manual visual inspections supported with electronical devices. Here, an example is given from Germany, where the joint research project StreetProbe [18] was conducted to provide a reasonable and efficient system for recording and detecting road damage and its development over time (Figure 4.14).

Figure 4.14 The state-of-the-art approach data acquisition pavement condition; the project StreetProbe, sponsored by German Federal Ministry for Economic Affairs and Energy (BMWi).

In China, the pavement research team of the JSTI Group developed a methodology and related equipment to use accelerometers in smartphones to collect data on roadway condition. The methodology comprises a prediction model of roughness based on accelerometer signals collected by a smartphone application "JSTI roadway routine maintenance management system". With the assistance of a computer and the Internet, data from daily maintenance work can be transferred and stored in a timely and precise manner (Figure 4.15). All data are processed in a control centre. The system facilitates data collection, flow-path procedures processing, and other maintenance-related work.

Figure 4.15 Photos showing roughness data collection with a smartphone; JSTI group, China.

Another example for a planned involvement of road users in the collection of condition data comes from the Vermont Agency of Transportation, which is working on the development of an application for motorists. The application would ask them to complete a pavement condition evaluation when they have stopped moving. The evaluation was intended to match the condition " as reported" by the agency, with the customers` perceptions. The application also questions the driver on his expectations pertaining to pavements. To motivate the driver to complete the three different evaluations, a minor incentive (gift card) is offered.

However, public participation in data collection does not have to be associated with the possession of telecommunications equipment and the use of specific applications. Collecting data on road infrastructure, traffic problems and any situations affecting road users can also be performed via interactive forms placed on websites of road agencies. For example, the corporate website of Infraestruturas de Portugal has a dedicated part for customer relations where anyone can submit information requests, complaints or send any suggestion to the company (Figure 4.16). The main categories of complaints are chosen by the user: tolling, damage to a vehicle, environment, roadway or other issues. For every category, it is mandatory to provide the exact location (district, municipality, road number, kilometre point and direction), by filling the details or simply clicking on a map. Additionally, for roadway complaints, it is also mandatory to select one of the following subcategories: drainage, safety equipment, lightning, expansion joints, sidewalks, pavement, signals or other. The user then has to identify himself and attach relevant photos if necessary.

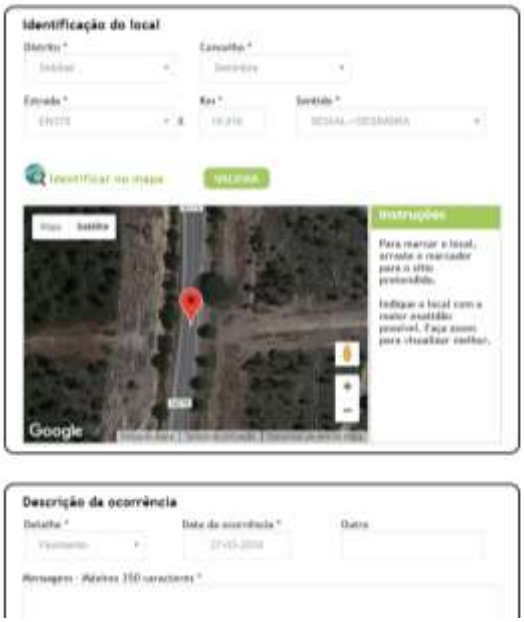


Figure 4.16 An example of filing a condition-related complaint by users; website of Infraestruturas de Portugal.

For the agency, each complaint is processed and forwarded to the relevant department, and the user receives an answer as soon as possible, with response timing being constantly monitored. In addition, every single complaint can be accessed through GIS (Figure 4.17), where dedicated layers include all the complaints submitted (since 2010), with a different icon according to the current status (first response pending, in analysis, terminated, suspended, etc.). This information can then be analysed in order to identify the network locations where the number of complaints is higher, and also in comparing it with the road condition data which are also available in the same platform. Recently, a quantitative analysis began development, where for each road network section, the number of complaints given over a certain time period (e.g. last two years) related to the road pavement is taken into account based on the exact location of each complaint, allowing a complaint rate per 10 km of each section of the network to be calculated. This type of indicator is now under discussion for the identification of maintenance needs, alongside the regular inspection data.

Figure 4.17 A review of the user condition-related complaints within GIS maps of Infraestruturas de Portugal.

It is important that participation of the society in data collection does not have to be understood as deliberate and conscious action. The various sensors and cameras can be mounted on vehicles at the factory to collect data. An example of this comes from, Southland District Council in New Zealand, where the “Fonterra“, a multinational dairy cooperative owned by New Zealand farmers, has the three fleet units for daily milk collection with dedicated “Roadroid Units” that provides results for both sealed and unsealed roads. Data are routinely uplinked to a cloud service where they are processed and a finished condition result is provided. It is reported, that the Council expect “Fonterra” drivers to provide pavement marking condition on their daily journeys including night and day conditions along with signage reflectivity.

4.7. Deterioration modelling

4.7.1. The purpose of deterioration modelling

It can be assumed that ”as built” infrastructure meets quality requirements and that these also apply to existing structures. The quality requirements can be expressed as the target/threshold values of a condition score or of relevant performance indicators (PIs) that are not to be violated during the lifetime. The purpose of deterioration modelling is to predict how the quality will change over time. This forecast is important for all parties involved in the investment, design/building and maintenance process. The owner/operator can use these forecasts to estimate an optimal maintenance strategy e.g. the amount of resources necessary to restore the condition of the infrastructure to an "as built" level or maintaining it at a level acceptable to users. These forecasts are also important for the contractor, as it may improve bidding for construction works and determines whether the contractor can fulfil the guaranteed obligations required by the investor/owner. Knowledge on asset deterioration is of particular interest for the tenderer, if the related contract covers the design, construction and maintenance of the infrastructure. In this case, knowledge from results of a suitable deterioration model, will allow submission of a more competitive tender even if the bid for the initial construction works is not the lowest one. Knowledge related to deterioration of individual components of infrastructure will allow adoption of solutions in the field of technology and materials, that will reduce maintenance costs over the asset life.

A variety of deterioration models can be applied at the following levels:

- Strategic level - to identify long-term needs,
- Network level - where performance estimates are made for new design, rehabilitation, or maintenance strategies on the network, and
- Project level: where more detailed deterioration modelling is applied.

4.7.2. Results from the survey & interviews

The modelling of deterioration of road structures as an innovative approach related to the use of condition data (survey question C5) was only explicitly indicated by a few respondents (Transport Scotland, DPTI of South Australia and Connect Plus Services from UK). However, for the question related to deterioration forecasting for infrastructure assets, agencies reported that they account for changes in physical condition of objects, changes in performance indicators or that they consider both (Figure 4.18).

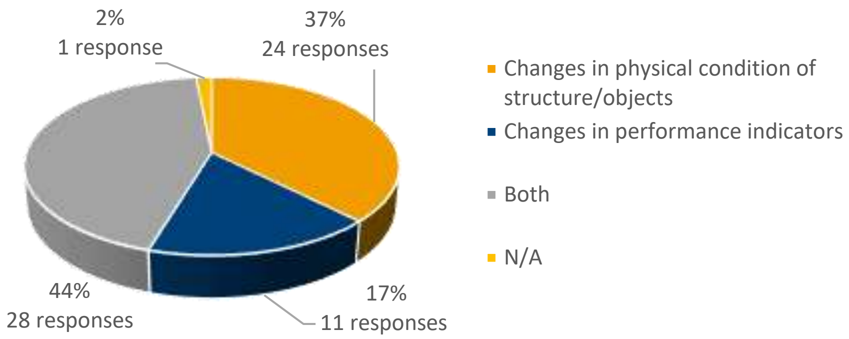
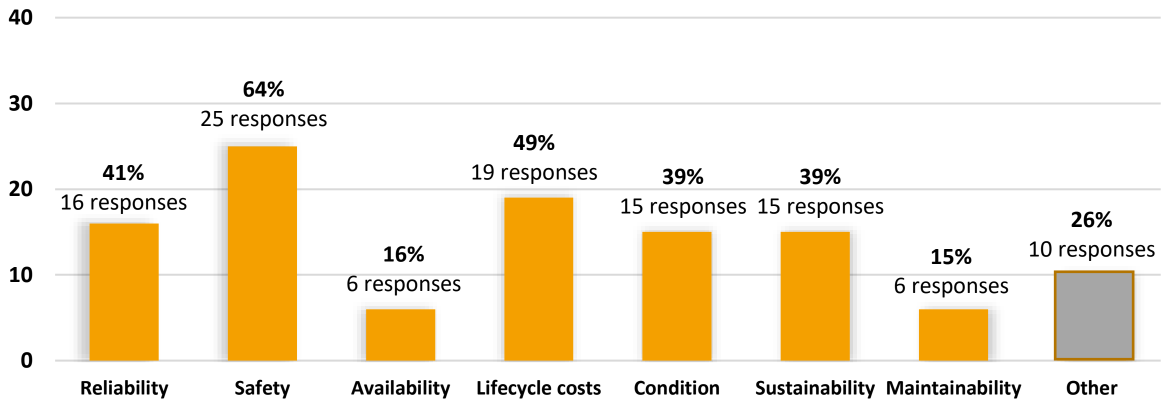


Figure 4.18 Deterioration forecast of infrastructure objects; survey question RR2 -64 respondents.

Besides the performance indicators (PIs), which are usually given in the form of a single rating (e.g. as for pavements IRI, rutting, cracking), in the survey 39 agencies (61%) also reported on the use of a total of 16 different key performance indicators (KPIs) in deterioration forecast (Figure 4.19). Where the responses were combined indices (e.g. Pavement Condition Index, Bridge Condition index) they are included in the category Condition.



"Other" (1 response per category, excl. Comfort which had 2 responses):

Figure 4.19 Frequency of the reported PIs; survey question RR2.1. - 39 responses.

The KPIs and their use in decision-making are further discussed in chapter 5.5.

4.7.3. Data necessary to model asset deterioration

In order to create condition deterioration models of an infrastructure asset, the initial state (i.e. as built) must be known. To determine the trends in change of indicators which define condition, it is good to have knowledge of deterioration. However, it is difficult to model the degradation if the road network is fairly new or reconstructed recently. For example, Poland developed models in the 1990s, which unfortunately cannot be used nowadays. The reason for this is the significant increase in investments in the road network from 2004 (Poland's entry to the European Union), which involved building new or reconstructing old infrastructure. The use of new materials and technologies made the old degradation models inadequate for the new/reconstructed road network.

The data necessary to model deterioration of pavements is summarized in the following:

- Pavement data (inventory and condition)
  Inventory data: category of road, carriageway and shoulder width, drainage conditions, surface type, thickness, pavement layer details etc.
  Condition data: Structural and functional evaluation. Structural evaluation is carried out by measuring surface deflections (e.g. with Benkelman Beam Deflection method). Functional evaluation is carried out in pavement condition survey, roughness survey and with skid resistance measurements.
- Environmental data (temperature and moisture content)
  Temperature has a great influence on the creep properties of asphaltic material, which is directly related to the development of rutting. Moisture content is related to the stability of the base layer and sub-base layer. It is directly related to the structural capacity of the pavement.
- Traffic data
  Traffic levels have the most direct impact on road surface condition, which is the direct cause of road surface damage. Heavy traffic conditions cause road surface damage to increase more rapidly.
- Construction quality and maintenance information
  Clearly, roads with good construction quality have better performance at a later stage. Also, the type/schedule of maintenance has an effect on the development of deterioration over time.

The four mentioned datasets are similar for the issue of modelling deterioration for structures such as bridges and tunnels. But, the main difference lays in a fact that the assessment of condition/performance for these structures is not as standardized as in the case of pavements, and is more complex for a number of reasons:

- Assessments are based on a number of elements which are pertinent to the structure type and its static system, and these elements have different importance to condition/performance of the whole structure.
- The elements have different deterioration rates due to their material properties and/or diverse exposure to the processes which cause and/or thrive deterioration.
- Some elements cannot be accessed and, therefore, not inspected to collect the necessary information on their deterioration.
- In some cases, there are non-observable processes (e.g. fatigue) which can affect the life span of an element.
- Condition may be affected by the maintenance of another asset e.g. winter maintenance of a road.

The decision on whether some of above-mentioned issues are to be considered as deterioration parameters when developing deterioration models depends on volume of data. It should be noted that the statistically relevant sample has to be available for each combination of deterioration parameter in order to develop reasonable deterioration models.

4.7.4. Deterioration models and available tools for deterioration modelling

There are two types of deterioration models i.e. deterministic and probabilistic. The deterministic models can be phenomenological models, empirical models or a combination of these two. The phenomenological models are based on the mathematical model, in which all relevant properties are considered. Clearly, such a model is a deterministic one. The parameters for the model can be estimated by a statistical analysis of the available data, i.e. they are obtained from empirical data. If the properties are assumed to be stochastic variables or the obtained parameters from the statistical analysis are considered as stochastic then the deterioration model is regarded as probabilistic model. The forecast using these models can include the Monte Carlo simulation if it is too complex to be handled analytically. These probabilistic models can be regarded as a generalization of the underlying deterministic model. The other types of probabilistic model are based on conditional probabilities. They are expressed as probabilities of a condition change that is dependent on a current condition. These models are based solely on statistical analysis and have no phenomenological background. A typical example of such a probabilistic model is a Markov chain model.

The Highway Development and Management Tool, HDM-4 software, developed by the World Bank for global applications is utilized for identifying an optimum maintenance strategy for highway pavements. HDM-4 includes relationships for modelling Road Deterioration (RD) and Road Works Effects (RWE). These are used for the purpose of predicting annual road condition and for evaluating road works strategies. The road deterioration model contained in HDM-4 is deterministic and phenomenological as it models the complex interaction between vehicles, the environment, and the pavement structure and surface to predict the future condition of pavements.

The road deterioration models predict the deterioration of the pavement over time and under traffic and which is manifested in various kinds of distress. But as each mode of distress develops and progresses at different rates in different environments, it is important that the HDM-4 relationships can be calibrated to reflect local conditions and to ensure their relevance to techno-economic analysis of maintenance and rehabilitation alternatives for a road network constructed in a particular geographical region. Some of the surveyed organizations did not directly mention the fact that they utilize deterioration modelling in their activities, but indicated they use the HDM-4 Tool (e.g. in Malaysia, Mexico and Chile). A few countries indicated they use various Pavement Management Software (PMS).

The probabilistic models/methods are often used where it is deemed reasonable to model condition development as a stochastic process. For bridges, it is a common approach to utilize so-called discrete-time Markov chains, which can be obtained directly from inspection data, or, if these are not available, through expert elicitation. This method is used predominantly for predicting the evolution of average condition rating of a bridge stock or an expected condition rating for a single bridge. In general, a good correlation with practical results is obtained if there are sufficient and adequate data on asset advanced deterioration, which is usually the case in developing countries. However, only a few countries have already implemented such probabilistic models in their bridge management systems (BMS), e.g. AASHTOware BrM (formerly PONTIS) in USA [19] and KUBA in Switzerland [20]. Interestingly, only one agency in the interview (VicRoads, Australia) indicated that they are be on the way to implement a probabilistic approach (incl. Markov Chains) in their BMS.

5. MAINTENANCE

5.1. INTRODUCTION

Infrastructure assets range globally from those that are at the end of their lifespan to new, recently constructed assets in developing countries. Adequate and timely maintenance is essential for all these assets to ensure that the infrastructure fulfils its function in an optimum way for all stakeholders. The term maintenance in asset management relates to both routine i.e. regular maintenance, as well as to major maintenance and rehabilitation. Major maintenance comprises rehabilitation and replacement of deteriorated components and elements and preventive maintenance, e.g. surface treatments, painting of structural steelwork, etc.

In this chapter, the results from survey and interviews will be summarized, followed by examples from practice and discussion on the innovative approaches in decision making with regard to maintenance. Finally, the ideas for the future will be given, which is an introduction to chapter 6.

5.2. ROUTINE MAINTENANCE – SURVEY & INTERVIEW RESULTS

The information reported in the survey did not indicate any innovations on routine maintenance. However, some basic information was provided on the use of service providers, split by region (Table 5.1).

Region	Organization	No.	In-house	Private/Service Provider
Australasia	Public	2	1	1
	Private	-	-	-
Asia	Public	16	8	8
	Private	5	-	5
Europe	Public	20	9	11
	Private	9	-	9
Middle East	Public	2	1	1
	Private	-	-	-
Africa	Public	-	-	-
	Private	1	-	1
Americas	Public	9	6	3
	Private	-	-	-
Totals		64	25	39

Table 5.1 The reported policy on performing routine maintenance; survey question R1 – 64 responses.

What is apparent from the responses is that regardless of region, a significant proportion of routine maintenance activity is still claimed to be carried out in-house.

The questions in the interview on routine maintenance were limited to those on the involvement of 'abutters', general public and sponsoring systems. The responses from the 21 interviewees were limited on involvement of third parties with some comments on communication with the public in general. However, some countries do train and develop local communities along the route of the highway to carry out routine maintenance, e.g. the micro business promoted by the Bolivian Highway Authority, as WG members were informed at the PIARC meeting in Santa Cruz 2017.

The responses on a sponsorship were more limited. The Ministry of Infrastructure Development (MoID) in the UAE reported an intention in future plans to establish an 'Adopt a Road' plan. Also, the response on experience from India suggests that sponsorship exists for maintenance of traffic islands and rotaries. It is speculated that the latter may be related to a sponsorship in payment for advertising space at such locations.

5.3. MAJOR MAINTENANCE - SURVEY & INTERVIEW RESULTS

5.3.1. The survey responses

As indicated by the majority of survey respondents, decision making for repair and rehabilitation actions is based on condition rating (physical and functional) (Figure 5.1). However, several organizations (a total of 10 responses) indicated that they perform risk/vulnerability assessments, i.e. they assess the probabilities and consequences of a network asset failure, which was discussed in more detail in chapter 3.3.1. In addition to inventory and inspection data, the organizations use the data they gather or obtain from different agencies on weather, traffic, hazards, accidents etc. The application of the latter data in decision making is discussed further in chapter 6.

