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RENEWAL AND REJUVENATION OF AGING INFRASTRUCTURE

A PIARC TECHNICAL REPORT

TECHNICAL COMMITTEE 3.3 *ASSET MANAGEMENT*

STATEMENTS

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

The study that is the subject of this report was defined in the PIARC Strategic Plan 2020–2023 and 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 do not necessarily reflect the views of their parent organisations or agencies.

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The Technical Committee was chaired by Gerardo FLINTSCH (USA), with James SMITH (Canada) as English-speaking Secretary, Pascal ROSSIGNY (France) as French-speaking Secretary, and Miguel VALDES FLORES (Chile) as Spanish-speaking Secretary.

EXECUTIVE SUMMARY

2023R29EN

RENEWAL AND REJUVENATION OF AGING INFRASTRUCTURE

A PIARC TECHNICAL REPORT

Introduction

What is meant by “aging infrastructure”? At first glance, this seems to be mainly a problem for High Income Countries due to their earlier investment in the development of extensive road networks. However, this just as much of a problem for Low- and Middle-Income Countries, as they also have infrastructure that no longer meets today’s requirements. Ultimately, all nations are facing, or will soon be facing, the challenges of aging infrastructure.

For the purpose of this research, “aging infrastructure” is defined as any road related assets that are approaching the end of their expected service life or have prematurely deteriorated in condition and are no longer providing the required level of service. This may be due to shorter service life due to assets not performing as expected, changing usage of the network, changing environment since design and construction of assets, and / or underinvestment in maintenance that has created a backlog of work required.

Approach

The project commenced with a literature review, where all members of the group collated relevant information and case studies from their respective countries. To broaden the knowledge base and to gather further relevant information from member countries, either from members of the wider Technical Committee, from across the broader PIARC community and also from any relevant contacts and networks outside of PIARC, the next stage of work involved the design and delivery of an online survey. This was circulated during summer 2022, and the Working Group would like to thank all contributors for their valuable input. The survey generated both quantitative and qualitative findings for the project, along with further potential case studies.

Changes and challenges for road networks

With aging infrastructure comes an ever-increasing need for renewal and rejuvenation by the road administration. This need is amplified by various challenges, including increase in volumes of traffic and weight of vehicles which accelerates deterioration of assets. Funding is also pressured and investments in new roads are sometimes favoured over maintenance of existing infrastructure. Changing climate over recent decades also provides a range of impacts, such as the effects of more intense cold, heat, drought and rainfall. The project has identified the main changes and challenges faced by road administrations and how they are coping with this range of challenges. The following themes provide structured guidance to road professionals in addressing these challenges.

Monitoring and assessment

To effectively manage and improve aging infrastructure, it is critical to understand the condition, performance and safety of it. Road administrations are increasingly testing and implementing new technology to increase efficiency and depth of knowledge of their assets. This includes assistance in bridge inspections with unmanned aerial vehicles (UAVs) and the emerging use of Artificial

Intelligence in processing video surveys. Asset information systems are also vital to managing this knowledge and making more informed decisions. Better understanding of service lives can improve the optimisation of maintenance scheduling and management of risk, based on asset data and engineering knowledge.

Risk management

Road administrations do not typically have sufficient funding to address all risks related to aging infrastructure. However, due to the critical role they play in supporting the economic and social well-being of their countries, the assets themselves need to operate as normally as possible. Therefore, the project investigated various approaches used to minimise risks where renewal or rejuvenation has not yet been completed. Methods include increased frequency of inspections for assets or sections of higher risk, or the use of remote sensors to gain near real-time understanding of performance and thus early warning of any problems. Alternatively, signage and / or speed limits helps minimise risks related to vehicles, with restrictions such as weight limits or even closures of assets where required.

Prioritisation, programmes and funding

Given the scale of challenges in managing aging infrastructure, it is vital that there are robust processes to develop investment plans, deliver works programmes and communicate these. Criteria that can influence this include network hierarchies, safety deficits, reliability, condition, environmental impacts, level of service, economic efficiency etc. As well as reviewing needs from an engineering perspective, it is increasingly important to understand and consider road user needs and expectations. Key to all of this is the ability to finance interventions to the network. Various sources of funding are available, but it is critical the case for investment is clearly articulated to decision-makers, politicians and the public, to convince them of the benefits.

Technical skills and skilled staff

Formal training in the roads sector has predominantly focused on design and construction of new infrastructure, however, addressing the needs of aging infrastructure requires additional skills and experience. This may apply to new recruits to the roads sector, and also upskilling of more experienced workers already within the industry. The project has investigated emerging skillsets that are required, such as mobility and digitalisation. Also, it has reviewed levels of awareness and take up of training in maintenance techniques across different asset types, along with various methods of delivering this.

Conclusions and Recommendations

The key findings from this study have confirmed the challenges that aging infrastructure provides to road administrations of all income levels, plus it has identified a range of evidence and good practice related to the themes listed above. However, the work has also confirmed that there is little formal existing research dedicated to the specific issue of aging infrastructure, and there may be opportunities to address this better. A series of recommendations have been developed against each of the themes listed above, and these are described within each respective chapter. A number of recommendations have also been developed for PIARC's consideration, especially as "renewal and rejuvenation of aging infrastructure" is likely to be a topic of interest to road administrations for the foreseeable future – this report is just the first step to helping roads professionals address its challenges more comprehensively.

CONTENTS

1. INTRODUCTION

1.1. PROJECT BACKGROUND

The PIARC Strategic Plan 2020 – 2023 identified the issue of "Renewal and Rejuvenation of Aging Infrastructure" as a priority for this cycle and allocated it to the Technical Committee 3.3 "Asset Management". To address this, a Working Group was established in 2020 to identify best practices and approaches that support the renewal and modernisation of aging road infrastructure and management of road renewal backlogs. The Working Group represented a broad mix of road administrations, covering various types of networks, climates and geographic regions, with members from Belgium, Colombia, Finland, France, Germany, Japan, Malaysia, Mexico, Morocco, Slovakia, Slovenia, South Korea and UK.

As this was a completely new workstream rather than a continuation of work undertaken in a previous cycle, there were a number of iterations of the project plan to define the scope clearly, achieve the required objectives laid out in the PIARC Strategic Plan and manage risks around its delivery. This report of the Working Group's findings is not intended to be a technical manual of engineering options and practices for specific assets (as this would duplicate work elsewhere within the PIARC Technical Committees). Instead, the report aims to provide an overview of the problems related to aging infrastructure, and the broad spectrum of potential solutions that road professionals may use to address them.

But what is actually meant by "aging infrastructure"? At first glance, this seems to be mainly a problem for High Income Countries due to their earlier investment in the development of extensive road networks. However, the Working Group considered this to be just as much a problem for Low- and Middle-Income Countries, as they also have infrastructure that no longer meets today's requirements. Ultimately, all nations are facing, or will soon be facing, the challenges of aging infrastructure. To help clarify this, for the purpose of this research, "aging infrastructure" is defined as any road related assets that are approaching the end of their expected service life or have prematurely deteriorated in condition and are no longer providing the required level of service. This may be due to:

- Shorter service life due to assets not performing as expected.
- Changing usage of the network.
- Changing environment since design and construction of assets.
- Under-investment in maintenance that has created a backlog of work required.

1.2. PROJECT OBJECTIVES

The objectives of the Working Group were outlined in the PIARC Strategic Plan as follows:

- Identify best practices and approaches of road asset management that support the renewal and modernization of aging road infrastructure, including the management of road renewal backlogs.
- Take in account the emerging vehicle and infrastructure technologies.
- Build on the findings of T.C.D.1 – Asset Management within Cycle 2016-2019.
- Encourage coordination with other TCs and TFs.

1.3. Structure of Report

This report has been structured in the following format:

- Methodology – outline of the stages used to deliver the project.
- Changes and challenges* – new demands on infrastructure, such as greater traffic volumes, heavier vehicles, changing standards, climate change.
- Monitoring and assessment* – established and emerging techniques to understand the condition, performance and safety of aging road infrastructure.
- Risk management* – approaches used to minimise risks where renewal or rejuvenation has not yet been completed (or cannot be completed).
- Prioritisation, programmes and funding* – the decision-making process to develop investment plans and how to communicate these for greatest effect.
- Technical skills and skilled staff* – development of specialised skills within the sector to deal with the different challenges of managing aging infrastructure compared to more modern assets.
- Conclusions and Recommendations – overall findings and actions for road administrations to consider, to help them develop or improve their approach to managing aging infrastructure.
- Glossary – definitions of terms used in the report.
- References – detailed reference of relevant documents covered by the report.
- Appendices – supporting information to the main report.

* Section includes survey findings and case studies relevant to each particular themes

2. METHODOLOGY

2.1. APPROACH

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

- Refinement and agreement of scope for new PIARC Working Group topic.
- Review of current practice and examples from Working Group member nations.
- Engagement with road authorities of both HICs and LMICs.
- Exploration of the different challenges and solutions which are being or can be adopted by road administrations in both HICs and LMICs.
- Literature review, and identification and development of case studies.
- Production of a detailed report summarising the project findings in a clear and structured manner.

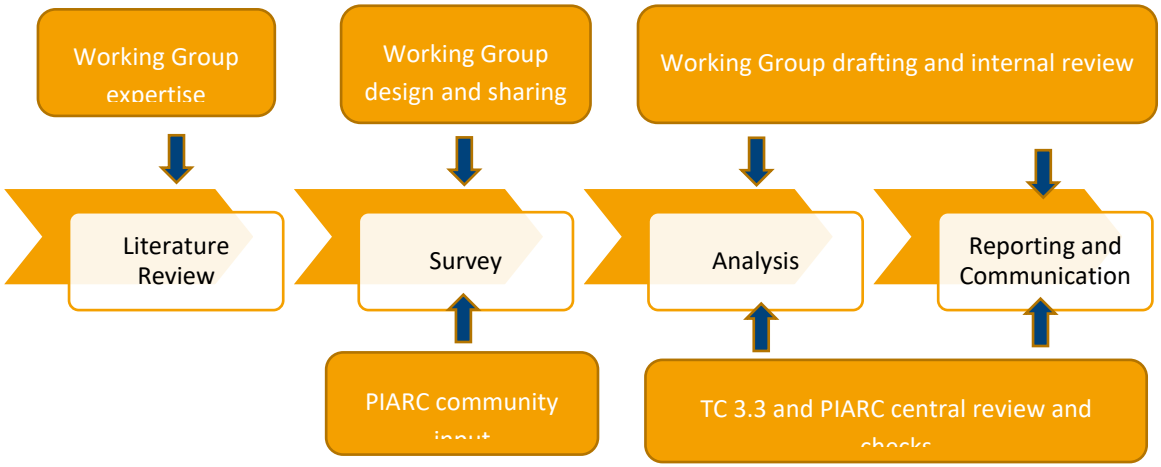


Figure 1 – Project Approach

2.2. LITERATURE REVIEW

Once the scope was refined, each Working Group member identified potential sources of literature which were mapped to the themes of each chapter. These were supplemented later in the project by more recent publications within each member's country, plus a range of PIARC studies with subject matter relevant to this report.

The long list of literature was then assessed and prioritised to produce a short-list, providing a better balance across the report's themes and representation of geographical and income level (where possible). The short-list was reviewed to provide the basis for the context and/or current practice in each of the report's themes, and a summary of the findings is included in each chapter of the report.

Some sources of literature identified examples of good practice that were considered of value in complementing the report. Where appropriate, these were developed into short, structured case studies that are also included in the relevant chapter of the report.

2.3. SURVEY

The survey was designed and developed collaboratively within the Working Group, with additional review by representatives from the wider Technical Committee, then issued to all members of PIARC via the PIARC General Secretariat. To maximise engagement with stakeholders and encourage higher response rate, the survey was provided in three languages as per PIARC's usual research practice: English, French and Spanish.

The response to the survey was incredibly positive, with a high number of respondents and a good blend of income level countries. Most respondents were from road administrations, but there were also significant contributions from consultants, contractors, universities and institutes.

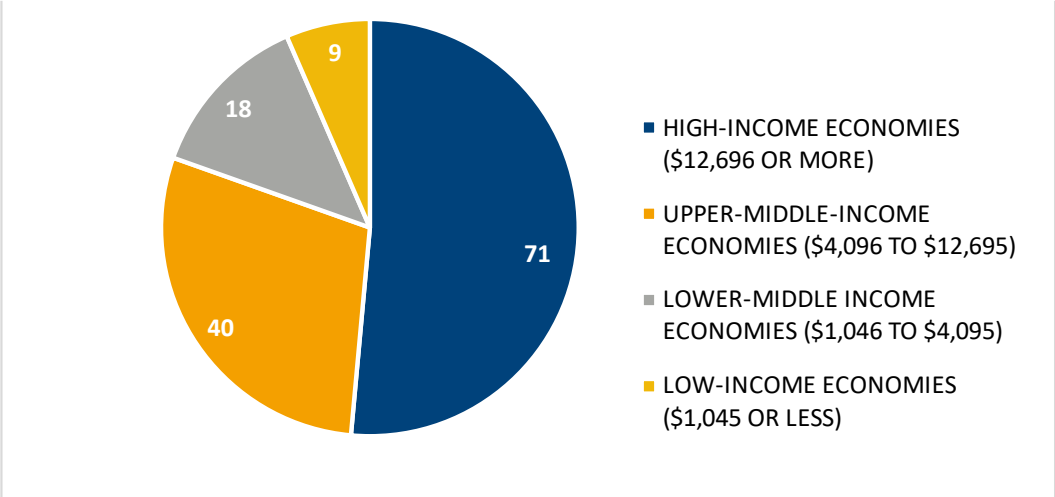


Figure 2 – Number of Respondents by Income Level Countries

2.4. ANALYSIS

Following completion of the survey data analysis, the structure of each chapter was agreed on, with the following consistent format used:

- Introduction – a brief summary of what the section covers.
- Literature review – referenced content from sources.
- Survey – charts and commentary of responses by each theme.
- Case studies – examples of good practice from both High Income Countries and Low- and Middle-Income Countries.
- Conclusion and recommendations – overarching review of the content within each section, with lessons learned identified.