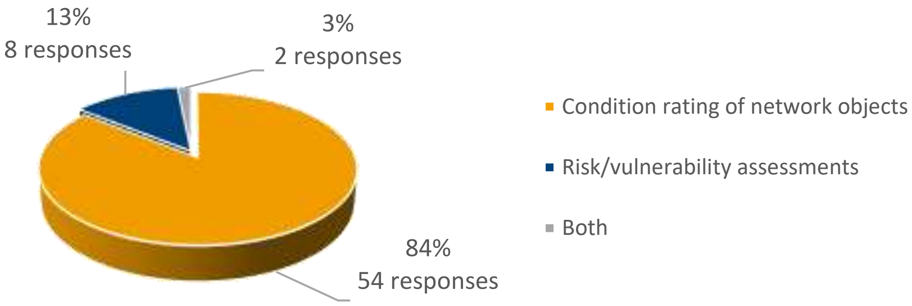


Figure 5.1 Decision making for repair and rehabilitation; survey question RR1 - 64 responses.

The respondents which indicated that their decision making relies on a condition assessment, were further asked how they perform prioritization in the face of budgetary constraints (question RR1.1). It can be seen that a majority rely on agency (heuristic rules) and/or risk/vulnerability assessments (Figure 5.2).

Figure 5.2 Frequency of reported types of prioritization in face of budgetary constraints; survey question RR1.1- 54 responses.

With respect to the modelling of the effects of interventions, the majority of agencies use deterministic modelling, but a considerable number also use probabilistic models (Figure 5.3).

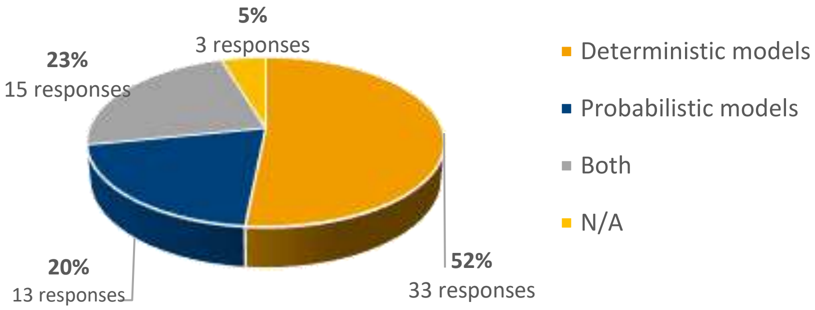


Figure 5.3 Modelling of effects of interventions; survey question RR3 - 64 respondents.

With regard to estimating optimal intervention strategies, the majority of responses in the survey indicate that optimisation methods are used (Figure 5.4). The optimisation methods are applied in most of the cases considering specific time horizons and/or analysis of lifecycle costs.

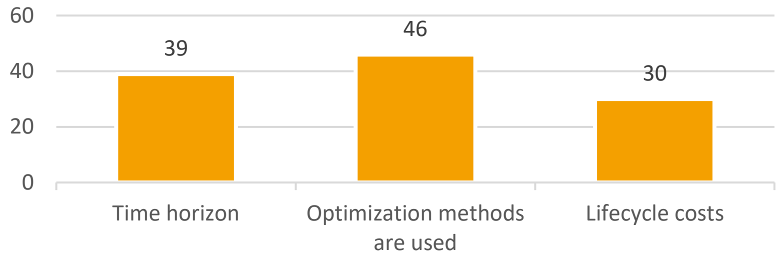


Figure 5.4 Frequency of reported approaches in estimation of optimal intervention strategies; survey question RR4- 64 responses.

For most of the agencies, the work programmes are based on budget constraints, but predefined time periods are also considered and/or optimisation methods when estimating these (Figure 5.5).

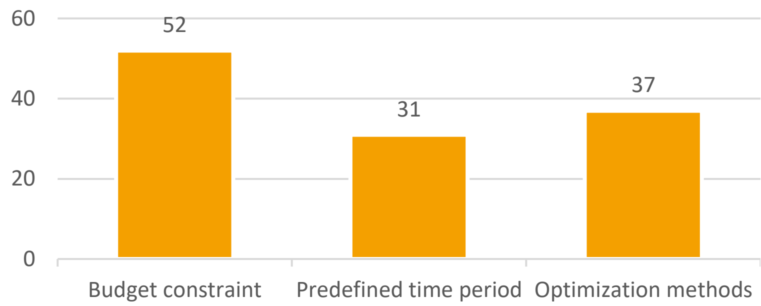


Figure 5.5 Frequency of reported basis for definition of work programs; survey question RR5 - 64 responses.

There were specific comments on innovative approaches to repair and rehabilitation planning in 24 out of 64 responses received (survey question RR7). These were quite diverse in nature and some of the key topics raised are:

- Mapping of programmes to allow visualisation of opportunities,
- Use of geodata,
- Adoption of economic assessment tools,
- Providing strict performance requirements for concessionaires,
- Recycling, materials technology, mobile based applications and SMART technology,
- Matching maintenance and renewal to use – fit for purpose service based on providing life extension in 10-year increments,

- Risk assessment and whole of life assessment in the decision-making process,
- Maintenance approach based on quality indicators and performance-based management to maintain standards,
- Lifecycle approaches – longer term planning, e.g. 20-year planning but 5-year programming, determining consequences of funding restraints,
- Monetarising maintenance backlog,
- Balancing savings against user inconvenience,
- A number of references to optimisation and the use of specific models, and
- Evaluation of consequences of failure.

5.3.1.1. The interview responses

In common with the survey results, and given the diverse nature of interviewees (and interviewers), the responses are again diverse. But the responses obtained reinforced the answers in the survey. The interviewees indicated that their decision process was condition based in the majority of cases. Some also use both condition and performance-based approaches, with performance based being used for longer term decisions, and a few indicated the transition from condition based to performance-based approaches (in Malaysia and UAE). Most agencies reported use of deterministic models (14/21) in modelling the effects of interventions.

A brief summary of the information recorded in interviews regarding repair and rehabilitation is provided as follows:

- Australia, Vic Roads (state of Victoria)
  Decision making is condition based. There does not appear to be a feedback process from the asset management team to the bridge management team. The information on the use of specific KPIs for traffic signals is discussed in chapter 5.5,
- Australia, Department of Planning, Transport and Infrastructure (state of South Australia)
  It is a mature asset management approach for pavements in particular with reference to criticality of assets and coordinating interventions cross asset although via a manual process. However, decision making is reported to be condition based. An asset management plan exists, and long-term considerations are made. Further details on measuring compliance with asset management goals is given in chapter 5.5,
- UAE, Ministry of Infrastructure Development
  The authority is transitioning from condition to performance-based decision making. There appear to be strict contract requirements which governs the other responses. Long term is considered but only for 10 years. Reference is also made to ‘political’ decisions,
- Malaysia, Belati Wangsa (M) Sdn Bhd
  The interview response for this organization was very similar to that for the UAE as summarised above. However, the long-term considerations appeared to be even shorter and limited to 8 years,
- Malaysia, Roadcare
  The organization is transitioning from condition to performance-based decision making. There were multiple references to the use of HDM-4 in this response for pavement assessment and planning. Other assets are managed and coordinated around that. Public complaints are mentioned as one of the KPI’s considered in the decision-making process,
- South Korea, Korea Expressway Corporation

The section of the interview record on repair and rehabilitation was not completed, but the main points have been covered in chapter 5.4,

- Guatemala, Covial
  Decision making is stated to be based on condition, capacity, social and economic impact. Threshold condition criteria are also stated to be based on social and economic impact. Forecasting of condition or long-term views are not carried out. Maintenance appears to be carried out as risk mitigation and dealing with emergencies and critical points,
- Canada, Manitoba Infrastructure
  The interview response to the repair and rehabilitation section was limited. Decision making was advised to be condition-based. Prioritisation is within asset silos initial but combined through an annual project programming process. Long term view is short through a 5-year deterministic model,
- Highways England, UK
  The decision-making process tends to be more performance based for the longer term and condition based for the shorter term. Long term views are taken for pavement in particular, but tend to be less sophisticated for the more ancillary assets. Do minimum actions are often forced due to budgetary restraints,
- Connect Plus (M25 DBFO), UK
  Condition based decision making as part of contract with asset interventions at asset level but hybridisation opportunities are sought to minimise traffic and network impact. A long term (25-year contract term) view is taken with ultimate requirement of returning the asset to the client (Highways England) with the condition profile as at the start of the contract. Deterioration modelling for structures is complex – down to sub-element/component level and then rolled back up to structure and stock level.
- New Zealand Transport Agency
  The agency adopts a sophisticated asset management approach, particularly for the major assets such as pavement and structures. Performance indicators are increasingly reflecting customer requirements. The agency has established a Road Efficiency Group in conjunction with the New Zealand local government organizations to pursue improvement to road asset management practice and tools. As part of that it is producing a road classification and performance framework to enable consistent fit for purpose service offerings. More detail on this framework is provided in chapter 5.5,
- Spain, Ministerio de Fomento
  The ministry used condition-based decision making but also recognises the functionality of the asset as it considers both aspects inter-related. Mention is made of the use of status indicators as a means of guidance and for interpretation by engineers and inspectors rather that use in a deterministic manner,
- Mexico, Direccion General de Conservacion de la Secretaria de Comunicaciones y Transportes de Mexico
  Condition based decision making is adopted in general but other factors including political matters also impact. HDM-4 is used for pavement modelling. It is stated that investments are allocated on the relative importance of each asset and that in that way priority is given to the pavement first, then bridges followed by remaining assets,
- Chile, Ministerio de Obras Públicas

Cross asset interventions are determined manually by the involvement of specialists from different asset group to ensure full recognition of need and appropriate coordination under scenarios of efficient use of resources. All subject to the availability of scarce financial resource and community and political considerations,

- Portugal, Infraestruturas de Portugal
  Condition based decision making is adopted. Long term (20 year) behaviour of the asset is considered. Deterministic models are used. A risk-based approach to asset management planning is beginning to be implemented (see example at the end of chapter 3.3.1),
- India
  The interview stated use of performance-based decision making. Interventions are carried out on the basis of critical condition first,
- China, YangMao Expressway
  Decision making is both condition and performance based. Condition is forecast using deterministic models, but longer-term planning is limited to 3-5 years. The other 3 interviews from China provide similar responses, and
- Morocco, Association Marocaine des Routes
  Decision making is condition based. HDM-4 is used to provide deterministic modelling of the pavement asset.

5.4. CURRENT PRACTICE - EXAMPLES

In the following, examples on current practices on routine maintenance and major maintenance from England, South African countries and South Korea are presented in detail.

5.4.1. Routine Maintenance

5.4.1.1. Practice in England

In many European countries routine highway maintenance has moved from a fully prescriptive to a risk-based approach. The approach adopted for the English strategic road network is described below as an example.

Highway network management in England, as part of the United Kingdom (UK), has been carried out by private service providers on behalf of a government owned company Highways England for a number of years. Historically, these private service providers have provided a complete asset management service. That is now in the process of changing with Highways England beginning to take the asset management function back in house while leaving maintenance and response and scheme delivery services with private sector service providers.

Routine maintenance is, however, delivered in a similar way in both old and new approaches. Some assets such as structures have a strictly prescribed inspection and maintenance regime. However, for the majority of assets the risk characteristics of the asset are determined, and an inspection and maintenance frequency are established that will ensure the outcomes required for that asset (Figure 5.6).

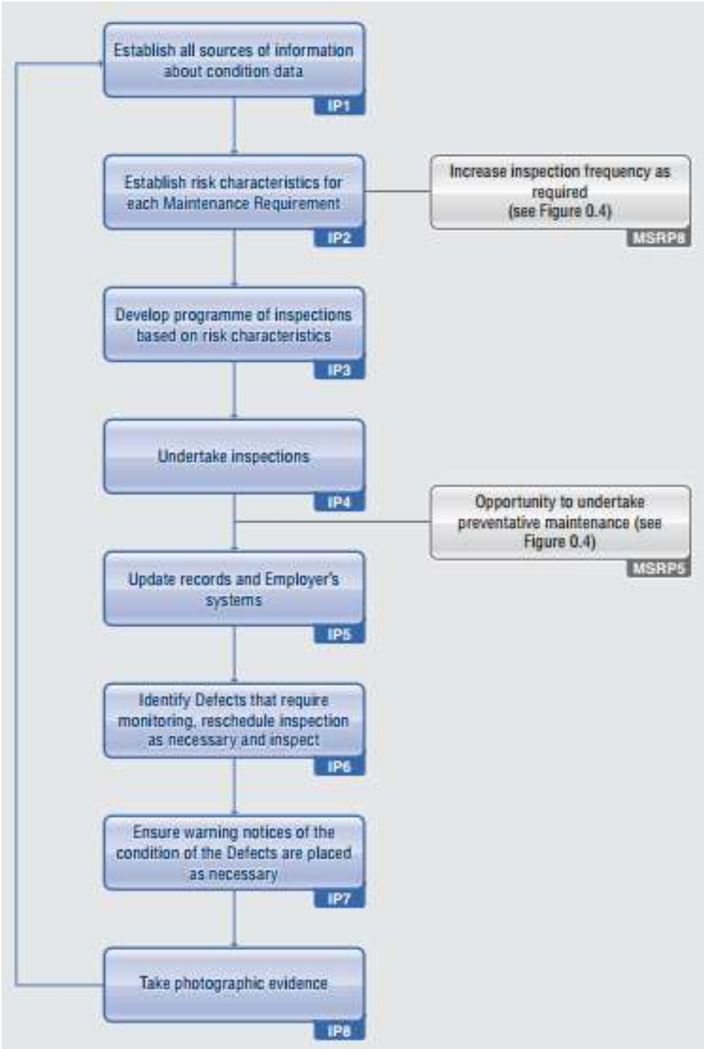


Figure 5.6 Risk-based inspection process; [21].

5.4.1.2. Practice in African countries

In South Africa, the South African National Roads Agency (SOC) Ltd. (SANRAL), manages all the strategic important roads in the country and routine maintenance contracts are divided into areas of local or district municipalities. These contracts are then managed by experienced contractors, but the use of local labour is encouraged and developed through these contractors, all of which are appointed from open tenders.

Routine maintenance contract definition in this context entails grass cutting and pruning or removal of trees and shrubs, pothole filling – including patching, drainage maintenance, limited slope repairs, crack sealing, mile marker maintenance, road sign maintenance, limited road marking and road stud maintenance, guardrail maintenance and replacement as well as streetlight maintenance in some urban areas.

Work instructions are issued via a mobile platform and managers capture completed tasks with mobile phone cameras and geotagged photos to indicate completion of tasks. Incidents are also captured on the same platform to enhance decision making with regard to road safety improvements. Provincial and municipal road authorities in South Africa still use their own personnel for this type of work and don't appoint private contractors for such work.

In most other South African countries, routine maintenance on major routes is also done either through contractors or road authorities. However, in practice, for many South African Development Community (SADC) countries, routine maintenance is either never done or left to local communities, which in general lack finance and appropriate skills and resources. There are cases where foreign contractors have built roads in SADC countries, but never trained local authorities or communities on how to maintain or fund the maintenance of these roads. With high rainfalls in central and South African countries, maintenance of existing roads is of utmost importance, but even sections of new roads are often washed away due to improper maintenance of drainage. This is usually exacerbated due to the use of inappropriate building materials and/or disregarding local conditions and potential hazards.

Senegal set up its Road Works and Management Agency (AGEROUTE) in 2010 to replace an earlier Autonomous Road Works Agency as part of a system to improve and make more effective its management of road assets. The system also includes a funding mechanism, an autonomous road maintenance fund (FERA) to guarantee sustainable and timely funding including contributions from a road tax charged to petroleum products. This has resulted in a three to four-fold increase in road maintenance funding and as a result the proportion of paved roads in good to average condition has increased from 52% in 2009 to 80% in 2018 (Figure 5.7).

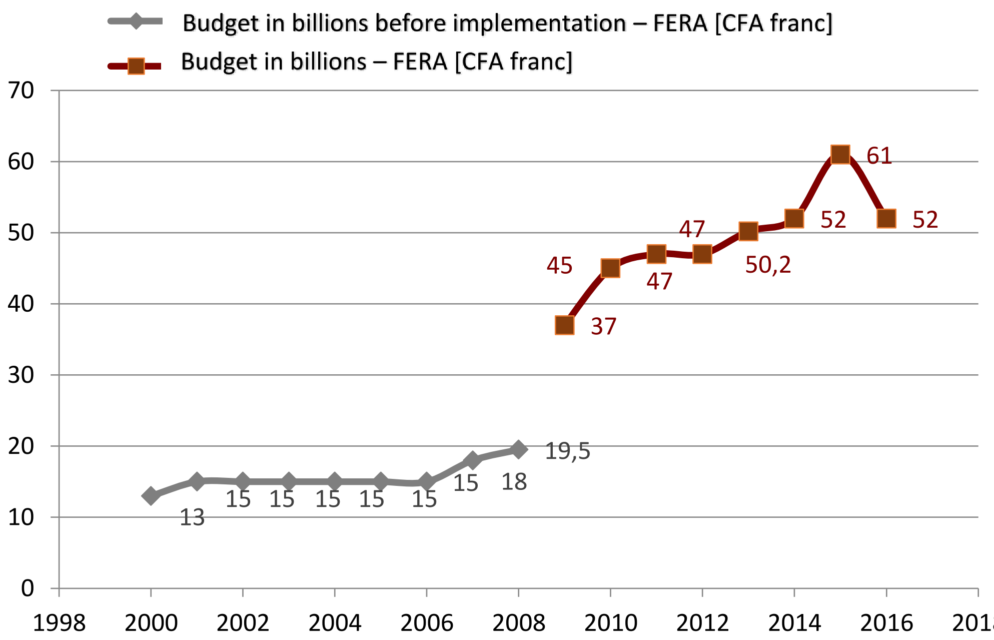


Figure 5.7 The evolution of maintenance budgets before and after implementation of the FERA.