2.5. REPORTING AND COMMUNICATION

Based on the initial findings from the literature review and the use cases identified up to that point, the working group published an article in the PIARC magazine Routes/Roads in September 2022. This article provided - as a kind of appetiser - a brief outlook on the report and on some of the use cases included in the report.

After the survey was closed, the results were analysed and presented in diagrams. All working group members named in the acknowledgements were actively involved in the drafting of the report. In particular, it was a matter of amalgamating the literature research and the use cases into a common format, and then developing the key findings and recommendations.

In addition, special attention was paid to ensure that the entire spectrum of PIARC member countries was taken into account and that the document was not limited to findings from particular country categories (e.g., European countries or HICs). The draft report was reviewed by members of the Working Group, then by members of the wider Technical Committee 3.3 for Asset Management, and finally by PIARC.

The final report is to be presented by the working group at the World Road Congress in Prague in autumn 2023, as part of the session of the TC 3.3 Asset Management. Dependent on the PIARC Strategic Plan 2024-2027, it would be conceivable to deepen the findings and communicate them further in the subsequent cycle.

3. CHANGES AND CHALLENGES

3.1. INTRODUCTION

Many road networks have grown over several decades, and with this aging infrastructure comes an ever-increasing need for renewal and rejuvenation by the road owner / administration. This need is amplified by various challenges. For instance, there has been a significant increase in volumes of traffic and weight of vehicles, which increases levels of deterioration of assets. In the case of bridges, this may even result in restricting traffic on the bridge to prevent the structure from failing. However, technical and safety standards as well as guidelines have evolved too. While they cover new sections of road networks, older sections (which may make up the majority of the network) may not be compliant with these newer standards. But also changes in the vehicle fleet or the renaissance of the bicycle impose new demands and expectations on the road infrastructure.

Funding is also pressured. For unrelated, non-technical reasons, investments in new roads are sometimes favoured over maintenance of existing infrastructure, or other demands on public spending taking priority over investment in roads. Changing climate over recent decades also provides a range of impacts, such as more extreme cold and heat affecting materials, the impact of drought on ground conditions, flooding due to heavier rainfall exceeding drainage capacity plus scour of bridges. The new challenges to infrastructure often mean that simple rehabilitation measures are no longer adequate, and extensions or renewals are necessary. These measures are partly made considerably difficult by a new and more complex legal framework, e.g., in the environmental sector. In some countries, the situation is worsened by the lack of qualified professionals to meet these enormous challenges.

The project identified the main changes and challenges faced by road administrations and how they are coping with this range of challenges. It presents how they are performing in the management of their road networks against required performance targets and what estimated proportions of their asset stock are considered to be aging infrastructure. The following themes provide structured and exemplary guidance to road professionals in addressing these challenges.

3.2. LITERATURE REVIEW

3.2.1. UK – ALARM Report [1]

In the UK, an annual survey is undertaken by the Asphalt Industry Alliance in the UK and completed by local highway authority representatives. This produces what is known as the ALARM Report, which describes the state of local roads, funding available and impacts on the service provided. This is a long-term survey, and as of 2023, it is in its 28th year of operation – the following findings are related to the 2023 report.

The survey was based on a response rate of 75% of local road authorities in England and Wales, which was then extrapolated to give a full national picture. While maintenance budgets had increased on average by 4.5%, this is less than inflation, so in real terms this was essentially a cut in funding. The annual shortfall in maintenance for carriageways is estimated to be £1.3bn, compared to what would be required for road authorities to achieve steady state condition. To address the backlog of repairs required to return the network to a good condition would involve a one-off investment of over £14bn.

Other factors noted as impacts on the condition of the network included adverse weather, plus a reported 2.4m openings of roads by utility companies, with a resulting loss in structural life of the asset. Overall, the impact on condition was a reduction in the number of roads in good condition, with a corresponding increase in roads showing deterioration. The proportion of the network in poor condition, however, remained stable at 11%. A reported 1.4m potholes were filled in 2022-23, equivalent to one every 22 seconds. Potholes still played a major part in compensation claims rising, with the cost of payments and management of claims totalling over £22m.

Despite all these issues, the report acknowledged the professionalism and skills of highway practitioners to keep the road network safe in such challenging conditions.

3.2.2. Germany – Bridges on federal trunk roads: Bridge inventory, structural condition and challenges [2]

https://bmdv.bund.de/SharedDocs/DE/Anlage/K/presse/bruecken-an-bundesfernstrassen-bilanz-und-ausblick.pdf?__blob=publicationFile

The German Federal Ministry for Digital and Transport reports regularly to the German Bundestag (German Federal Parliament) on the condition of road bridges and the status of bridge modernisation. The report starts with a description of the bridge stock and a rough overview of the condition of the structures. In addition, the current challenges in bridge engineering are addressed.

The latest report is from 10 March 2022. The following are some exemplary excerpts on those parts of the report:

In 2021, the network of German trunk roads (federal motorways and federal highways) comprised about 40,000 bridges. The total bridge surface of all federal trunk road bridges is about 31 million m² (corresponding to about 4,350 football fields), the total length adds up to about 2,150 km (roughly the distance Berlin-Rome). In the western federal states (formerly: West Germany/FRG), most bridges were built in the period from 1960 to 1985, at a time when the emerging German economy demanded modern transport routes. In particular, many large valley and river bridges date from this period. In the new federal states (formerly: East Germany/GDR), the bridge structures mostly date from the period after reunification. The following graphic from the report shows the age structure of bridges on federal trunk roads in proportion to the number of partial structures:

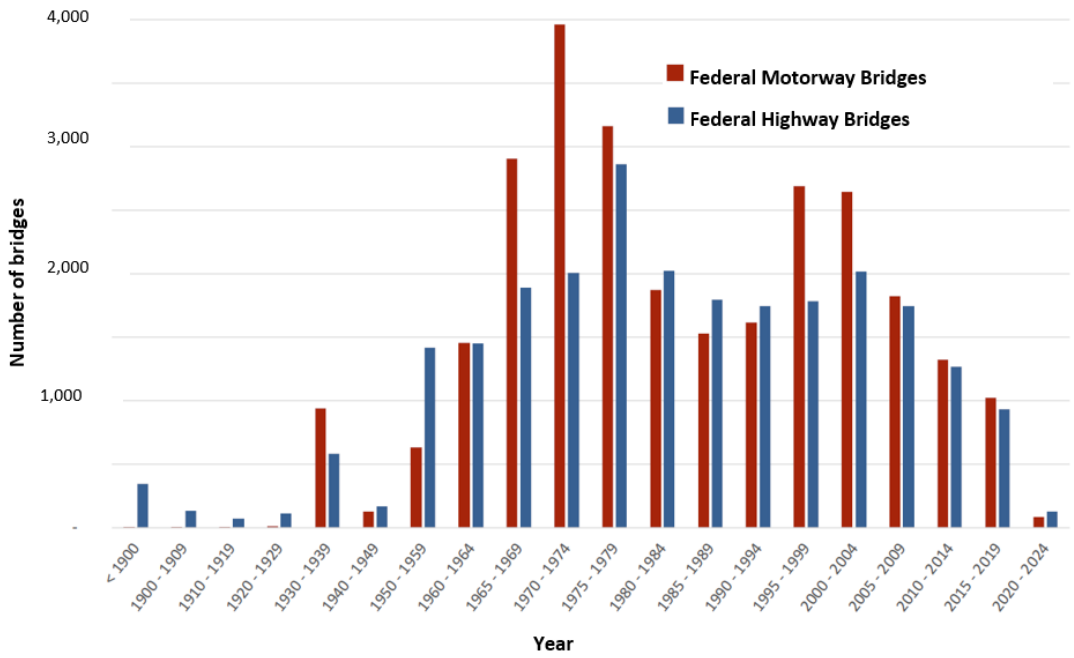


Figure 3 – Number of bridges in Germany 1900-2024

The bridges are regularly inspected according to DIN Standard 1076. The condition of the bridge is assessed according to the criteria of structural stability, road safety and durability. The structural condition of the bridge is documented with a condition grade (fabric Indicator): 1.0 very good to 4.0 inadequate. It can be seen, among other things, that the structural condition of federal highway bridges tends to be better than that of federal motorway bridges. This is due to the significantly lower volume of freight traffic with generally lower total vehicle weights on the federal highways. Vehicles on the motorways are significantly heavier loaded, which leads to a permanently high static load on the motorway bridges with all the negative consequences, such as faster aging and increased wear. In particular, high axle loads, partly due to overloading or incorrect loading of the lorries, put additional pressure on the motorway bridges.

In addition to the condition grade, the so-called load bearing index is determined for the bridges, too. Among other things, this takes into account the fact that there are deficits compared to today's requirements due to the enormous increase in heavy traffic and due to weaknesses in the former dimensioning regulations. For this purpose, an evaluation is carried out in a target-performance comparison between the required/future-capable bridge load-bearing capacity and the actual calculated load-bearing capacity. The results are categorised in five levels.

The report also describes the current challenges for the bridge stock. Firstly, the development of traffic has to be considered. The disproportionate increase in heavy traffic in the last decades - both in terms of total vehicle weights and axle loads and in terms of frequency – puts an extraordinary strain on the bridges. Because of this, the normative traffic load models have been adapted again and again in the past. This has shown that bridges of older years (before 1985) were partly designed for significantly lower traffic loads.

Finally, it is mentioned that some old structures suffer from structural deficits resulting from the lack of experience with new/modern construction methods at the time of construction (e.g., problems with coupling joints of pre-tensioned concrete construction, stress corrosion cracking, buckling of large sheet metal fields in steel bridge construction).

3.2.3. Slovenia – Extreme traffic growth on Slovenian motorways [3]

The reviewed presentation discusses the significant increase in traffic on Slovenian motorways since Slovenia joined the European Union. The document was created by DRI Investment Management Ltd.

One of the key points raised in the presentation is that freight traffic on Slovenian motorways has increased four-fold on motorway A1, which is the route from Italy through Slovenia towards Hungary. However, the pavements on the motorway were not designed to handle such high levels of traffic, which has caused a significant strain on the infrastructure.

The presentation goes on to explain that a large portion of the motorway network in Slovenia has extremely under-designed pavements, which has resulted in early deterioration of the pavements. The under-designed pavements and premature deterioration have made it difficult to maintain the motorways according to standard maintenance life cycles.

The rapid traffic growth has also caused issues with standard road closures when one direction of the motorway is closed to traffic, and traffic flows on the other direction with reduced numbers of traffic lanes, causing traffic jams when reconstructions take place. To solve this issue, either motorways should be widened or works have to be performed in more complicated closures. Both challenges cause a strain on the budget and other resources. As a result, a new approach to maintenance was needed to address the problem.

The presentation also provides statistics and figures that illustrate the changes and challenges facing the Slovenian motorway network, including extreme traffic growth, the need for a shift from standard maintenance life cycles, and the strain on the budget caused by the increased traffic and maintenance requirements.

3.2.4. Slovenia – Reconstruction of a Motorway Section Ac A2 0015/0615 Koseze – Brdo [4]

The document being referenced is a project documentation for the reconstruction of an existing motorway section in Slovenia. The original design of the motorway dates back to the 1970s, and as part of the reconstruction process, the existing pavement and bridges will be restored, and an additional lane will be added to the existing 2-lane cross section.

Slovenian motorways are designed to withstand the resistance of the 100-year high flood water level. However, during the reconstruction process, it was discovered that the new level of the 100-year high flood water level is 30 to 40 cm higher than that of the 1970s. This increase in the flood water level is attributed to climate change and the forecasted increase in high-intensity storms during the summer months. As a result, the pavement needed to be reconstructed instead of overlaid, and some of the bridges needed to be replaced with new ones.

The example of the AC A2 Koseze – Brdo motorway reconstruction project documentation emphasises the importance of risk management, particularly when faced with changing demands that put a strain on infrastructures that may not have been taken into account during their initial design. In this case, the changing demands arise from the effects of climate change and can also cause a strain on the budget.

3.2.5. International – Resilient Transport – Managing climate risks in the road sector [5]

Focusing on the continent of Africa, this report by the Nordic Development fund in 2021 provides an overview of the risks climate change poses to the road sector and provides suggestions of measures that can be implemented to improve the resilience of road networks.

The paper first outlines how climate change impacts the road sector. The increased frequency and intensity of adverse weather conditions such as heatwaves, storms and floods that are associated with climate change place an increased strain on a country's road network. With the impacts of climate change being burdened heavily on the global south, the NDF outlines how within lower income countries there is a disproportionate effect on rural populations due to road network failures leaving people cut off from markets and services. Overall, climate change's impact on the road sector can therefore lead to a loss of human life as well as a having a negative impact on incomes and livelihoods.

The NDF outlines two possible adaptation strategies. The first option would be to do nothing and hope that the existing institutional capacity in road agencies and design codes is sufficient to withstand future climate challenges, albeit with an increased maintenance budget.

The second option would be to take on active readaptation. This would include investment to provide training to key stakeholders within the road networks such that the climate change process is built into future planning, asset management and risk management procedures as well as national transport policies and plans. Additionally, the NDF cites the importance of vulnerability mapping of existing road networks combined with key climate data such that optimal intervention methods can be devised and maintenance work can be effectively prioritised.

The NDF also advocates for the need for reform in many design standards for road transport infrastructure, highlighting the case of Zambia whose road guidance documents from 1994 had no consideration of climate change impacts. It also notes the importance of training and capacity building in road administrations to deliver any and all of the required measures.

3.2.6. South Africa – Road maintenance in SA: challenges, progress, and solutions [6]

This article from 2021 explores the challenges that South Africa is facing as a result of its deteriorating road network. The report then outlines some of the progress and possible solutions that the country has had.