Planning is based on a three-year rolling programme and an annual maintenance programme. Manual and mechanised routine maintenance is an integral part of the annual road maintenance programme and includes clearing brush, cleaning ditches, structures, etc.

5.4.1.3. Practice in South Korea

The expressway network in this country has been operated by Korea Expressway Corporation (KEC), a government owned company, which has been dedicated to building, operating and maintaining the expressway network since the late 1960's. It is mainly a toll road network. In the 1990's, Public Private Partnerships were introduced to build expressways and 10% of expressways are now operated by private companies. The concept of asset management on expressways was introduced in the early 2000's as major expressway projects, east to west and south to north, were completed. The KEC now has an integrated road data computing program, Integrated Road Data Platform, in which historical data and data by asset types are accumulated (both construction and operational). The accumulated data is utilized in decision making for the company's major issues such as maintenance planning, budgeting, technical solutions and diverse managerial analysis.

Allocation of the road maintenance budget has become an increasingly important topic under ever-present budgetary restraints. In 2011, a standard ratio for the estimation of maintenance cost was developed based on the road data which are contained in the Integrated Road Data Platform. The main issue for the allocation of the routine maintenance budget was how much funding would be distributed among regions reflecting quantity and quality of assets and other natural and managerial conditions. Following this standard ratio for estimation of road budget allocation allows the maintenance budget for the 8 regional areas to be calculated. The ratio is derived by the following process:

- Step 1: Calculation of regional standard maintenance cost.

  Here a three-year average unit cost is calculated from the database. Road assets are classified into seven categories – pavement type and other (e.g. bridge, equipment, landscape). The amount of assets by category which is managed in the region is multiplied by the unit cost,
- Step 2: Correction by regional characteristics

  Factors of correction are applied for age, traffic volume and the major maintenance cost (capital expenditure) in the region for that year,
- Step 3: Calculation of draft budget allocation ratio

  The draft budget allocation ratio is produced from the multiple of regional standard cost and correction by a regional characteristics coefficient,
- Step 4: Additional specific requirements for the region

  Specific additional regional budgeting requirements for special structures, facilities, weather condition, etc., and
- Step 5: Final standard ratio for maintenance budget allocation for the year.

5.4.2. Major Maintenance

5.4.2.1. Practice in England

Most European countries have well developed processes for identification and prioritisation of their network needs. These usually incorporate some element of risk identification and management of those risks in relation to the ongoing use, serviceability, availability and reliability of the route being considered. In the UK, Highways England management of the process is by reference to a Highways England document [22]. It is designed to ensure that Highways England maintains the capability of its asset to meet their customer's aspirations in a cost efficient and timely manner. Figure 5.8, Figure 5.9 and Figure 5.10 are extracted from the framework document and reproduced below to illustrate the different phases and stages in the development of major maintenance.

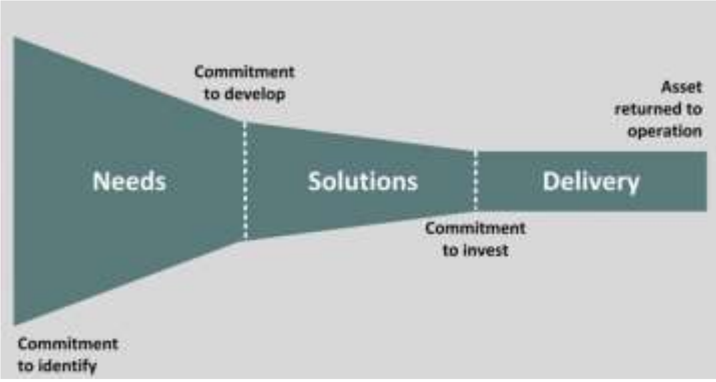


Figure 5.8 The three programme phases for NDD scheme implementation; [22].

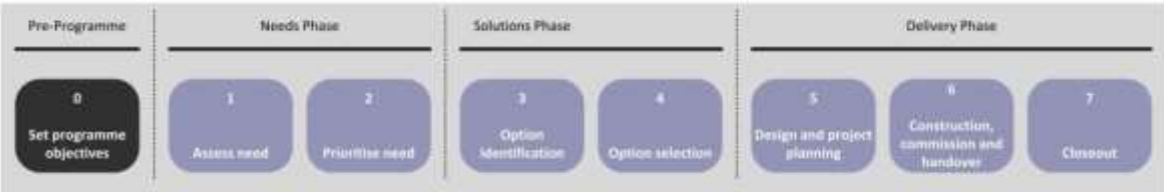


Figure 5.9 The programme lifecycle; [22].

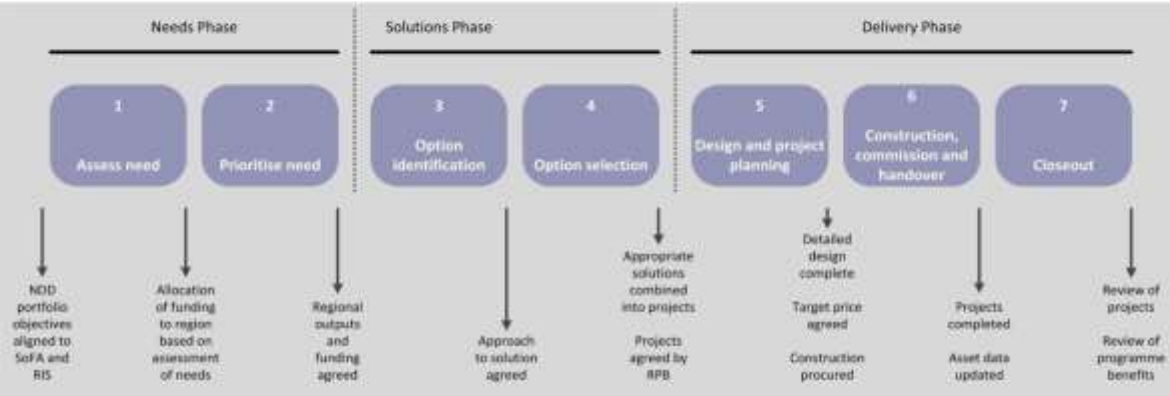


Figure 5.10. The key decision points within a framework; [22].

The framework is based on a rolling five-year programme of identifying network needs and implementing programmes of projects to meet those needs. The programme is split into three distinct phases as illustrated above:

- Needs,
- Solutions, and
- Delivery.

Asset management is most relevant in the Needs phase. Asset needs are identified by comparing network condition information (gathered through routine inspection, surveys, etc.) with engineering standards (designed to maintain a safe and serviceable network) and Highways England's objectives which will have been derived from asset inventory, condition and performance data and traffic and demand forecasts.

These needs and the work required to address them are prioritised and distributed considering any maintenance strategies that might exist for specific assets or routes within the five-year programme. Risk review is also important at this stage. The programme will inevitably be constrained due to funding availability and impact on network and customers. If the constrained programme includes significant residual asset risks these will need to be managed accordingly.

Solutions and Delivery phases follow well defined processes from option identification and selection through detailed design and planning to construction and handover. Governance and approvals are managed through distinct stages and gateways. Management of the flow of asset data into schemes and back out to asset data systems at scheme completion is a key aspect. The increasing use of BIM in the UK highways environment is assisting in this asset data update process.

5.4.2.2. Practice in African countries

In South Africa, there is a legislative framework in place (National Roads Act) which includes within SANRAL's mandate, the responsibility of taking charge of the management and planning of the South African national roads system.

In this legislative framework, it requires SANRAL to:

- Submit an annual Business and Financial plan and a five-year Strategic Plan,
- Treasury requires SANRAL to annually submit a proposed Strategic Plan for approval by the Executive Authority (Minister of Transport). The Strategic Plan must amongst other items include objectives and outcomes as identified by the Executive Authority,
- The Board Charter specifies that the Board must provide strategic direction and monitor the implementation of approved policies and strategies,
- The Shareholder Contract with the Executive Authority requires the Board (Accounting Authority) to provide strategic direction,
- The King IV Report on Corporate Governance 2016 applies to SANRAL. King IV requires the Board to direct the strategy and operations of SANRAL to ensure sustainability, and
- The Framework for Strategic Plans and Annual Performance Plans (Framework) released by National Treasury requires SANRAL to produce a Strategic Plan with a five-year planning horizon, ideally from the first planning cycle following an election, and an Annual Performance Plan for three years consistent with the medium-term expenditure framework (MTEF) period.

Within SANRAL, a well-established Asset Management System is utilized to prioritise major maintenance actions. Information from inspections, traffic monitoring stations, routine maintenance operations and accident statistics are all utilized in the RAMS system. Deterioration and maintenance effects are modelled through HDM-4 with South African developed mechanistic models. Prioritisation and optimisation are done using efficient frontier methodology. A project list is then produced and finalised and adapted to also include socio-economic and other factors that cannot be modelled. This final list of projects in a five-year window is then sent for a board approval.

There is a difference from many countries in the classifications of actions in the South African context as Maintenance actions and Rehabilitation actions are funded differently and separately. Periodic maintenance actions like re-surfacing (new chip seals) or asphalt overlays, are seen as Operational Expenditure (OPEX) projects, whereas any layer works (the replacement of layers or addition of layers and new construction) are seen as strengthening actions or New Facilities and classified as Capital Expenditure (CAPEX) projects.

There is quite an extensive network of roads in the SADC region, with South Africa having the most developed road network, supporting movement of goods and people, to the many highly developed urban areas and busy ports in South Africa (Figure 5.11). The SADC countries are collaborating to stimulate trade and development along most of the major movement corridors.

A large portion of the toll network is managed for SANRAL by concessionaires and the rest by SANRAL. This includes both the toll and strategic non-toll roads in South Africa. The funding is allocated from the fiscus for non-toll roads, but the toll roads are funded from the toll income.

Figure 5.11 Roads in the SADC member countries.

Most of the other South African countries don't have established asset management systems in place and major maintenance is likely to be hampered through the lack of availability of funding. Maintenance and rehabilitation activities may only be funded and carried out where the particular highway has a key role in proving access to a separately funded infrastructure project or private enterprise. In 2013, a self-assessment survey was organized by the Association of Southern Africa Roads Agencies (ASANRA) under the guidance of IES Asset Management [23]. The summary of the main road inventory data of the countries which participated is given in Table 5.2. The topic of the survey was to review the maturity of asset management in the SADC countries using the PAS-55 assessment methodology (predecessor of ISO 55000 ff). Firstly, the participating countries carried out their own self-assessments of their performance in road asset management (blue line in Figure 5.12). These were reviewed in-country by the IES team and some adjustments made (red dashed line and green line in Figure 5.12).

In Figure 5.13, a big difference can be seen between mature asset management environment in South Africa and the rest of the SADC countries where it is evident that awareness of asset management is only beginning to arise and major improvements are necessary.

Country	Paved	Unpaved	Total	Structures
Botswana	6400	18000	19400	50
Lesotho	1217	6211	7438	37
Malawi	4300	11200	15500	Not known
Mozambique	6363	24199	30562	903
Namibia	6664	39000	45664	600
South Africa	153000	593000	746000	8500
Tanzania	7000	28000	35000	5132
Zambia	7000	33454	40454	Not known
Zimbabwe	8900	79233	88133	Not known

Table 5.2 The main road inventory data of countries that participated in the ASANRA survey.

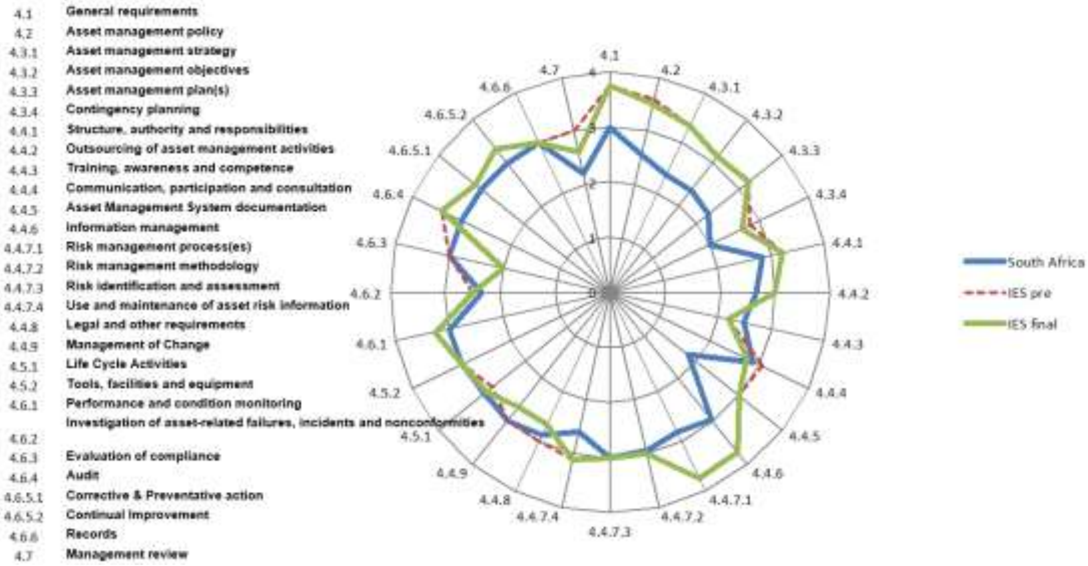


Figure 5.12 The ASANRA survey questions and results for South Africa; [23].

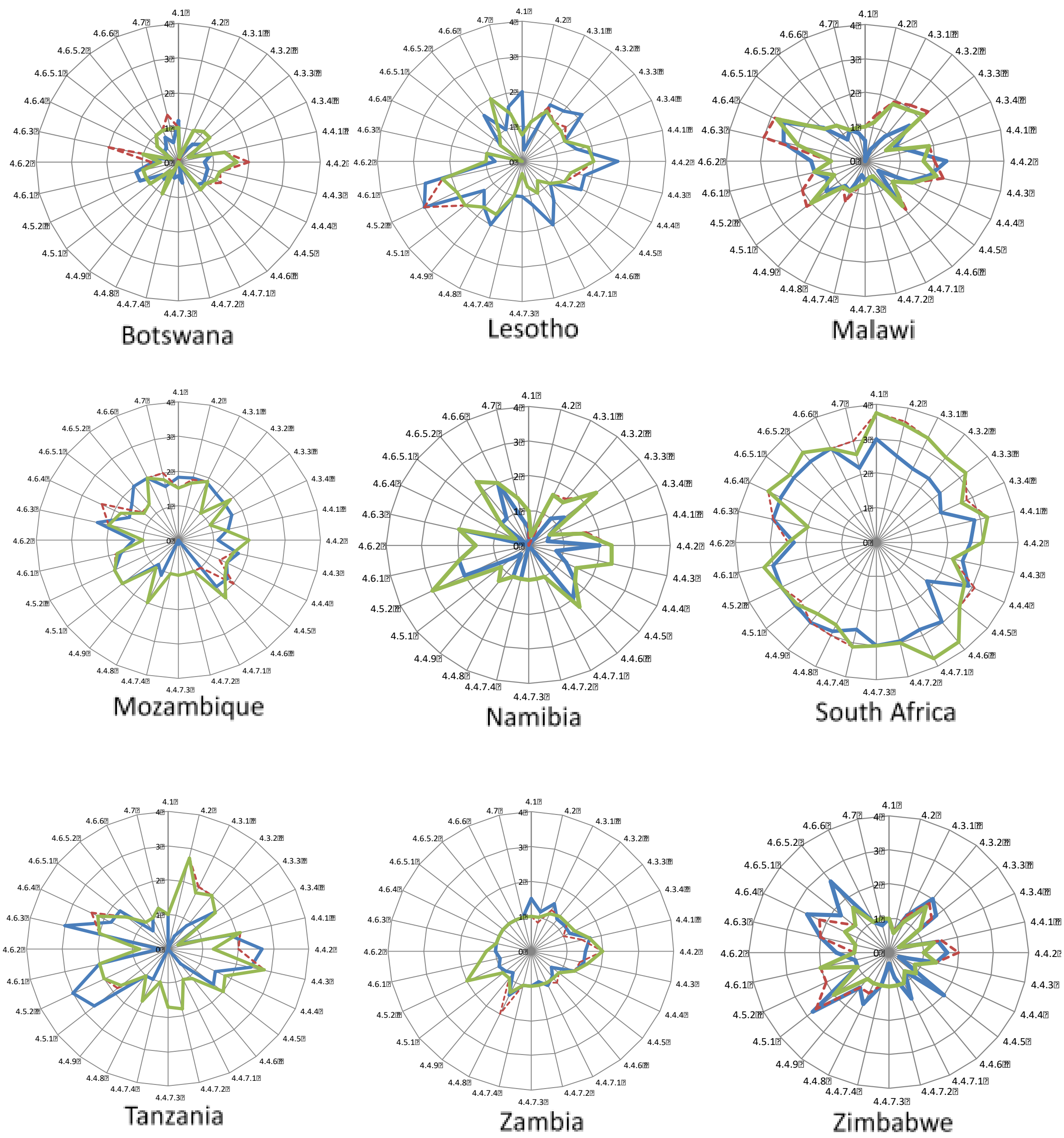


Figure 5.13 Maturity of asset management systems in 9 SADC countries; ASANRA survey; [23].