With estimates suggesting that approximately half of South Africa's gravel roads are in poor or very poor condition, it is a widespread problem affecting municipalities across the country. The first major challenge that the South African government faces is accurately quantifying the extent of the road maintenance backlog such that a measured funding response can be administered. In 2014, the road maintenance backlog was reported as being R197-billion, against an estimated asset valuation of R2-trillion. More recent studies estimated it to be over R400-billion, however, the precise scale of backlog is not known.

With deteriorating road network conditions, the report also outlines the negative socio-economic impacts that South Africa has faced. Access to essential services can be compromised which has disproportionately affected those in rural communities as many of them rely on agriculture and have experienced spoiled crops as a result of poor road networks. This comes alongside a consensus within the government and road network bodies that without timely maintenance, roads

deteriorate to the point where the cost to restore them is three to five times more than if they had been maintained earlier.

In terms of solutions, the president of the South African Road Federation mentioned how once the extent of the problem is accurately captured, roads that are not contributing to economic and social need will begin to be decommissioned. Some concerns were raised around the skills and competencies that road maintenance depends on, and potential human resources capacity and deficits. However, it was also noted that young professionals are continuing to be trained to build road sector management capacity at a local government level. A challenging observation from the article is that it is cheaper to train staff than to rehabilitate roads.

3.2.7. PIARC Special Project – Overweight Vehicles: Impact On Road Infrastructure And Safety [7]

A high concern for road network owners is overweight vehicles which can damage or collapse road infrastructure. While benefiting transport operators and potentially reducing CO2 emissions, it largely disadvantages road infrastructure managers who have the responsibility of maintaining and repairing roads and bridges with a limited budget. Damage to the structural properties of road and bridges are mainly caused by heavy vehicles. And overloaded vehicles are responsible for more damage than the rest of heavy vehicle traffic.

This PIARC report extensively covers the impact of overweight vehicles on road infrastructure and safety. It compiles available information on overweight road freight vehicles around the world, and the impacts they have on pavement and bridges, road safety and the economic position of road infrastructure managers. It further details a collection of best practices to prevent and mitigate overloading.

The effect of overloading on pavement residual life depends on various factors including the type of pavement, its structural and functional condition, type of traffic, vehicle wheel and suspension, etc. It constitutes a true challenge for road authorities, especially in LMICs where most of the road networks are unpaved or feature thin flexible pavements, particularly sensitive to overloaded traffic.

Pavement damage increases exponentially with axle load. Several studies have established that it increases with a power of at least 4 (known as the “fourth power law”). Unevenness and corrugation in turn increases wear due to the dynamic effect of traffic travelling over the surface. Cracking allows water penetration which in turn accelerates pavement degradation. Thus, poorly maintained pavement is even more affected by overloading than a better-maintained pavement. It is therefore essential to improve vehicle practice to avoid as much as possible overloading and improve pavement design and maintenance practices, taking into account real world situation instead of hypothetical weight limits for instance.

On well-designed and healthy bridges, only very high overloads may cause severe damage immediately. But on older or partly damaged bridges, much lower overloads may induce wear or collapse. The type of bridge will also have an influence on how overloading affects the structure. Short and medium span bridges with low self-weight can be quite sensitive to overload whereas long span bridges will be affected if several overloaded trucks are crossing simultaneously without respecting mandatory spacing. A high proportion of overloaded vehicles will affect steel bridges due to fatigue and reduce significantly lifetime. It is therefore important for road owners to identify

sensitive bridges, maintain steel parts and concrete sub-structures but to also monitor as much as possible vehicle loads, limit loads where necessary, reducing overloading frequency and severity of overloading.

Increased loads lead to a much higher degree of increase in annual maintenance costs. And poor maintenance accelerates further deterioration. This PIARC study concludes with recommendations for effective prevention of damage: strong enforcement (monitoring, detecting, applying severe penalties), high quality infrastructure which better withstands heavy loads and high-quality vehicles with good safety specifications less sensitive to overloading.

3.3. SURVEY FINDINGS

The overall picture of aging infrastructure across the surveyed countries is outlined in the Figure 4

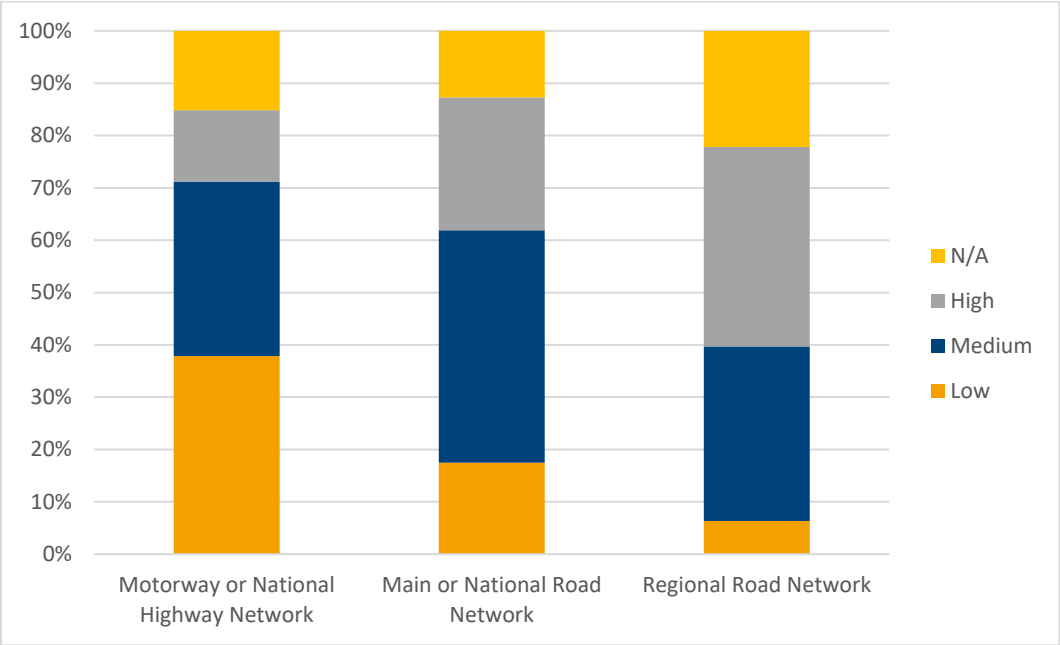


Figure 4 – Overall Proportion of Aging Infrastructure

What we see is that regional road networks generally have a higher proportion of aging infrastructure compared to motorways and main road networks. This is fairly intuitive as, if a budget were to be limited, it would make sense to ensure the most in demand roads that connect business hubs are maintained as a priority. However, in lower income countries, the issue of poor regional road networks has been shown to lead to communities being cut off and an overall lower GDP for the country as a result.

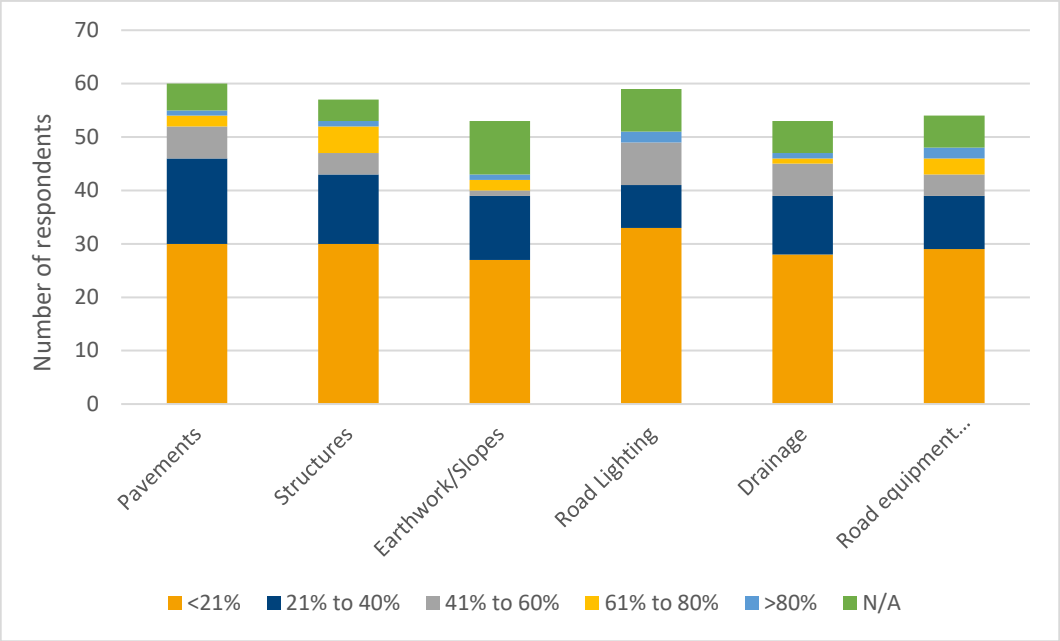


Figure 5 – Overall Proportion of Aging Infrastructure - Motorways or Highway Network

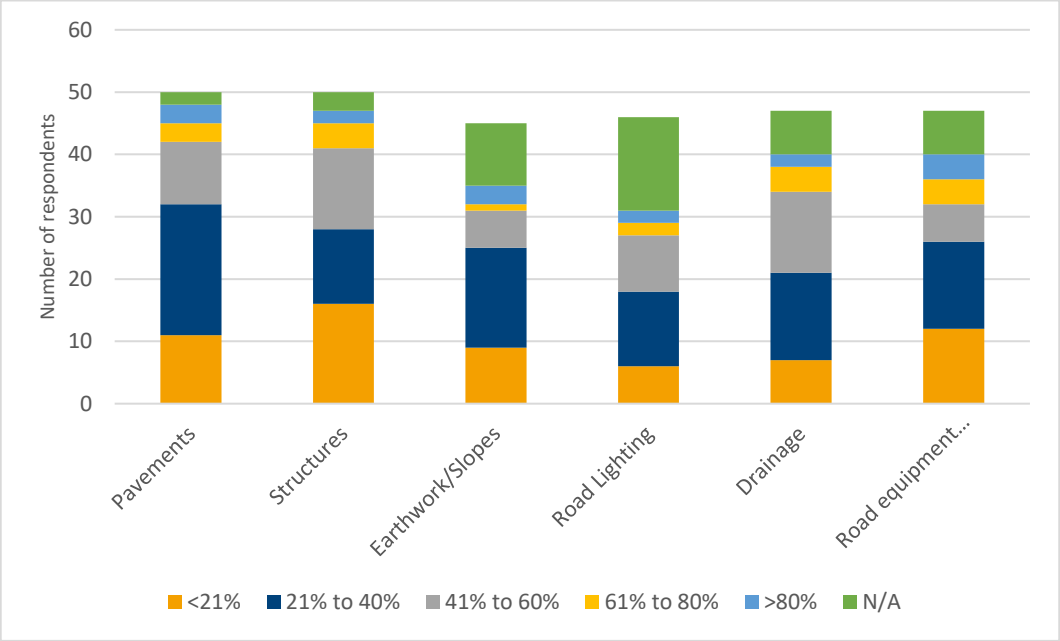


Figure 6 – Overall Proportion of Aging Infrastructure - Main or National Road Network

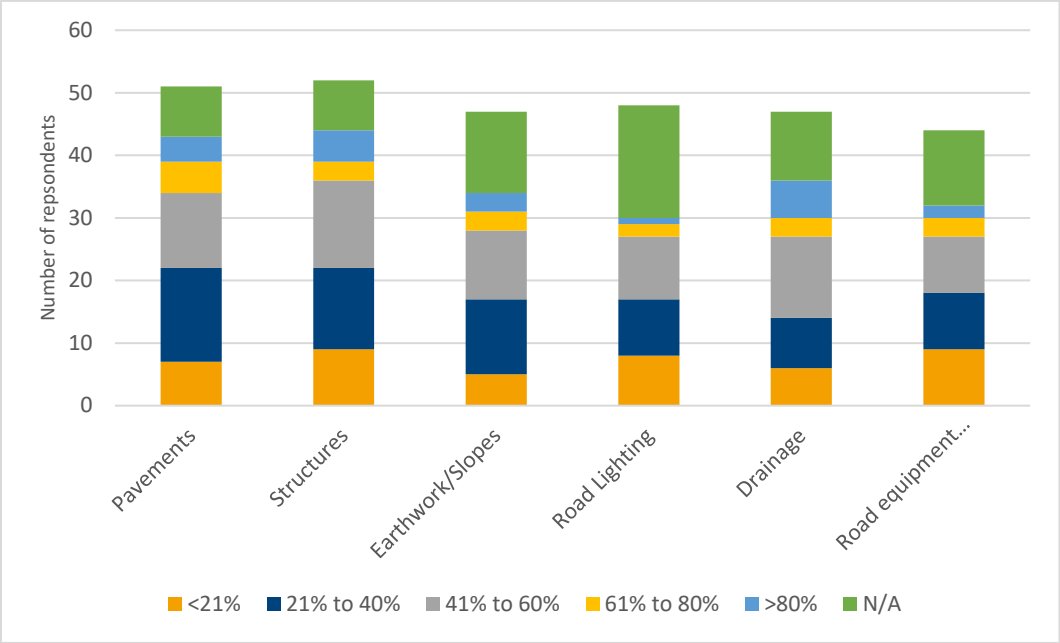


Figure 7 – Overall Proportion of Aging Infrastructure- Regional Road Network

As global population grows and consumption patterns change, we are seeing an increased strain on global infrastructure and transport networks in particular. For example, a majority of the countries surveyed by the working group reported an increase of traffic volume for vehicles such as HGVs, cars and LGVs using the road network in the last 5 years, along with projected further increases over the next 5 years too as shown in Figure 8 and Figure 9