Senegal has a classified road network of 16495 km of which 5956 km are paved (36%) and 10539km are unpaved roads (64%). The AGEROUTE maintenance planning is based on a three-year rolling programme and an annual maintenance programme. The three-year rolling programme is supported by visual inspection and condition survey of the road network and traffic, deflectograph and an IRI measurement. The condition of each road section is characterised by a quality index using this data for both paved and unpaved roads to provide the basis for the three-year programme. HDM-4 is used for assessing economic viability of projects and prioritising interventions.

Programming is based on a road network condition objective (percentage of roads in different states: good, medium, poor) taking into account the available budget. The objective is to maintain roads in a good condition, to stay in that condition and to improve the roads in poor condition to a good/medium level. The annual maintenance programme comprises implementation of the three-year programme based on available funding and also incorporating systematic routine maintenance.

5.4.2.3. Practice in South Korea

The decision making for major maintenance in South Korea expressway network depends on the data and analysis from the Integrated Road Data Platform (see chapter 5.4.1.3). For example, the condition of pavement is classified into seven levels according to the results of periodic inspection. If a road section is classified in the fifth, sixth or seventh level, it needs major maintenance. It is similar for bridges which are classified into 5 levels (A to E) according to the estimated level of deterioration. The bridges in D and E level would need major repairs or rehabilitation.

Decision making for major maintenance has different aspects than routine maintenance. Here, it is a priority issue (not an issue of budget allocation) and not a regional issue but related to one object (e.g. a section of road, a bridge or an unstable slope). The prioritization requires detailed research and wider and upper-level discussions to reach fundamental and comprehensive conclusions among diverse functional departments in the company. To do this, the first step is to assemble candidate projects by asset types, which is reported from the regions to national headquarters every year. The budget committee of the company select priority projects of the year and multi-year under a three-year mid-term target and a 10-year long-term strategic goal.

5.5. INNOVATIVE APPROACHES FOR DECISION MAKING IN MAINTENANCE INTERVENTIONS AND ASSET MANAGEMENT GOALS

The strategic goals in asset management are pertinent to the type of an asset and procedures within decision-making. These goals are set in planning of maintenance i.e. prioritization of repair and rehabilitation actions, finding optimal intervention strategies and defining the work programmes. To achieve these specific goals, agencies usually rely on condition-based approaches, but more recently many include key performance indicators (KPIs) as well as risk/vulnerability methodologies.

The application of KPIs in decision making is the step beyond the classic condition rating assessment and represents a comprehensive approach to estimate quality of assets. It focuses on each stakeholder: owner/operators, users, society, financial institutions, government etc. and their requirements on asset i.e. specific performance goals.

Within the interviews, the use of several KPIs was mentioned, and those which are an addition to the list in Figure 4.19 are: risk reduction (IP in Portugal, see chapters 3.3.1), damage caused by natural disasters (Roadcare, Malaysia) and Benefit – Cost Ratio (BCR) mentioned by DPTI in South Australia. In the latter one, it is reported that the benefits are evaluated based on: savings in Vehicle Operating Cost (VOC), savings in Travel Time Cost (TTC), reduction of the cost of casualty crashes, reduction in Greenhouse Gas emissions and reduction in Air Pollution. Further, for sealed roads DPTI provides an example of relevant KPIs, their definitions and metrics (Figure 5.14).

Customer Level of Service Statement (Road Network)		Customer LoS Statement (Sealed Roads)	Technical LoS Standards (Sealed Roads)	Performance Measures (Sealed Roads)
Travel Time Efficiency	The flow of traffic is as expected given the time of day and location	The road carriageway has sufficient capacity to accommodate traffic flows without unreasonable delays.	Intersection performance in terms of vehicle delays	Average delay / vehicle at peak times
			Network performance from origin to destination on selected routes	Average Travel Times % Variation from posted speed
Travel Time Consistency	My journey time from day to day is consistent	Journey times are as expected given the time of day	Variation in journey times from origin to destination on selected routes	Variability measure – Standard Deviation of trip time
Road Condition	The road is maintained to an appropriate standard for where I am driving	Sealed road assets are well maintained and comfortable to drive on (Driver Comfort Index)	Standards by road category for: • Smooth travel exposure • Average roughness • Rutting • Cracking • DPTI Driver Comfort Index • Pavement Health Index (PHI) • Pavement Structural Index	Level of achievement with target values Proportion of surface deficient roads
		Sealed roads are repaired in a timely manner	Defects removed within minimum resolution times. Minimise planned disruption time by carrying out work when traffic volumes are low.	X% resolved within 3 and 12 months by road category. < X% total operational time involving lane closures Hours of downtime as a result of maintenance or rehabilitation

Figure 5.14 An example of the KPIs related to sealed roads, their definitions and metrics (LoS = Level of Service); the interview with DTPI, South Australia.

An example of decision making for signal asset classes in general, is given by VicRoads in Australia, which looks at several KPIs (the related metrics given in brackets):

- Availability – duration of time the asset was operating to its design/intended function (network/site uptime and high availability sites),
- Reliability – performance of an asset without failure under normal conditions (network average faults and high reliability sites),
- Fault management
  (attendance and rectification time compliance),
- Record and Report Compliance
  (records and reports accuracy and timing),
- Contract Compliance
  (non-compliance),
- Safety Performance
  (safe working time), and
- Efficiency and Improvements
  (project proposals, return on investment, reduction in carbon emission).

The measurement of compliance with specific asset management goals pertinent to a certain KPI or group of KPIs, differs from country to country. From the interviews, there are not many specific thresholds/targets for the desired quality by operators indicated to be in use (e.g. Figure 5.15 and Figure 5.16).

These are reported to be either specified within the contracts and delivery plans and mostly relate to an asset physical condition and availability.

For the agencies in the interviews, the trade-offs between various indicators are either not completed in a systematic way or not performed at all. Some agencies report on using weighting factors for rating of pavement condition (e.g. within HDM-4), balancing between agency and user costs or give information on ongoing plans in development of quality assessment approaches (e.g. IP in Portugal).

Figure 5.15 An example of KPI targets established by Highways England; [24].

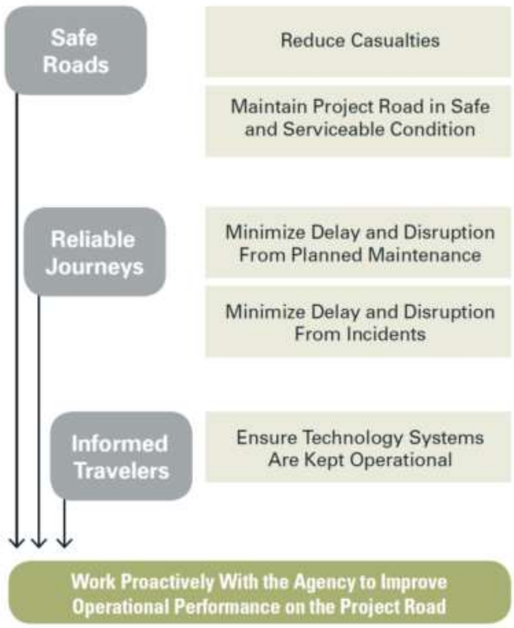


Figure 5.16 An example of asset management goals by Highways England; [24].

The New Zealand Transport Agency response included a report on a Road Efficiency Group, which the agency has established in conjunction with New Zealand local government organizations to pursue improvement to road asset management practice and tools. That has included production of a road classification and performance framework to enable consistent, fit for purpose service offerings. The group has developed the first version of a One Network Road Classification (ONRC) and related performance framework (Figure 5.17), and is currently working on enhancements to it.

This framework is a set of consistent performance targets for all roads in New Zealand whoever administers them. The framework recognizes that transport customers should receive consistent, fit for purpose, service offerings on roads with the same purpose, irrespective of the administration arrangements. The framework targets achievement of a consistent set of customer level of service statements for roads of a similar classification. The current statements focus on certain aspects of rural performance. Classifications are driven by use and purpose. Roads with greater traffic, greater freight, and that connect strategic destinations such as export ports, employment centres or regional facilities such as hospitals are classified higher. This means that roads with low traffic that have a primarily local access function are the most numerous by length, but not by traffic volume.

Figure 5.17 ONRC Framework; NZTA, New Zealand; [25].

Service aspects can be grouped into four broad groups:

- Access, the ability to get from A to B as expected,
- Travel time, and the cost to get from A to B,
- Safety, the ability to get from A to B confidently without alarm or harm, and

- Amenity, the comfort and delight of travel for users against the potential adverse aspects of human and environmental harm associated with travel service provision and use.

The service targets (i.e. performance goals) are reported to be collective and absolute, targeting the right level of access, and travel time (cost), and safety and amenity for each classification. These are all achieved when the value for money of delivery is good. However, the framework recognizes that due to external factors such as topography the ideal is not always affordable, so, for example, the travel time expectations for lower classification roads is more context variable than for higher classification roads when an investment priority is to provide a more consistent and safer environment. The travel time expectations for high classification roads are greater and more consistent than for lower classification roads where topography or historic urban form constrain development of transport geometry supporting greater operating speed. Also, it is perfectly acceptable for the roads to appear “longer” than similar function roads in new developments on flat land that are purpose built for the modern transport context.

The elements that have mattered most when considering the merits of proposals with a range of stakeholders including local communities, political representatives, and with the technical experts are:

- Service levels described in customer terms, not those of technocrats because these are not understood by investors and customers,
- Comparative reporting of metrics against peer agencies enabled because of a common performance metric framework enabling the recognition of:
  - Performance improvement opportunities in comparison with peer organizations and networks,
  - Efficiency improvement opportunities, and
  - Practice improvement opportunities exposed because of the collaborative environment created by the sector wide approach and the recognition nationally that we are all better off by us all doing better by sharing and employing better practice implemented elsewhere.

The framework is deliberately focused on customer levels of service, by community outcomes, because these are the strategic drivers of investment, whereas outputs are a means of achieving these. The performance measurement framework, therefore, has a hierarchy of performance metrics. At the top are community outcome measures such as nationwide deaths and serious injuries that occur as a result or road crashes, then classification specific service level measures such as collective and personal risk, and then technical measures relating to the efficacy of outputs, e.g. skid resistance, delineation performance, hazard warnings and guidance.

The framework is focused on performance and not road form or outputs because this focus leads to the best customer service outcomes, and the best value for money for the investors who are the customers. Road form statements are a useful means of improving the efficiency of service delivery where investment will be made to improve service level deficits that exist because of output (or form) deficiencies, e.g. on high volume routes such as motorways. Elsewhere (on lower classification roads), they are an impediment to value for money investment because they prioritize investment to output rather than to need, and output is often engineer driven and not customer service driven.

5.6. IDEAS FOR THE FUTURE

5.6.1. Integral Asset Management

One of the key tasks in the highways asset management process is an improved and optimized coordination of all maintenance activities on the different highway asset types according to the expectations and requirements of road users, road operators, road owners and other affected stakeholders. It is a complex process which requires flexible and adaptable methods.

Integral (or cross) asset management and optimisation are subjects which have been discussed and explored over recent years. It was the subject of one of the working groups of the WRA technical committee on road asset management during the previous (2012-2015) technical committee cycle [26]. That followed the PROCROSS project [27] carried out under the Era-Net Road initiative for collaboration and implementation of road research in Europe. That project ended in 2012.

Despite this being an issue, which challenges highway infrastructure managers globally, not much cross asset management is currently being carried out in the highway sector and most networks are managed using the traditional approaches where monitoring and inspection data are used to assess condition levels and asset needs for each asset type - more or less separately.

This is an area that can, and should, be addressed to provide an improved and optimized coordination of all maintenance activities on the different sub-assets according to the expectations and requirements of road users, road operators, road owners and other affected stakeholders. These activities are usually carried out within an environment of constrained funding and it is essential in such situation that the needs of the network are considered and addressed in a consistent manner and to allow any latent risks to be mitigated and managed consistently.

Swiss Federal Roads Office has developed a pragmatic approach to integral asset management using simple heuristic rules [28] to define maintenance corridors of 5 km and ensuring a free ride of 30 km between maintenance corridors. The interval between the maintenance interventions on the same corridor or part of it is to be no less than 15 years. Based on this approach a concept and a software prototype that supports judicious integral asset management has been developed [29]. In particular, the concept provides a methodology to define optimum maintenance corridors. Currently, canton Uri has implemented parts of this project in its decision-making practice [30].

5.6.2. Application of Building Information Modelling (BIM)

BIM is becoming established in the construction industry for delivery of new projects. It is not just about the 3D models that are often associated with BIM but also about encouraging collaboration between the different parties to the process – client, contractors, subcontractors, road users, etc. Mechanisms for the acquisition, transfer, handover and management of asset data are included as well as for the use of that data right across the planning, design and construction cycles. All of the above are equally relevant to highway repair and rehabilitation, but BIM is not being widely used in that sector at the moment.

Today, the applications of BIM in the maintenance projects are usually limited to capital infrastructure assets such as the landmark bridges and tunnels (e.g. see Figure 2.13). By using 3D visualization based on BIM, the precise locations of distresses can be recorded and other relevant information can be stored, e.g. history of maintenance actions, which significantly facilitates maintenance planning and execution.

Thus, there is need to extend the BIM to entire asset inventories, with emphasis on its use to improve transfer, handover and management of asset data. This will certainly reduce information losses that traditionally occurred when a new team takes ownership of a project and provide more extensive information to owners on the entire inventory.

6. IMPROVEMENT

6.1. INTRODUCTION

The improvement of roads has been one of the major issues that road agencies around the world have had to address in the past 20 years. This is not only related to the workload within agencies but it is also due to ever-changing budgetary allowances and restrictions. The demand for additional and improved roads is not only pertinent to large and dense population centres but has also become important for roads with less to moderate traffic, where there are circumstances that have not been addressed within the practice of Road Asset Management until now. The road asset management practice is currently focused on maintenance, which encompasses intervention that remedy damages, i.e. reverse their effect on asset performance. The functional properties of the asset remain unchanged, e.g. number of lanes, posting, noise emission, resistance to natural hazards. The change of these functional properties is referred to here as improvement. The costs of improvement intervention belong mostly to capital expenditure (CAPEX). The clear distinction between the maintenance and improvement is often not possible and perhaps not desirable. The maintenance interventions are mostly triggered by condition rating and their benefit is measured by the change in long-term maintenance costs. The maintenance interventions ensure that the condition rating doesn’t drop below certain level, but they don’t target an increase of the benefit to road users beyond the as-built situation. The improvement interventions target exactly the change of functional properties and can’t be economically justified by condition improvement, but by the change in road users’ or more broadly in societal benefit, e.g. travel time reduction, reduction of accident/fatality rate, reduced risk due to natural hazards, noise reduction, pollution reduction. The road managers should strive to evaluate this societal benefit and compare it with the costs, which is usually possible, although not in all cases. The evaluation of environmental impact is often difficult and regulators resort to threshold values that need to be met. This leads to improvement interventions that are triggered by the imposed thresholds. Clearly, one can use the cost of performed interventions to evaluate monetarily the lower bound of environmental impact.

This chapter will present the results of the survey with regard to agencies’ practices on hazards, traffic and accident data collection/storage and give examples on how some countries introduce improvement in the decision-making process with respect to above-mentioned topics. The issue of traffic noise is also covered with respect to national regulations and the most common solutions in practice.

6.2. USE OF TRAFFIC DATA IN ROAD IMPROVEMENT

The data that is gathered on traffic is normally used in conjunction with other types of asset data (inventory and inspection) in the decision-making process. For example, the number of vehicles in a network per road section is measured over time as well as traffic delays, and can be used to plan timely pavement maintenance actions. This type of information on traffic is essential also in risk-based decision making where the consequences of inadequate road performance on road users (e.g. prolonged travel time and distance), need to be duly considered. Besides planning on a network level, specific traffic data is collected to make decisions on an asset level. For example, traffic composition and vehicle (axle) weights are crucial for issuing of crossing permits and planning adequate maintenance or improvement of bridges.

The above-mentioned applications of traffic data are already fully or to an extent utilized in practice. According to the responses to the survey (question T1), the traffic data in half the cases is collected solely by the agencies themselves (32 out of 64). In roughly 30% of cases (18 out of 64), agencies rely additionally on the resources of government or private consultants. The rest (14 out of 64) don't collect this data in house. The most used sensing technology for the traffic measurements is inductive loop detection, which was reported by 95% of the respondents (question T1.2). The other data which is used in practice comes from weigh in motion (WIM), video recognition and Bluetooth devices or represents a fusion of various data. For storage of data on traffic, agencies mostly use databases (53 out of 64), while a few agencies still use only spreadsheets and/or paper archives (11 out of 64) (question T1.3).

The responses in the interviews indicate that policies on frequency of traffic data collection are pertinent to the available equipment that agencies use for either constant data monitoring or data updates at one, two or up to four-year intervals. As an example, the Ministerio de Formento in Spain uses a pyramidal data collection system with permanent, semi-permanent, primary, secondary and coverage gauging stations. Each type of a station has a different data acquisition frequency for hourly traffic: all year round (permanent); one full week every month (semi-permanent); one full week every two months (primary); two full days every two months (secondary); two full days every year (coverages). The latter data is officially published annually and the provisional traffic estimates for the entire network are published once a month.

The Korea Expressway Corporation (KEC) reported that various ITS equipment is installed and operated on the expressways, to collect, store and process relevant traffic data:

- Loop detectors and surveillance detectors (radar, video camera, etc.),
- The origin-destination (OD) time is collected through a Toll Collection System (TCS) and Hi-pass system (non-stop tolling system); the sectional travel time data is collected through detectors which are installed on the road side every 3.0 to 5.0 km, and
- The collected data is stored in real time in the integrated traffic information management system.