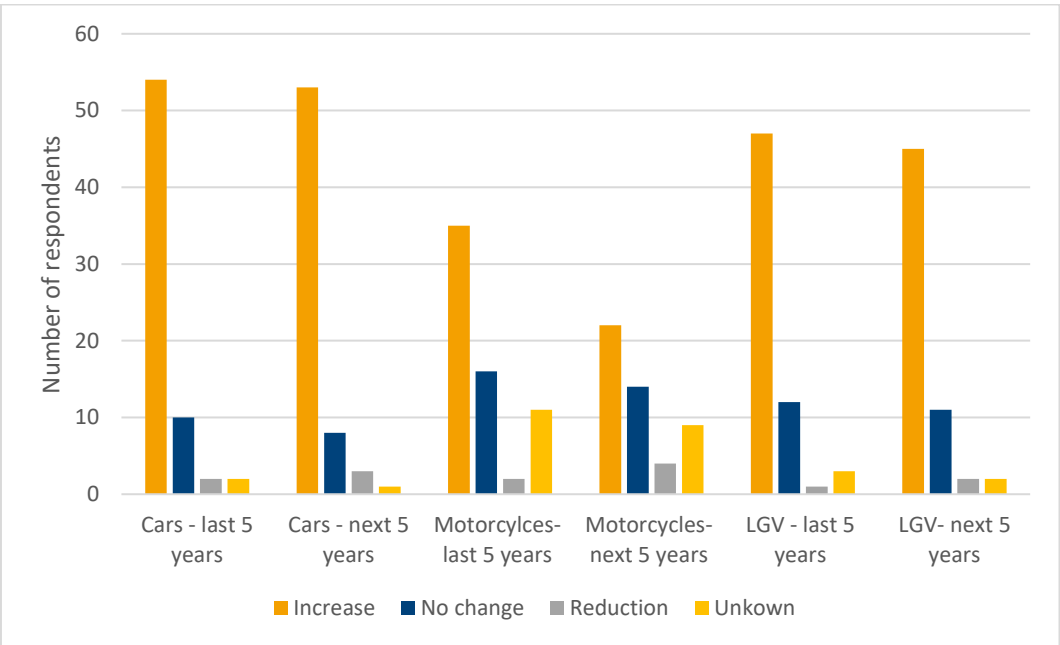


Figure 8 – Change in traffic volume (1/3)

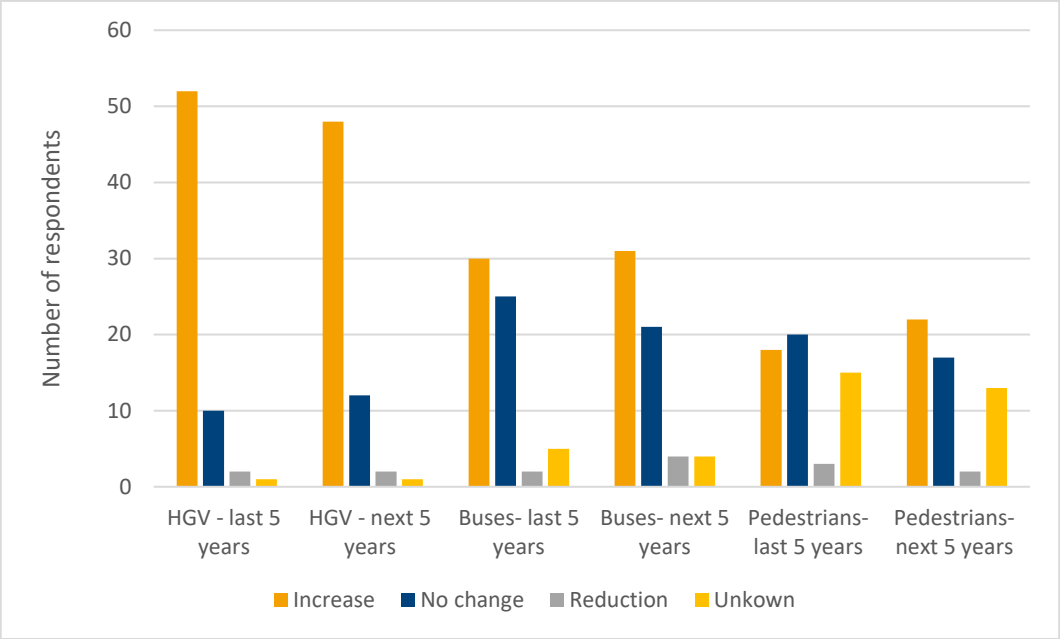


Figure 9 – Change in traffic volume (2/3)

From a standpoint of sustainability, it is promising to see the increased volume of bicycle use across road networks both in the past 5 years and the projections for the next 5 years. Bicycle use is obviously much kinder to the environment in that no C02 is produced but it also places less strain on the pavement surface compared to traditional methods of transport such as cars.

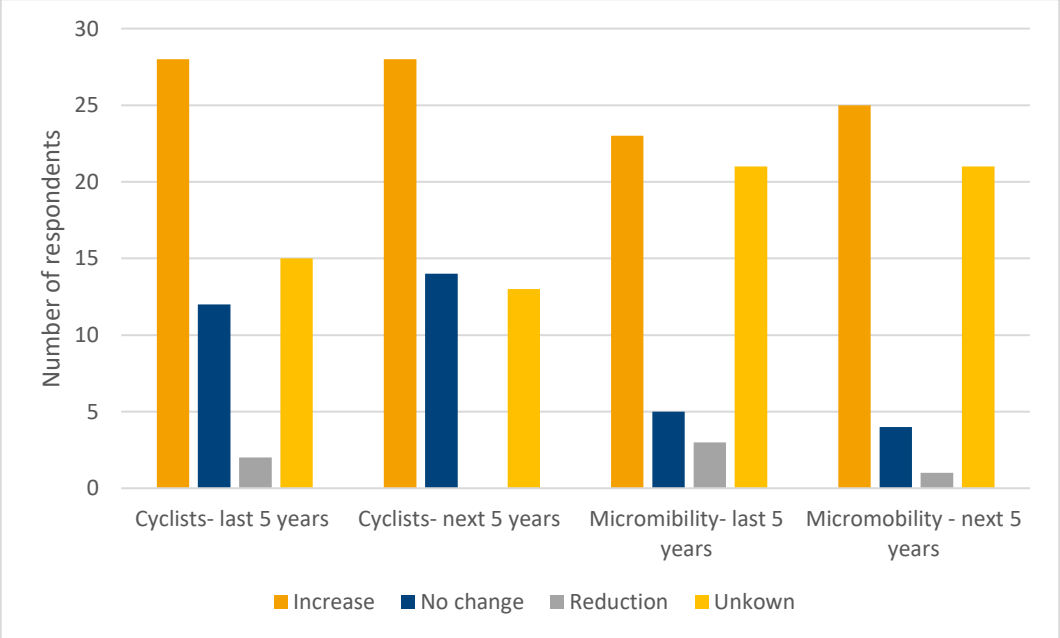


Figure 10 – Change in traffic volume (3/3)

Additional to increased traffic volume on the majority of road networks surveyed, Figures 11 and 12 highlight a clear disparity between the number of countries that have seen the total weight/ axle loads permitted on the road networks raised and the number that have updated their standard guidance off the back of this.