Related to the previous, the various indicators are used to measure the performance of traffic system:

- Percent of Congested Travel (PCT): the percentage of the vehicles in congestion (for an expressway - speed < 40km/h), for a certain road section in 24h.
- Traffic Consistency Index (TCI) for each route/region: If the traveling speed of vehicles on a certain section or a regional road network is more than 80 km/h for 24-hours of a certain day, the TCI is 100. The total distance travelled by vehicles with travel speed less than 80 km/h is subtracted from the total length travelled. The percentage of remained distance with respect to total distance is TCI.
- Travel Time Index (TTI): The ratio of average travel time to freeway travel time per highway section. It is less than 1.0 when traffic is smooth (no congestion) and 1.0 or more when congestion occurs

The DPTI in South Australia, reports on using a proprietary system of Bluetooth receivers “Addinsight”, which uses Bluetooth signals received from vehicles (e.g. from car stereos and smartphones) travelling on arterial roads to estimate travel times between key points on the metropolitan road network and to identify traffic delays due to crashes, road works and traffic congestion. The smartphone app has been developed to allow this information to be fed back to road-users via their mobile phones to enable them to make more informed decisions about their travel routes or mode of transport.

The majority of agencies (13 out of 21) reported in the interview that they use a traffic model and that it has variable impact on decision making. The traffic data (e.g. demand) is normally used for prioritization when the condition of assets is at the same level.

6.3. USE OF ACCIDENT DATA IN ROAD IMPROVEMENT

In addition to the availability of infrastructure, public perception is mainly focused on user safety. Road agencies tend to give this indicator a high priority with respect to maintenance of asset condition, even when it is known that condition is not the main cause of accidents in the vast majority of cases. Traffic accidents can have both direct consequences (life and limb and infrastructure) and indirect consequences in the sense of reduced road availability.

In order to reduce accident rates and black spots in the network, agencies perform various activities on collection of relevant data such as causes of accidents and related consequences (Figure 6.1). According to the survey, accident data are for the most part obtained from government agencies such as police or a public insurance agency, or the agencies collect the data themselves (60 out of 64). In only one case (SANRAL in RSA), is a private consultant reported as a lone source of information. The accident data is generally stored in databases (43 out of 64) and less frequently in spreadsheets and paper form (19 out of 64).

From the survey respondents, the scope of the collected data predominantly include location, time, number of victims and the causes of accident. However, large number of respondents indicated they also pay attention to damage to infrastructure items (43 out of 63 agencies). The latter was also confirmed in the interviews, in 16 out of 21 responses.

Figure 6.1 An example of storing the data on accidents; the interview with MoID, UAE.

Within the interviews, the great majority of agencies (19 out of 21) have reported that they perform classification of accidents. For example, in Korea, there is a related traffic safety management standard. Traffic accidents are classified into A, B, C, and D classes according to the degree of damage and traffic blockage. The traffic accidents data classified as A-C are open to the public. The class D traffic accidents are managed as internal data. Traffic accidents are recorded in the integrated system through a report generated by the safety patrol agent. Death and injuries are classified according to the accident classification criteria of the National Police Agency – Death (within 30 days), Injured severe (> three weeks treatment) and Injured ordinary (> one day treatment). In addition, as reported by KEC, the collected traffic accident data are used as basic data for improvement projects.

Interestingly, almost all agencies in the interview (20 out of 21) reported that they collect information on road condition at the location of accidents. The IP in Portugal and Ministerio de Formento in Spain indicated that they carry out specific inspection and studies at black spots in order to determine and design the actions that are necessary to eliminate or reduce their accident rate.

In most developed countries there is an established procedure for road safety audit that is applied to examine an existing or future road or intersection and to identify opportunities for improvements in safety for all road users. These audits can often trigger improvement interventions.

6.4. USE OF DATA ON NATURAL HAZARDS IN ROAD IMPROVEMENT

The hazards are usually defined as sudden man-made or natural events which may impair road infrastructure. In recent years, they have become an important factor in the design of roads and their subsequent maintenance and improvement. So far, the impacts of hazards have been managed in such a way as to account only for the areas in the vicinity of infrastructure but with little or no attention being focused on events away from investigated locations. For the latter, the practice has shown that these are truly significant since they can jeopardize a significant portion of road infrastructure, as discussed in [31].

Many road agencies are developing comprehensive procedures to adequately consider hazards in their decision-making processes. Besides restricted budget scenarios, there are various uncertainties related to a hazard scenario, i.e. location, frequency, magnitude and unknown extent of related damage which represent significant issues for decision makers in implementing state-of-the-art research in practice. The most recent approaches are related to production of hazard and risk maps that identify the magnitudes, affected areas and most importantly the severity of eventual consequences.

6.4.1. Responses from questionnaire and interviews

According to the responses from the questionnaire, data on hazards are in the most cases solely collected “In-house” (28 responses). Other respondents rely on the government agencies and/or private companies or combinations of the three options (Figure 6.2). In 6 responses, no information is provided i.e. it can be concluded that these agencies don’t account for hazards in their practices.

In the interviews, more than half of the respondents (14/21) indicated that they share or obtain hazard data from other agencies and institutes (environmental agencies, government, police, etc.)

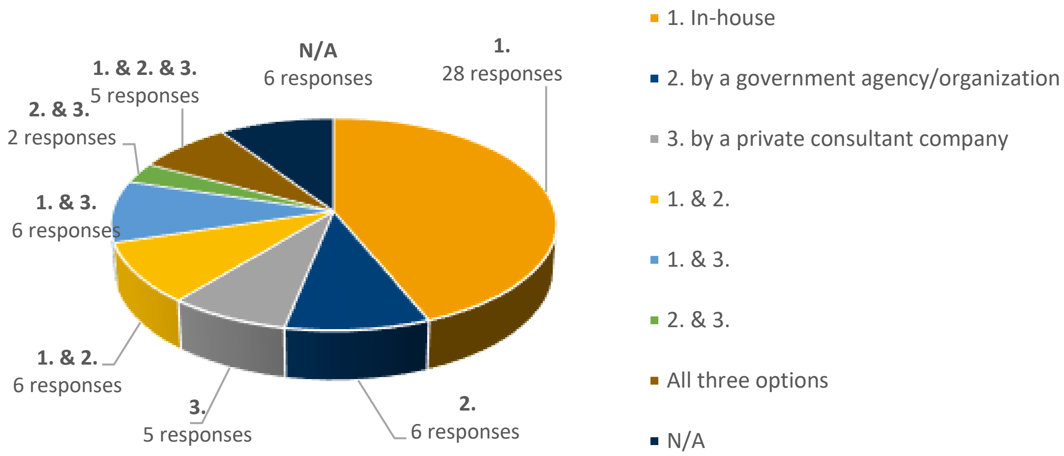


Figure 6.2 The practices of data collection on hazards; survey question H.1 - 64 responses.

When it comes to a way of storing the data on hazards, a variety of answers were also received. It is concluded that many agencies (28 out of 58), still don't use databases to structure their data, but only spreadsheets and/or archives (paper).

For the frequency of data collection, the majority of the respondents in the survey indicated that it takes place following an event (Figure 6.3). For others, the frequency of collection is carried out on an annual and/or seasonal basis, or at specific time intervals of several years (2 responses).

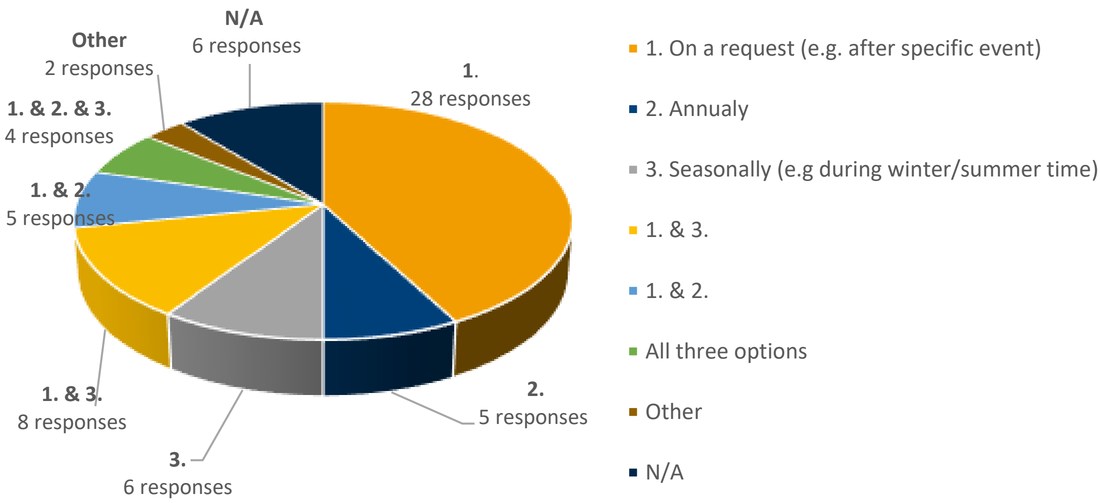


Figure 6.3 The frequency of collection hazard data; survey question H1.1. – 64 responses.

For data extent which is collected on hazards, agencies mostly record data on the magnitude of an event, direct costs and damage to infrastructure items and their exposure. Interestingly, only roughly 40% (22 out of 58) record the information on downtime of infrastructure items.

In the interviews, 8 out of 21 agencies reported that they have historical databases on hazards, but in 5 of the cases this data is not structured or is just limited to certain network locations. Two agencies indicated that they use hazard intensity maps in prioritization (Roadcare in Malaysia and NZTA in New Zealand) and more specifically the respondents from the UK (Highways England and Connect Plus) reported that they use maps of flooding hotspots and geotechnical hazards in prioritization of activities but not for initiating the interventions. Two agencies are using hazard maps for emergency planning but not systematically in decision-making process (COVIAL in Guatemala for floods, and DGCC in Mexico for bad weather and seismic events).

The Swiss cantons have recently completed hazard maps for gravitational hazards that focus on urban areas but can be used to assess the impact of hazards on road sections (e.g. [32]). In addition, since 1990's the hazard events are collected in a database StorMe and it is now a valuable source to assess the frequency of hazard events [33].

In addition to answering the questions in the survey, the agencies were asked to provide additional data on innovative approaches regarding collection, storage and usage of hazard data in their organizations. In Malaysia and New Zealand, photos and videos of hazard sites are collected. The agency SANRAL in RSA inspects critical slopes on a regular basis by routine maintenance personnel and report related data in their routine maintenance database. The Department of Planning, Transport and Infrastructure (DPTI) in South Australia, indicated use of an innovation tool for data collection - 'Rapid damage assessment tool' developed in the State Government Recovery Office. This is a spatial database currently used by police, fire department and State emergency services in their initial damage assessment at a location affected by a natural disaster event. In addition, fog, ice, smoke and temperature detectors report real-time information to DPTI's Traffic Management Centre via their platform STREAMS, where decisions to reduce speed or redirect drivers can be managed centrally.

In the UK, Connect Plus Services indicated that drainage sensors linked to advanced algorithms are used for early warning on flooding events. In Malaysia, the Belati Wangsa agency reported that during a monsoon season, specific surveillance is performed at vulnerable spots where incidents that can be caused by flood, erosion, mud flow are expected. In Norway, data on avalanche, flood and landslide hazard warnings are available in on-line maps. New Zealand Transport Agency report on using drones to capture videos/photos of a hazard aftermath to better plan restoration measures and estimate downtimes.

Thus, based on the responses from survey and interviews, it can be concluded that countries have specific guidelines and regulations when it comes to treating hazard impacts on assets and related management, but also that up to this point there is no unified approach, mainly owing to climate factors and various levels of exposure of networks to a whole range of different hazards.

6.4.2. Examples of approaches in practice

The consequences of landslide hazards are high not only due to the loss of human lives but also due to land erosion impairing infrastructure. The related costs in resources for emergency actions, replacement of damaged infrastructure and consequences to road users represent a significant percentage of the annual budget that a road agency might allocate to adequately maintain its road network. For example, in some regions of Chile which have suffered from such hazards, more than 4% of the budget allocated to road maintenance has had to be allocated for emergency activities and recovering road connectivity in the short term.

In Malaysia, a study discussed in [34] assessed slopes along roads and highways to predict the probability of a landslide occurrence in the 1990s. The results were then presented in the form of landslide risk and hazard maps and used to prioritize the maintenance of slopes (Figure 6.4). This work involved collecting a significant amount of data along the routes and required appropriate forms to record the relevant information. The most innovative aspect was that the spatial data were collected using a Digital Video Geographic (DVG) survey system, which integrates helicopter positioning, video images and laser profile data.

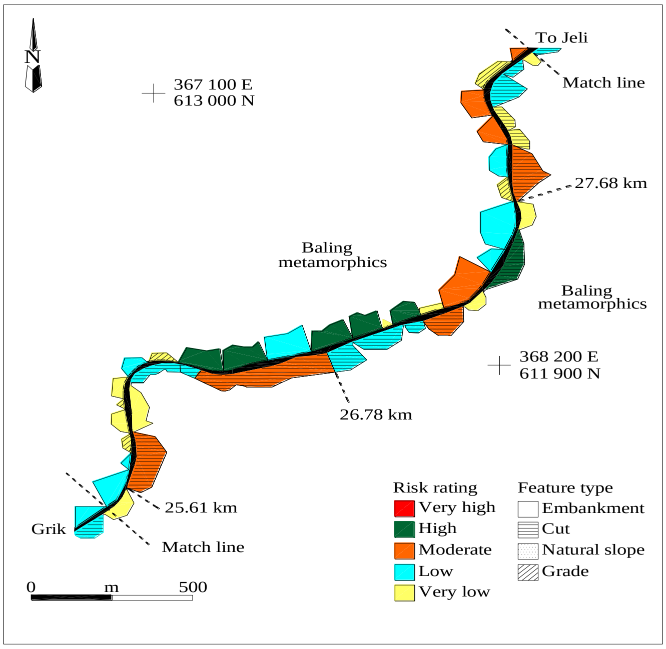


Figure 6.4 Typical risk maps for a section of the East-West Highway study in Malaysia; [34].

The landslide hazard identification and risk assessment project were carried out along 298 kilometres of the Tamparuli-Sandakan road in the state of Sabah, Malaysia. An analysis was carried out using the Statistical Package for Social Science (SPSS) software to correlate the occurrence of landslides with relevant factors - the main slope parameters that contributed to land sliding. The categories of landslide risk were classified on a scale of 5 values. This analysis was aimed at determining the probability associated with landslides, which can be correlated with the need for road improvements and subsequently determine the financial investments needed to control the hazard and its effects.

Potentially dangerous mass movements such as debris flows and rockfall are considered a major challenge in populated alpine regions which are inaccessible and thus difficult to treat and detect. A case of interest is presented in the example of Switzerland. In the analysis given [35], the movements of the Ritigraben rock glacier are analysed using images taken at time intervals which are projected in the Swiss coordinate system CH1903. The images are taken every three hours and then analysed using a MATLAB software [36] algorithm. The digital elevation model used for the projection of the time-lapse data was acquired using terrestrial laser scanning (TLS). The resulting horizontal displacement velocities and accelerations were validated against GPS data measured at one point on the rock glacier front. The high temporal resolution of the time-lapse image velocities provided new insights on the kinematics of the rock glacier front, which could not have been discerned with the GPS or TLS measurements applied. This simple and low-cost solution allows the observation of speeds and changes in the kinematics of mass movements and is, therefore, of great interest to road transport safety managers.

In Chile, the Roads Directorate of the Ministry of Public Works of Chile reports that approximately 750 million dollars are allocated annually for roads maintenance, and that part of these resources must be used to aid in the numerous emergencies that arise due to earthquakes, tsunamis, volcanic eruptions and landslides. The tsunami hazard maps (e.g. Figure 6.5) have been developed based on the effects of actual and recent events as well as on modelling of the events that could be triggered at any time. With the use of the maps, the affected areas can be clearly identified throughout the country, allowing choice and application of adequate and preventative actions to prepare the infrastructure to withstand events of certain nature and magnitude. The maps can also provide information on possible alternative routes for connections outside an affected area, thus greatly reducing consequences to users and society.

Figure 6.5 Flooding Area after the Tsunami of February 2010 in Chile; National Geology and Mining Service, Chile.

One of the natural events that can greatly impair infrastructure is an earthquake. Enormous resources are necessary to repair damaged road infrastructure, recover road connectivity and subsequently replace/retrofit the damaged infrastructure to comply with the same or higher quality standards in respect to the time prior to the event. In Chile, the ongoing research is related to soil types and the ways that seismic waves propagate through soil. This can provide valuable information when designing or improving road infrastructure to better withstand major seismic events, thus making road networks more resilient (Figure 6.6).

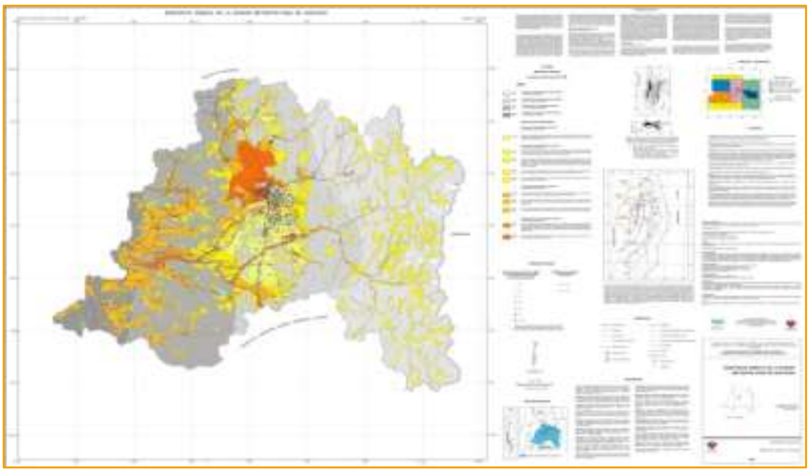


Figure 6.6 Seismic Response Map of the Metropolitan Region of Santiago, Chile; National Geology and Mining Service, Chile.

In Portugal, forest fire is one of the most dangerous hazards. In 2017, large forest fires caused many deaths on roads as vehicles were trapped in the fire. A study by the road administration followed to define specific measures for the roads on which fuel is transported, and which consisted of: screening of vegetation before the summer period by creating firebreaks i.e. vegetation-free 3m strips on the both sides of road shoulder and selective trimming of vegetation between 3m and 10m from a road shoulder. The rules on trimming of vegetation are defined by law, e.g. there is a minimum tree spacing of 4m defined (10m for eucalyptus and pine trees), or a maximum vegetation height of 50cm in shrub areas [37].

The previous examples indicate that the focus of road agencies must be broadened to account for areas beyond the level of a single item/segment of infrastructure to adequately maintain and manage its road networks. In the case of South American countries, the South American Council for Infrastructure and Planning (COSIPLAN) has developed a manual [31] with the methodology for COSIPLAN/IIRSA to incorporate the disaster risk management (DRM) process into the planning and development of regional infrastructure. Herein, there are three clearly defined phases:

- "Identification", which allows definition of the investigation and specification of the infrastructure(s) and threat(s) that will be considered in the risk study,
- "Risk analysis", which begins with the definition of performance objectives, the characterization of hazards and exposed infrastructure, and based on this, the depth, scope and terms of reference for risk analysis. Risk analysis as such and the identification of possible risk reduction measures are also carried out at this stage, and
- "Managing risk", where decisions are made based on the results of Phase II to reduce risk, transfer risk and/or prepare for emergencies and disasters.

The threats and risks associated with natural hazards, although they have been identified in the past, have become radically important recently because of climate change and increased road coverage. The hazards occur with greater frequency and magnitude and are having a stronger impact on road infrastructure. Road agencies should have methodologies for early detection of possible hazards and associated risks, to quantify their impact and to measure their probability of occurrence. Simple and economic methods such as the recording of mass movement using digital photography, or the mapping of areas affected by recent events, are data that should not only be obtained to record the event occurrence but should also be used to prepare road infrastructure in the face of future events and to estimate the levels of the related economic impacts.

6.5. TRAFFIC NOISE IN ROAD MANAGEMENT AND IMPROVEMENT

It is generally known that noise causes disorders to health when the recommended levels are exceeded. This is particularly valid for noise originating from movement of vehicles on roads and people living adjacent to these roads. Within the survey and interviews, there were no questions related to this topic, but instead the members of the WG3 were asked to provide crucial information on the regulations on noise from their countries.

In 2012 and 2013, CEDR launched four research and development projects, addressing various aspects of road traffic noise and noise attenuation:

- **DISTANCE** (**D**eveloping **I**nnovative **S**olutions for **T**r**A**ffic **N**oise **C**ontrol in **E**urope);

http://distanceproject.eu/ ,
- **FOREVER** (**F**uture **O**perational impacts of **E**lectric **V**ehicles on national **E**uropean **R**oads); http://forever.fehrl.org/ ,
- **QUESTIM** (**QU**ietness and **E**conomics **ST**imulate **I**nfrastructure **M**anagement); http://www.questim.org/, and
- **ON-AIR** with the aim of developing this guidebook on integrating noise into many aspects of road planning; http://www.on-air.no/ .

The main context and conclusions of these projects are summarised and available in the ON-AIR website.

The Organization for Economic Co-operation and Development (OECD) considers a noise level above 65 decibels (dBA) to be "unacceptable and incompatible with certain land uses" for its member countries [38].

In September 2017, the Conference of European Directors of Roads (CEDR) published a guidance document on noise in road infrastructure [39]. As a technical background, the guidance book presents a toolkit for the road planners working with noise problems. The document gives a brief description and background knowledge about noise assessment and offers practical methods for integrating noise as an important factor in road planning. Noise effects and management guidelines are presented as well as noise predictions in complicated situations such as tunnel entrances or at highway intersections with many lanes built as overpasses or bridges. Methods to assess noise, the impact of noise on recreational activities, the effect of general noise and noise from different sources, and the setting of priorities are also included in the guideline. The common procedures to reduce noise, including source, low propagation and receiver noise reduction are presented. There is a general rule that the most cost-effective noise reduction can be achieved at the source. However, noise barriers are often given priority.

The planning of new roads and the improvement or extension of existing roads is one of the key parts of the guidebook. It explains how noise can be described, analysed and taken into consideration at different stages of a road project; from early planning where knowledge of the project is low, through the Environmental Impact Assessment (EIA) stage where different solutions are evaluated and for more detailed project planning where the physical framework of the project is completed.

Road authorities have a responsibility to maintain road infrastructure and ensure that existing roads and road-related equipment are in satisfactory condition and that infrastructure assets are maintained as well as possible. The guidance document [39] explains how noise can be taken into consideration in maintenance procedures. It focuses on a continuous process of pavement maintenance, as well as the maintenance of noise attenuation structures such as acoustic barriers and earth dams. This includes planning and prioritising active noise reduction on existing roads with noise barriers and facade insulation, with a section on how to avoid the problem of an increase in existing noise that can be caused by urban development along roads and motorways, as well as by increased traffic.

A significant challenge facing urban road construction projects and construction projects near recreational and vacation areas is the need to plan construction-related noise mitigation measures. Although construction noise is temporary or short-term, it can adversely affect nearby owners, residents, users and wildlife. In this context, the Road Directorate of the Ministry of Public Works of Chile carried out a study in 2018 to make a diagnosis, information gathering and the development of a Model of Acoustic Emissions, following the steps of important initiatives in Europe and the United States of America. This study is the beginning of a work that will help the Chilean Road Directorate to identify the opportunities for evaluating, predicting and mitigating traffic noise. To date, Chile's Ministry of the Environment (MMA) has developed a framework that aims to obtain noise maps of regional capitals using modelling software and considering vehicle traffic as its main source of noise [40]. Work has already been carried out with vehicle traffic noise prediction models in the cities of Antofagasta and the municipality of Providencia [41], Santiago [42] [43] [44] and in the Gran Santiago [45] [46], among others. Based on these studies, the use of vehicle traffic noise models has become a fundamental tool for identifying and evaluating existing environmental noise on roads. It is now necessary to interpret this information and its possible use in environmental and asset management in order to implement as noise control measures at the local, regional and national levels.

In the last decade, many countries have carried out research on the different factors that influence the generation, transmission and reduction of noise resulting from vehicular traffic. CEDR published a document [47], which identifies three areas where progress has been made: quiet pavements, noise barriers, and cost/benefit and cost/effectiveness analyses.

In [39] methods are presented to facilitate the integration of noise mitigation in the three most common situations of national road administrations with regard to planning and management [48]:

- Planning of new roads and highways,
- Reconstruction and extension plans for existing roads and highways, and
- Maintenance and management of existing roads and highways.

According to the European Environment Agency's (EEA) [49], road traffic is the dominant source of environmental noise in Europe, with an estimated 125 million people in the European Union affected by noise levels exceeding 55 decibels (dB). This document indicates that the noise, in general, causes 10,000 cases of premature death in Europe each year, while almost 20 million adults suffer discomfort and another 8 million suffer from sleep disorders. More than 900,000 cases of hypertension are caused by environmental noise each year and noise pollution cause 43,000 hospital admissions per year.

In European national road agencies, there are ongoing activities related to the maintenance and management of road networks, as well as the planning of new roads and the extension or reconstruction of existing roads. Today, national agencies already take noise into account in many ways using different national methods and planning concepts. Useful information on the ways to combat noise pollution and current practice for communicating the impact of traffic noise to stakeholders can be found on the PIARC webpage [50].

6.5.1. Analysis of current road noise regulations

In this section, the most relevant regulations on traffic noise and its considerations in the management of road assets are discussed. It is interesting to know how far road agencies are prepared to include these regulations in their road infrastructure projects, whether in early stages or in maintenance or reconstruction stages.

6.5.1.1. Chile

In Chile, there is a noise emission standard [51]. The objective of this regulation is to protect the health of the community by establishing maximum emission levels generated by noise sources. Specifically, the regulation refers to emission of noise generated by activities that are or could in the future be located in a fixed location, for example: workshops, discotheques, bus terminals, construction activities, productive activities and commercial activities. This regulation establishes limits to be met, according to the time and land use of the site area of the receiver of the project or activity, which is assigned through the respective Territorial Planning Instrument.

6.5.1.2. The U.S. Federal highway administration (FHWA)

The FHWA has established in its Act: "23 CFR Part 772" a procedure for Reducing Road Traffic Noise and Construction Noise [52]. It is the standard (as mandated by 23 U.S.C. 109), which provides requirements for: (1) traffic noise prediction, (2) traffic noise impact analysis, (3) noise reduction criteria and (4) reporting requirements to local authorities. This decree applies to all projects that require FHWA approval or are funded by the U.S. federal government.

6.5.1.3. Swiss standard 814.41 on noise protection (OPB)

This Swiss Confederation regulation on protection against noise [53] is frequently applied in other countries, such as Chile, in the framework of the Environmental Impact Assessment System to evaluate the noise impact generated by vehicle traffic.

Its purpose is to protect receivers against harmful or disturbing noise and to regulate:

- Limitation of external noise emissions from the operation of new or existing installations,
- The delimitation and equipment of areas to be built in sectors exposed to noise,
- The granting of building permits for buildings with noise-sensitive premises and located in noise-prone areas,
- Insulation against noise outside and inside new buildings with noise-sensitive premises,
- The external noise insulation of existing buildings with noise sensitive premises, and
- The determination of external noise emissions and their assessment from exposure limit values.

It does not regulate:

- The protection against noise produced on the land of a farm, insofar as it affects the farm buildings and departments located there, and
- Protection against infrasound and ultrasound.

These regulations establish different assessment procedures associated with noise, including vehicle traffic, establishing different planning, emission and alarm limits, defined according to the sensitivity levels of each zone where the receiver or receivers are located.

6.5.1.4. Organization for economic cooperation and development (OECD)

In consideration of the current level of expertise and the economic implications of policies against road noise, the OECD proposes acceptable maximum limits on the facades of road housing areas, which can be achieved in the medium term, i.e. within 5 to 10 years. An equivalent sound pressure level of 70 dBA is set as the maximum acceptable value for the daytime running time on an existing road and an equivalent sound pressure level of 50 dBA is desirable for new roads at night [54].

6.5.1.5. World health organization (WHO)

The WHO indicates recommended noise values so that there is no interference with people's health. The Urban Noise Guidelines were prepared as a practical response to the need to act on urban noise, as well as to the need to improve legislation, management and guidance at national and regional levels. WHO guideline values are ordered by specific settings and critical health effects. The guide values consider the adverse health effects identified for the specific environment. The adverse effect of noise is any temporary or long-term impairment of physical, psychological or social functioning related to noise exposure. For each health effect, specific noise limits were set at the lowest level that produces a negative health effect (i.e. the critical health effect).

While the guide values refer to the sound levels affecting the receiver most exposed to the environments mentioned above, they can also be applied to the general population. The time for LAeq (A-weighted equivalent sound pressure level) during the day and night is 12 to 16 hours and 8 hours, respectively. No time is set for the morning but generally the guide value should be 5 to 10dB less than during the day.

6.5.1.6. The U.S. Federal transit administration (FTA)

The FTA has guidance on how to evaluate the noise and vibration impacts of proposed mass transit projects. This guide called "Transit Noise and Vibration Impact Assessment" [55] is used by project sponsors seeking funding to assess these impacts during the environmental review process. The guide contains procedures for assessing impacts at different stages of project development. The focus is on noise and vibration impacts during operations, but the impacts of the construction stage are also covered. The guide describes a range of measures to control excessive noise and vibration. The guide defines three impact magnitudes as a function of the increase in basal noise level: a) no impact, b) moderate impact and c) severe impact.

6.5.1.7. European Union (EU)

Approximately 40% of the population in EU countries is exposed to vehicular traffic noise at levels above 55 dBA, 20% is exposed to levels above 65 dBA during the day and more than 30% is exposed to levels above 55 dBA at night [56]. Some of the EU member countries that have been most concerned with improving the environmental conditions of their cities, report regularly on progress in terms of noise mitigation. For vehicular traffic noise, each country has established emission limits for new residential areas (Figure 6.7).

EU Member State	$L_{night,outside}$
France	62
Germany	49
Spain	45
Netherlands	40
Austria	50
Sweden	51 (converted from L_{Aeq} limit 30 dB(A) inside bedroom)
Finland	46
Hungary	55
Latvia	40
Estonia	45
Switzerland	50

Figure 6.7 Reported L_{night} limit values for road traffic noise in new residential area; adapted from [56].

6.5.2. Noise mitigation measures

The best solution to mitigate the traffic noise is to reduce the noise emission coming from its source i.e. interaction of a tyre and pavement. Additionally, the reduction of noise from car engines can make a significant contribution in urban routes, especially those with low traffic speeds. For the latter, it is necessary to implement changes from noisy combustion engine technology to quieter engines, such as those in electric vehicles. This measure can only be considered in the long term and through incentives for change from government agencies. The planning of traffic flows and the planning of cities can also make an effective contribution to mitigation of traffic noise. Significant decreases may be obtained, by increasing the distance between traffic and residential areas. In the following, a summary is given of the mitigation measures commonly used to reduce noise from road traffic, i.e. noise barriers and noise-reducing pavements.

6.5.2.1. Noise barriers

Noise barriers are the most widely used measure in the world to reduce the noise generated by vehicular traffic. The design of barriers must consider aspects related to noise reduction, urban design, safety and maintenance considerations.

The fundamental principle in noise reduction of an acoustic barrier is to block direct noise between a traffic lane and a given receiver (e.g. residential area). The mechanisms that affect the performance of an acoustic barrier are diverse. The barrier needs to be designed so that it can reduce the noise generated in the traffic lane (sound source) and must consider both acoustic and non-acoustic aspects. Fundamental design considerations must include the material, effective height of the barrier and its shape as well as the position where it is installed with respect to the source and receiver. The non-acoustic aspects include the design of the foundations and pillars to adequately support the static, dynamic and wind loads to which the barriers will be subjected to. In the following, a brief review of various barrier types is given.

Wooden Barriers

Wooden barriers are used in different parts of Europe, the United States and Australia. One of the comparative advantages is the lower price of these barriers. Other advantages include versatility in installation, given the ease of modification or cutting on site (Figure 6.8). From an aesthetic point of view, this type of barrier is normally preferred by the residents where it is installed, in comparison to concrete or steel barriers. One of the main disadvantages is the combustibility of wood. Also, when the correct type of wood has not been chosen or installation is inadequate, it is common to encounter problems where cracks and openings degrade a barrier's attenuation performance.

Figure 6.8 Examples of wooden acoustic barriers installed in Europe; [57].

Translucent Barriers

In recent years, the use of this type of barrier has increased worldwide, principally given the advantages related to the transparency achieved with the use of transparent panels (e.g. Figure 6.9). In general, this type of barrier is preferred when panoramic views or natural light restrictions are an essential requirement. There are three materials commonly used in translucent barriers: Polycarbonate, Acrylic and Glass. Some of the issues reported include a higher cost of implementing such barriers than a common solid barrier. Other disadvantages include deterioration in transparency over time mainly in acrylic panels. This phenomenon increases more rapidly when there is little or no scheduled maintenance of these barriers. Combustion problems in the case of acrylic or toxic gas emissions in the case of polycarbonate panels are also reported. Finally, with respect to vandalism, it is quite common for this type of barrier to be subject to graffiti.

Figure 6.9 Examples of translucent barriers in Denmark; [57].

Earth barriers

This type of barrier represents a favourable solution for implementation outside the urban environment or in rural areas. Greater space is required for the installation of these barriers but they allow greater integration with the natural environment (e.g. Figure 6.10). An important factor in the design of earth barriers is the proportions required between the slope, height and width of the embankment to maintain its stability. For example, the design of a 4-metre-high earth barrier will require a 13-metre-wide base to maintain its stability. Comparative advantages of this type of barrier are the low maintenance cost it requires, its durability, and the absence of graffiti-related vandalism. In addition, it may represent an alternative for the use of any excess fill generated from the construction of road schemes.

Figure 6.10 An earth Dike as a noise barrier in Germany; [57].

Green Walls and Bio-Barriers

Bio-barriers are constructions of wood, steel, recycled materials, concrete piles, etc., built to incorporate plants into their structure (Figure 6.11). They represent an alternative to earth barriers, in places where there is not much space to install them. A green wall is a vertically installed vegetation wall made from small containers filled with organic membranes, which implies a highly efficient system in terms of irrigation and maintenance. From an acoustic point of view, this system, like the previous one, complies with the minimum sound insulation and absorption requirements of EN 1793. On the other hand, they provide an increase in air quality, biodiversity and impact on landscaping and aesthetic design value.

Figure 6.11 Examples of barrier types: Green Wall (left) and Bio-barrier in construction (right).

Barriers with Photovoltaic Modules

The barriers that integrate photovoltaic panels have been in development since 1989, when they began to be installed in several European countries such as Switzerland, Germany, Italy and Netherlands. These barriers benefit decentralized electricity generation, providing a clean alternative energy system. Given the strong reflection component of the panels, the design should include a certain inclination. However, the final configuration will depend on the sun orientation of the route to be protected. Studies presented in [58] show advantages of photovoltaic barrier systems in "T" type configurations and with elements at the top inclined vertically 60^{o} (Figure 6.12). Some of the disadvantages for this type of barrier are problems with maintenance of the inverters and other components, in addition to the cleaning or replacement of the photovoltaic modules themselves.

Figure 6.12 Examples of barriers with photovoltaic panels installed in Brennero Italy; [58].

6.5.2.2. Silent or noise-reducing pavements

Faced with the high costs of acoustic protection, such as noise barriers in urban areas, the renewal of pavement by the use of noise-absorbing asphalt may appear to be an attractive palliative solution. In the U.S., this mitigation measure is known as use of "Quieter Pavements", whereas in Europe it is generally referred to as use of "Noise Reducing Pavements". Beyond the question of financing the laying of these more expensive pavements, the question of the mechanical and acoustic durability of acoustic asphalt must be addressed before any generalization can be considered. Indeed, the financing of these operations must include both the additional costs of implementation and the additional costs associated with reduced life cycle of the pavement.

In the U.S., the Federal Highway Administration (FHWA), funded a publication called "The Little Book of Quieter Pavements" in 2007 [59]. Several US state highway agencies have responded by researching and implementing solutions to develop recommendations for safe, durable, and cost-effective concrete pavement surface textures that minimize noise from tyre/pavement interaction besides the research on concrete [60] and asphalt [61] pavements.

In 2018, the French state and the Île-de-France Region decided to finance experiments with acoustic asphalt paving on national motorways as part of a more comprehensive action plan covering other types of innovation. The evaluation of this experiment will last three years and will aim to monitor the mechanical and acoustic characteristics of the materials. The monitoring of the mechanical characteristics will then be continued beyond the three-year period. Pending the results of ongoing experiments, on the basis of a reduced lifetime of 6 years compared to 10 years and an additional implementation cost of 25%, the additional investment cost can be estimated at twice the cost of conventional pavement.

7. COMMUNICATION

7.1. INTRODUCTION

Communication is a growing concern for road authorities all around the world as stakeholders and the general public seek regular and accurate information regarding the performance of national road assets. Increasing the focus on users is actually one of the four pillars mentioned by Austroads in [62], where the proposed practices are presented as having the ultimate goal of better responding to the needs of communities, users and stakeholders.

This chapter addresses the key findings from the survey and interviews on this specific topic. The communication practices between road authorities and road users are considered along with the processes involving road authorities and political decision-makers, including issues such as service level reporting. The innovative examples are presented and discussed for road authorities to consider in the future in this field.

7.2. SURVEY ANALYSIS AND KEY FINDINGS

Within the survey, the respondents entered information on their communication practice in a free text field. Thus, the first step in the survey analysis was identification of the general features of the practices reported, allowing for a statistical overview of the results. The features covered were: communication format, its frequency, the target body and the information type. Additionally, situations were identified where road users could communicate regularly with the infrastructure manager (IM), e.g. phone line or webpage for requests/customer feedback. The features mentioned and related options are reviewed in Table 7.1.

Feature	Possible options					
Communication practice reported	Yes	No				
Format used	Web	Social media	Printed media	TV/Radio	Outdoors	Not specified
Frequency	Constant	Monthly	Annually	Other	Not specified	
Target	Government/ Regulatory entities	General public	Other stakeholders	Not specified		
Information type	High-level/KPIs	Reports	Other	Not specified		
User to IM communication reported	Yes	No				

Table 7.1 Selected features and related options in the reported communication practices; survey question Ai3.

Only 70% of the answers (45 out of 64 responses) mention communication practices. It was considered that if nothing is reported (i.e. blank field submitted), it counts as the related organization does not follow relevant communication practices. It was analysed if the type of organization, size of network and other features are correlated with the communication practices. The considered features were: (1) Organization type (public and private); (2) Network size (km); (3) Network type (motorways or other roads); (4) Toll collection in the network; and (5) ISO 55000 compliance. Table 7.2 summarizes the results, where given percentages are with respect to chosen feature, e.g. for feature (4), 63% of agencies in the survey that have tolling system also apply communication practices.

(1) Organization type		(2) Network size (km)		(3) Motorways > 80% of the network		(4) Tolled roads		(5) ISO 55000 compliance	
Private	80%	< 1 000	43%	Yes	62%	Yes	63%	Yes	43%
Public	67%	1 000 < > 20 000	88%	No	76%	No	81%	No	78%
		> 20 000	76%						

Table 7.2 Application of communication practices in the cases of the five chosen agency and network features; survey questions G4, G9 - twice, G11, Ai2, respectively - 64 responses.

The results show that communication practices reporting is more prevalent for private companies. Considering network size, communication practices are frequent in the cases of larger networks, but the presence of motorways or tolled roads does not seem to be of importance here. It could be the case that, for higher hierarchy roads where users pay for the use, communication may be more common compared to other roads, as users may ask for more information, e.g. on the road condition or regarding future investments. Lastly, regarding ISO 55000, results don't show that compliance with this standard is correlated to application of communication practices.

The second part of the analysis was focused on the investigation of the most common formats reported, communication frequency, identified targets and the type of information used within those communication practices (Figure 7.1). Regarding the communication format, the web is undoubtedly the most commonly used for reporting (35/45 responses), followed by TV or radio, and printed media with the same share.

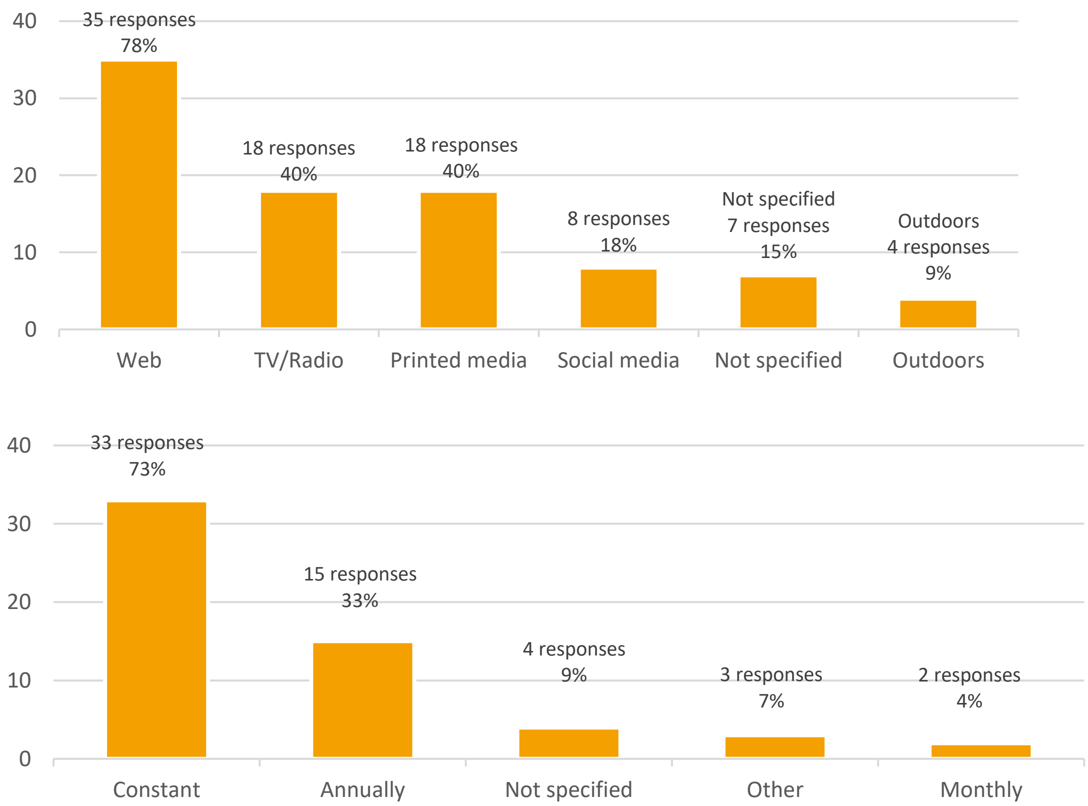


Figure 7.1 Reported communication formats (upper chart); Reported communication frequency (lower chart); survey question Ai3 - 45 responses.

A significant number of answers mention the use of social media. Regarding frequency, most answers mention constant communication i.e. information made available on the company's websites on regular basis. In several cases, this is only performed annually.

The surveys answers indicate that the general public is the primary target of the communication practices, followed by the government or regulatory entities (Figure 7.2). Even though the latter cannot be considered as a public format, it is relevant in the context of providing information to shareholders. Reports are the most common answer for the type of information provided, but the reference to high-level information (such as KPIs) is also relevant.

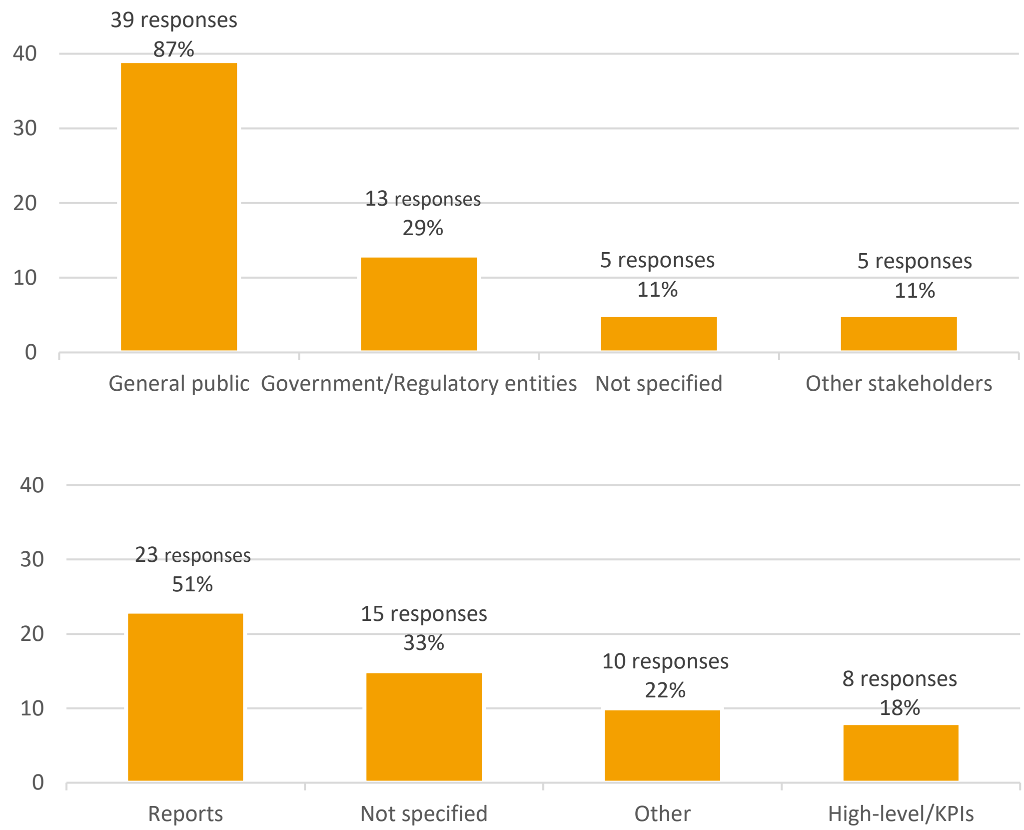


Figure 7.2 Reported communication targets (upper chart); Reported information type included in communication practices (lower chart); survey question Ai3 – 45 responses.

Finally, it should also be mentioned that 13 answers (20% of the total responses) reported practices where a road user can easily interact with the infrastructure manager (e.g. reporting a poor road condition). In these cases, the vast majority of respondents are public companies (11 of 13).

For the interviews, the template followed by the interviewers while addressing road authorities across the world did not include specific questions related to communication practices. However, in some cases, the topic was mentioned, and relevant practices will be described in the following sections.

7.3. DIVERSE COMMUNICATION TOOLS FOLLOWING CHARACTERISTICS OF INFORMATION

Based on relatively short and general responses in the surveys and interviews, not much information could be extracted on examples with innovative ways of communication. The more general features of diverse ways of communication are addressed in the following.

Most countries, which responded to the survey, apply similar tools of communication, from letters to Social Network Service (SNS). The selection of a proper communication tool is very important for an effective communication practice. The NCHRP report [63], emphasizes the necessity to figure out what channels people are using to gather information about transportation issues. It is considered as most effective when using all three major avenues of delivery including traditional, one-on-one, and new internet media opportunities. Choice of the tool of communication depends on the kind of information and to whom messages need to be delivered. In this chapter, examples will be presented to illustrate the relationship between information type, who needs it and how it is delivered. The relationship between data and communication tools will also be discussed through the results of the survey, by searching respondent's website, and by other references.

The interview from the New Zealand Transport Agency (NZTA) indicates link across almost all the communication methods and information the organization offers. This is discussed further in the following section along with comparison with other examples.

7.3.1. Open data Policy

Most websites which are listed in the survey, especially governmental and public entities' websites, display diverse information from policy to practical data. Some countries have guidelines about public data disclosure.

New Zealand has a policy which officially opens governmental data to the public. According to the policy, as a public body, NZTA via its official website provides its data to the public in the form of report, statistical data, video, etc. In addition, certain data is provided through mass media, mobile applications and SNSs.

In South Korea, the public can easily access abundant information on all public bodies in South Korea as this is defined by law. The Ministry of Economy and Finance (MOEF) runs an open data web site (Figure 7.3) which provides general information on 338 government-owned organizations. This information includes: key business features, performance achievement, salary levels from board members to general staff, government audit reports, financial statements, recruitment schedules, etc.

Figure 7.3 ALIO - all public Information in one-system; MOEF, South Korea.

7.3.2. Statistical data on a road network

Statistical road data are mainly represented in a form of a data spreadsheet along with a typical fixed report type, paper or a pdf file, which usually consists of numerous tables of data.

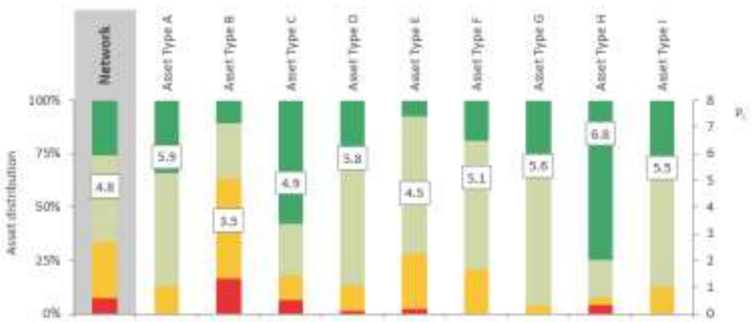
Most countries, which answered the survey or interview, have web pages that are dedicated to present major statistic data on networks. The data sets which NZTA provides in the field of road and transport are: length of road network, traffic volume, vehicle-kilometre, accident, safety, public transportation, etc. Ministry of Land, Infrastructure and Transport (MOLIT) in South Korea also provides similar kinds of data. This network data on web sites can be easily downloaded in a spreadsheet form and used without restrictions.

7.3.3. Information on Performance

Performance information is generally provided in the form of an annual report of an organization. It is published in a paper form or a pdf file uploaded on the organization's web site. It usually looks like a scorecard which shows either good or poor road/network performance for a certain period of time. Based on this, an organization can be assessed by its stakeholders and can make plans for the future. In New Zealand, the NZTA provides its State of Performance Expectation and annual report in the form of a pdf file which is available to public. The DPTI of South Australia similarly communicates performance to the general public through Annual Reports and this includes a review of objectives archived from of South Australia's Strategic Plan.

Assessing and reporting the performance of its assets is a crucial task for organizations acting as road infrastructure managers and is also a widely recognized need as stated in the applicable standards (ISO 55001). However, the need for standardized approaches arises when the performance of the different asset types in a road infrastructure is reported, not only to top management but also to the general public and other stakeholders.

For example, Infraestruturas de Portugal uses the performance indicator P (ranging from zero – the worst, to eight – the best value) in the annual publication of a Network Condition Report (Figure 7.4). The value of this PI is based on a percentage of assets in four (qualitative) condition states: Good, Satisfactory, Attention required and Unsatisfactory.



	Network	Asset Type A	Asset Type B	Asset Type C	Asset Type D	Asset Type E	Asset Type F	Asset Type G	Asset Type H	Asset Type I
Good (%)	28	34	11	58	21	8	19	31	75	34
Satisfactory (%)	41	53	26	24	65	65	60	65	18	54
Attention required (%)	26	13	47	11	12	25	21	4	3	12
Unsatisfactory (%)	7	0	17	7	1	3	0	0	4	0
P, year n (trend from year n-1)	4.8	5.9	3.5	4.9	5.8	4.5	5.1	5.6	6.8	5.5

Figure 7.4 Overall network condition by asset type; Infraestruturas de Portugal, Network Condition Report.

Another example is performance reporting using various dashboards which comprise the high-level KPIs (Figure 7.5).

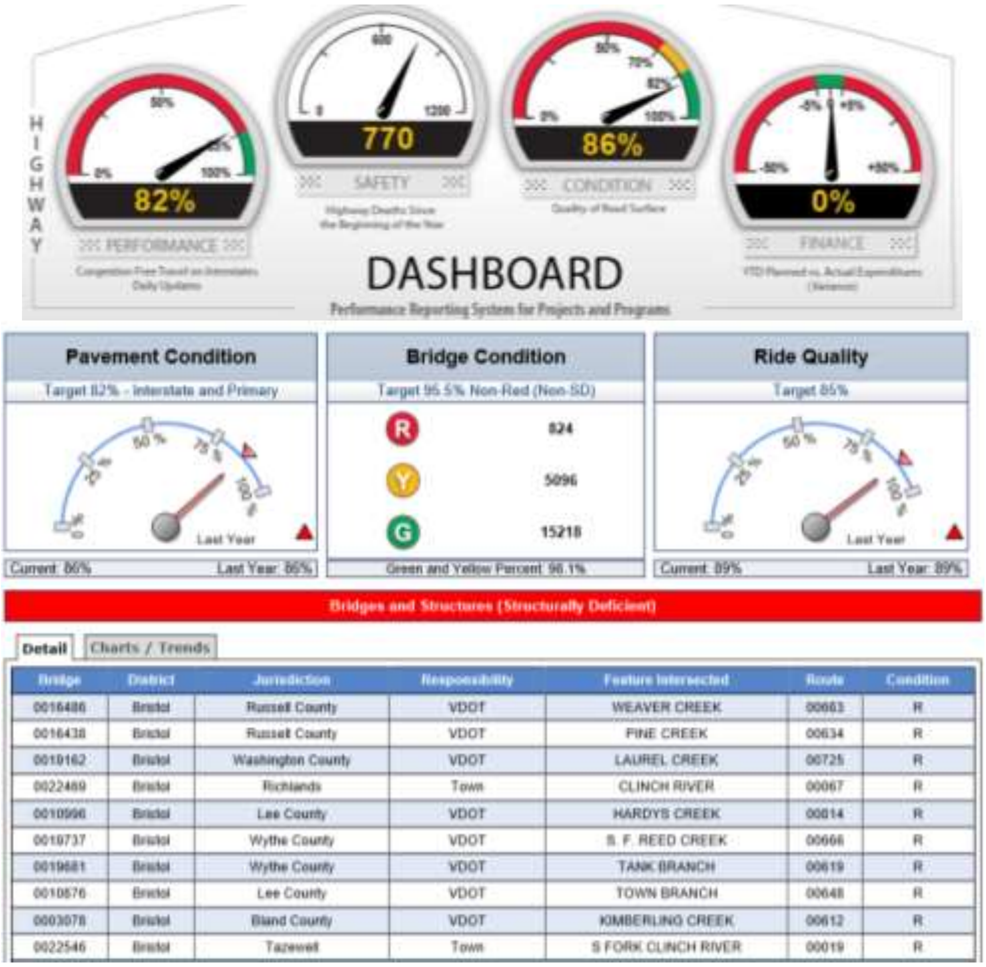


Figure 7.5 An example of performance reporting by VDOT, USA; [64].

The gauges in the dashboard in Figure 7.5 are interactive, i.e. on the web page one can click on them and access another dashboard with more detailed information. In this way the user can drill-in into data. As an example, and for the condition indicator (second image from the top), data on the condition of pavements, bridges and ride quality is displayed. More specifically, the condition of the bridges managed by this organization (Virginia Department of Transportation) is fully accessible with it being possible to analyze both the evolution of the indicator as well as the condition of a given structure.

7.3.4. Traffic condition data

There are several entities which provide traffic condition data such as telecommunication service providers, road operating companies and regional governments. The organization which takes the role of operation and maintenance of road is the source of traffic condition data. It offers traffic condition information to diverse bodies such as mass media, telecommunication service provider, government, customers for onward dissemination.

In New Zealand, the NZTA provides core traffic condition data as a data feed for third party application providers and provides traffic conditions such as travel time, incident and road works information through its web page, SNS services like Facebook, Twitter, etc.

In addition to using the communication tools described above, reporting through mobile phone app is one of the best ways to deliver traffic information to stakeholders. The traffic conditions on the expressway network in South Korea is provided through the mobile app ‘Road Plus’. It displays a congestion map, traffic forecast, real-time traffic condition video, etc. (Figure 7.6). The road users can access traffic information to make optimized decision for their journey both before and during that journey. It also provides the fuel prices for all service areas in the expressway network.

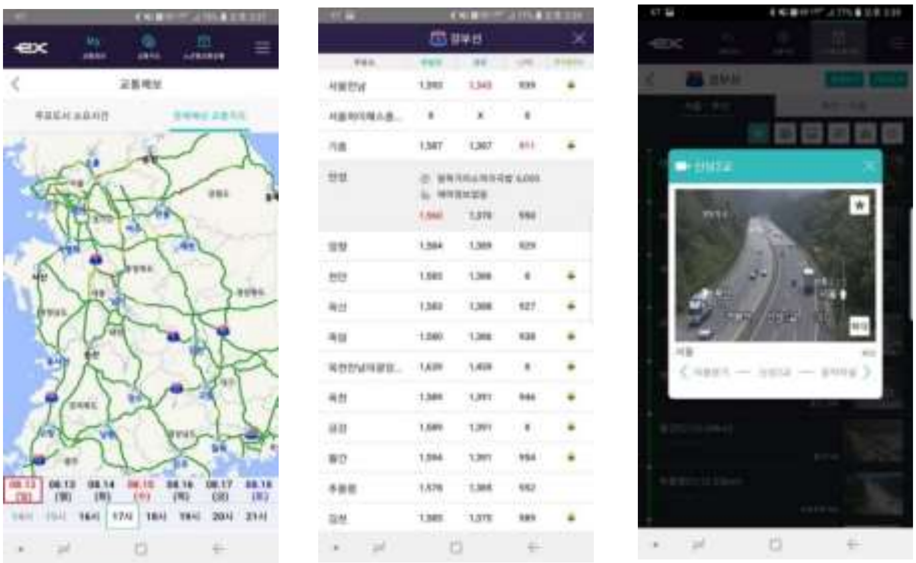


Figure 7.6 Example screenshots of the Road Plus App used in South Korea.

Agencies also usually display live traffic from CCTV (Closed Circuit Television) on road side and control cameras in the offices, on their websites. For example, Infraestruturas de Portugal monitors and manages its road network through the system which can discover and display abnormal events in the network (Figure 7.7), such as accidents, drivers needing assistance, the presence of wild animals crossing the road, severe weather situations, etc.

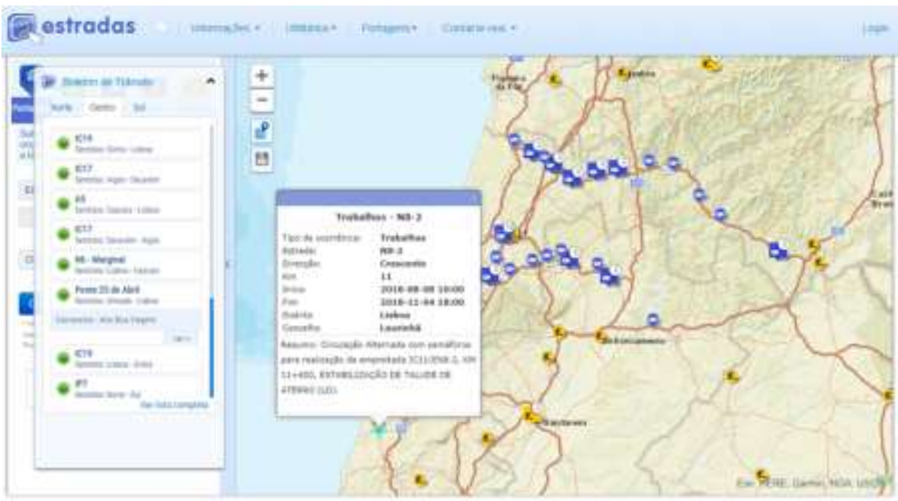


Figure 7.7 An example screen of a website with CCTV linkage on the road network in Portugal, also displaying ongoing or planned road works; Infreastruturas de Portugal.

Road works and traffic accidents are major factors affecting traffic flow. Information on the programme of works, which are carried out by a road operator, is commonly provided to the road users via TV, radio, webpage and social media. In the case of traffic accidents, it is difficult to predict and prepare announcements ahead. Communication tools on the road such as variable messages signs (VMS) are used to inform the drivers behind the accident spot of a safety hazard. Also, in order to reduce traffic congestion caused by accidents, TV, radio, internet and mobile apps are commonly used communication tools which can immediately deliver message to the public.

7.3.5. Current and Future Projects (Investment Plan)

The information on current and future projects are important not just for road users but to other stakeholders such as politicians, local residents, and contractors. Usually public hearings are preceded before decision making on new projects. The agencies usually post key information on major projects on their websites including costs, duration and benefits to stakeholders.

7.3.6. Safety and educational messages

One of the main concerns of road organizations is safety of road users. In general, safety comes from both the infrastructure side and the human factor, i.e. drivers and pedestrians. Thus, there are two types of safety messages. The first one is in a form of a notification via variable message signs (VMS) or voice/pop-up message on navigation in a car, which informs about a dangerous situation ahead on a road. The other type of messages is in a form of a safety campaign which is distributed to the public via mass media. The road organizations continuously produce and share educational information that enhances safety in human behaviour elements, such as safe driving habits and action in case of road accidents. Communication tools for educational campaigns have been spread rapidly from traditional mediums such are brochures, posters and TV campaigns to internet and social networks (e.g. websites, YouTube, Facebook and Twitter) (e.g. Figure 7.8).

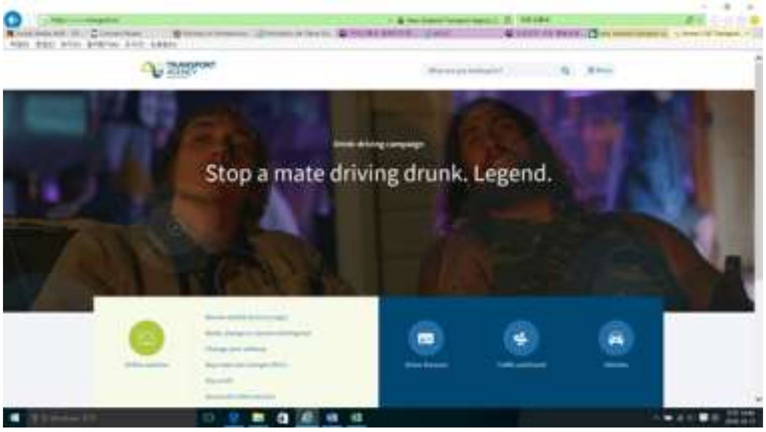


Figure 7.8 A video clip on drunken driving hazard; New Zealand Transport Agency website.

The South African National Road Agency Limited (SANRAL) uses two road safety campaigns, “WHOA!” and “Road Safety 365”. The goal of the first one is to raise drivers' awareness on the importance of resting more often while on the road during holiday periods. The second campaign is aimed at general safe behaviour in traffic and its influence on the future generation (Figure 7.9).

Figure 7.9 Two safety campaigns on road safety education & awareness by SANRAL in South Africa.

Other countries have similar campaigns also. Worthy of note are those from ASFINAG in Austria and German Federal ministry of transport and digital infrastructure (BMVI), which have a more alarming way of conveying the safety message on avoiding hazards due to divided attention while driving (Figure 7.10). The campaigns are not only deployed online, but also on billboards along highways.

Figure 7.10 The „Hallo Leben" campaign by ASFINAG, Austria (left); The "Runter vom Gas" campaign by BMVI, Germany (right).

7.4. CONCLUSIONS AND DIRECTIONS FOR THE FUTURE

Ways of communication between road agencies and stakeholders are becoming more and more diverse and expeditious and range from paper reports to social network services (SNS) thanks to the rapid development of telecommunication technologies. Utilization of various communication tools assists in delivering crucial information to stakeholders. Such information is now ever more transparent, economical and efficient than before. Most data and information are uploaded to agencies` web sites and they are linked among different tools.

7.4.1. Website, Mobile & Social media

Information delivery through on-line communication tools is becoming a common approach among different road and transport organizations. The website becomes the hub of diverse communication tools (e.g. see Figure 7.11). The report [63] indicates "A website can serve as the home for preservation initiative. It can provide a one stop for all of the materials and news related to the effort and allow to communicate with citizens and stakeholders in an inexpensive way". When it comes to adopting social media as a communication tool, there are several social media which are commonly used by the road organizations. Facebook, Twitter and YouTube are the most frequently used.

Figure 7.11 Examples of web pages with social media links to road organizations; upper left - Ministerio de Obras Públicas (Chile), upper right - NEXCO EAST(Japan), lower left – Department of Planning, Transport, and Infrastructure (South Australia) and lower right - VINCI Autoroute (France).

7.4.2. Whenever and wherever you are, you will be connected

In the past, communication between road agencies and stakeholders was predominantly a one-way: through annual reports, via mass media, in newspaper articles, etc. The interactive way of communication was limited to mail and phone calls. Now, thanks to rapid IT development, the public, drivers, passengers, researchers and other stakeholders can get a large amount of both academic and practical data on assets almost whenever and wherever they are. As a result, the public and users are participating more actively and specifically in road management and operation. The accumulation of various user information has allowed agencies to develop and provide more customized services. This has also made the management systems evolve more rapidly so that asset operators can be more flexible and more prompt in response to various performance issues.

8. INSTITUTIONAL AND ORGANIZATIONAL ISSUES

The survey and interview did not cover institutional and organizational issues, so that no results can be presented here. However, in WG discussions some insights in organizational structure in European countries has been revealed. There is an increasing trend to overcome traditional silos structures based on asset types. This means that the asset managers need to cover all asset types, which given their technical complexity is an increasingly challenging task. It has become clear that asset managers should act as long-term trustees of road infrastructure and they should:

- inspect and monitor infrastructure,
- forecast future development and assess associated risks,
- define if necessary, the cornerstones of the interventions and when it should be performed,
- hire an internal project manager to tender and manage the execution of interventions
- supervise the tender documentation and execution of interventions
- examine the outcome of the intervention, and
- store the relevant intervention data (e.g. costs).

The project managers are commissioned by an asset manager as a total contractor and act in accordance with requirements set by the asset manager. The project manager has to:

- tender the maintenance or improvement project,
- award the project to the best bidder,
- perform the time, quality and cost control,
- accept the finished project, and
- hand it over to the asset manager.

For the asset manager, the long-term commitment to a physical asset is of high importance, as is the performance of this asset within the road network. The generalist view of the asset manager is necessary in order to recognize pitfalls that may pose risks for road users. Regarding the specifics of each asset type, an asset manager needs to have access to specialists.

Modern road organization should be organized by distinguishing between asset managers and project managers, with specialists that serve as consultants to both. These general organizational guidelines should be followed disregarding the interfaces between government agencies, public enterprises and private companies.

9. CONCLUSIONS

In the last 40 years road organisations have been striving to adapt and upgrade their policies and procedures using the benefits of novel IT technologies. The efforts have been aimed at elaborating and applying innovative methods to collect useful data and to transform them into high-quality information. Furthermore, significant efforts have been put to resourceful approaches to use this information in decision making.

The work of Technical Committee D1 “Asset Management” focused on investigating the organisations’ procedures/policies and management systems to identify innovative approaches. Here, the most significant advances are made in acquisition/processing of inventory and inspection data. Recording and storing of video data has been applied to update existing inventories and gather new data. Although still in the testing phase, the application of sophisticated equipment such are UAS with image capturing devices (i.e. drones) and LIDAR is reported by many road organisations as a promising bedrock for management procedures and everyday work. Besides various vehicle-mounted devices that are used for collecting data on road condition, the latest trend is involving users in this inspection process (e.g. via smartphones and social media). Working with big data and inputs from various sources are seen as the greatest challenge for asset managers. However, several road organisations are already dealing with this issue and are using systems where information from various databases are interlinked, which allows stakeholders to seamlessly access and display relevant asset information. Only a few organisations reported that they apply Building Information Modelling (BIM) and are using 3D asset coordinates, which is certainly a path which others will soon follow.

The practices in routine and major maintenance vary around the world, as do the related innovative approaches. The main differences stem from a country’s wealth, size of network and its topology, which affect the adopted value system in defining organisational and asset management goals. Asset condition rating, which result from visual inspections and is supported by engineering judgement, is in many cases the main trigger for maintenance interventions. However, many road organisations also use numerous performance indicators and key performance indicators when planning maintenance and improvement interventions. The most reported indicators are: Reliability, Availability, Safety and various types of costs. The prediction of these indicators over time is predominantly carried out using deterministic models, but probabilistic models are also being applied. Currently, the risk/vulnerability approaches govern decision making for only a small number of surveyed road organisations (10 out of 64), but eagerly used in face of budgetary constraints. Although the performance indicators are introduced to address various asset goals (e.g. levels of service) and to optimize resource spending, the trade-offs between these indicators is still not carried out in a systematic manner or it is rarely performed. The organisations strive to consider requirements of all stakeholders regarding utilization of road infrastructure in a decision-making process. However, at the moment there are only a few organizations which carry out integral (or cross) asset management. This was also confirmed in the interviews, where the most of organizations indicated that they plan maintenance for each asset class separately, based on heuristic rules and priority/criticality ratings. The basic compliance of organisations’ policies with ISO 55000ff was only directly confirmed by 20% of the surveyed respondents but it was nonetheless emphasized in the interviews that organisations’ goals are improvement of current practices rather than just ISO 55000ff certification. The application of BIM in maintenance projects is currently limited to capital infrastructure assets, such are landmark bridges and tunnels. The BIM extension to entire asset inventories and related change in decision-making procedures are acknowledged by many organizations as a future, inevitable step. Both academic and engineering communities are already working on practice-ready solutions to seamlessly apply novel technologies that allow for this transition.

The one of the principal goals of road organisations is to increase the benefit from road assets by gathering traffic, accident and hazard data. The main objective of road organisations lies in reduction of accident rates (black spots) in network and to this end most of the road organisations collect their own data on the causes of accidents and on related damages/downtimes of infrastructure objects. Traffic data is usually used for prioritization when assets are in comparable conditions. The traffic models were reported to be used widely but with variable impact in decision making. Innovative approaches in road improvement are found in the field of noise protection, where the majority of countries have their own regulations. The instalment of various types of noise barriers are the most common solution but more lately noise-reducing pavements have been on trial. Countries have specific guidelines and regulations when it comes to treating hazard impacts on assets and related management, but up to this point there is no unified approach, mainly owing to climate factors and various levels of exposure of networks to different hazards. Advanced methodologies for screening of hazard vulnerable areas were reported by a few organisations who are directly applying state-of-the-art research in their approaches in practice.

The development of mass media and social networks has greatly facilitated communication between road authorities and involved stakeholders. In many countries, the general public are able to obtain regular and accurate information regarding the performance of road assets. Many road operators have designated ways to obtain performance complaints on-line (e.g. using predefined forms) and they are using this data to improve their responsiveness to the needs of communities and stakeholders.

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