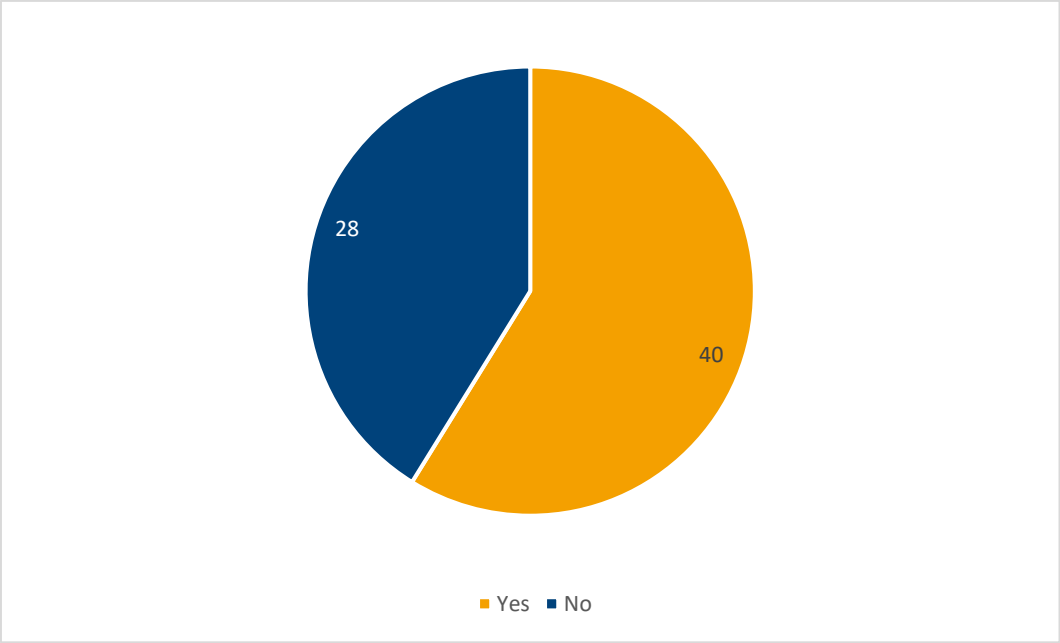


Figure 11 – Has the total weight and/or axle loads permitted on public roads raised in the last 30 years?

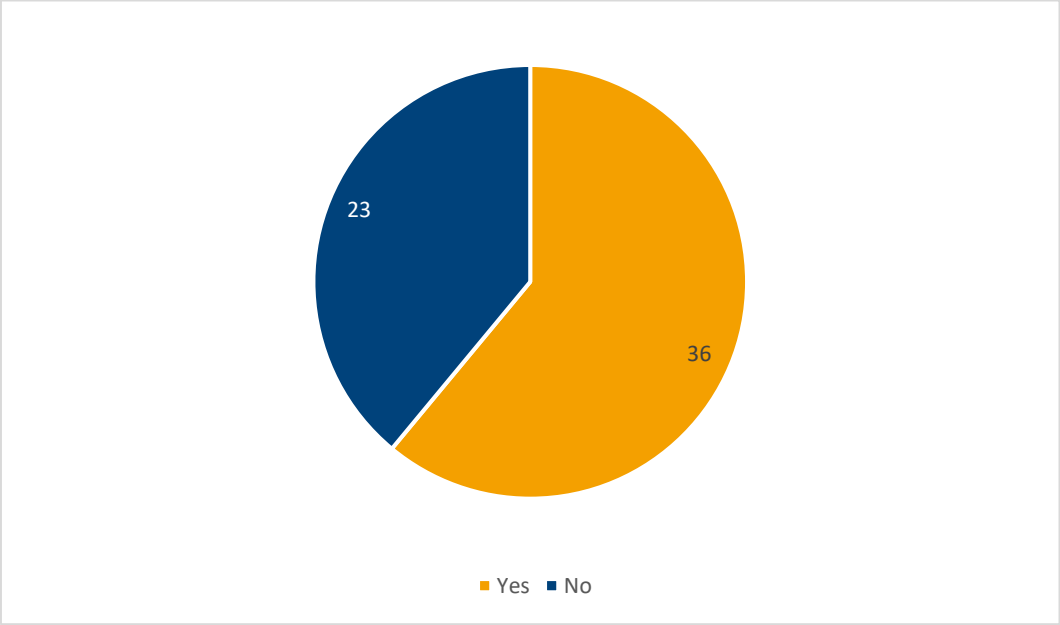


Figure 12 – Based on your answer to the previous question, is your organization updating standard guidance to cover innovation?

We are therefore seeing an increased strain on the infrastructure across the surveyed countries but a less than proportionate response to these challenges. This is captured in Figure 13 which reveals that close to half of the respondents are not updating standards to deal specifically with aging infrastructure.

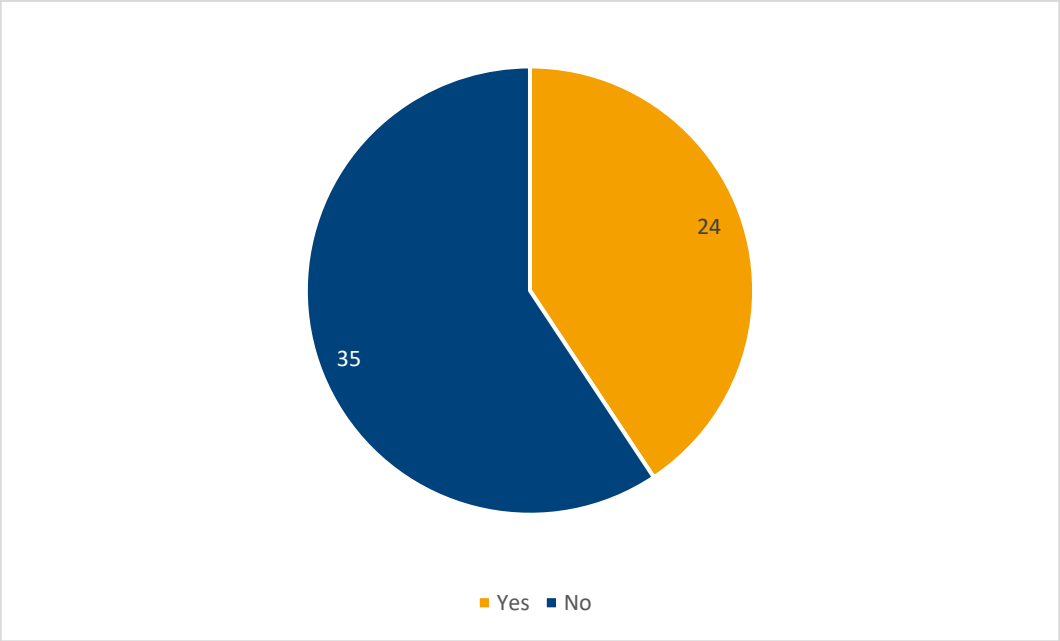


Figure 13 – Is your organization updating standards to deal specifically with aging infrastructure?

Despite the large majority of countries having performance targets in place for the management of the network, the overwhelming majority of the performance targets were geared towards safety and condition. Given the aforementioned increase in historic and projected traffic volumes, condition and safety are obviously of upmost importance. However, those concerned with the problem of aging infrastructure may be alarmed by the seeming low importance placed on resilience and sustainability within these performance targets.

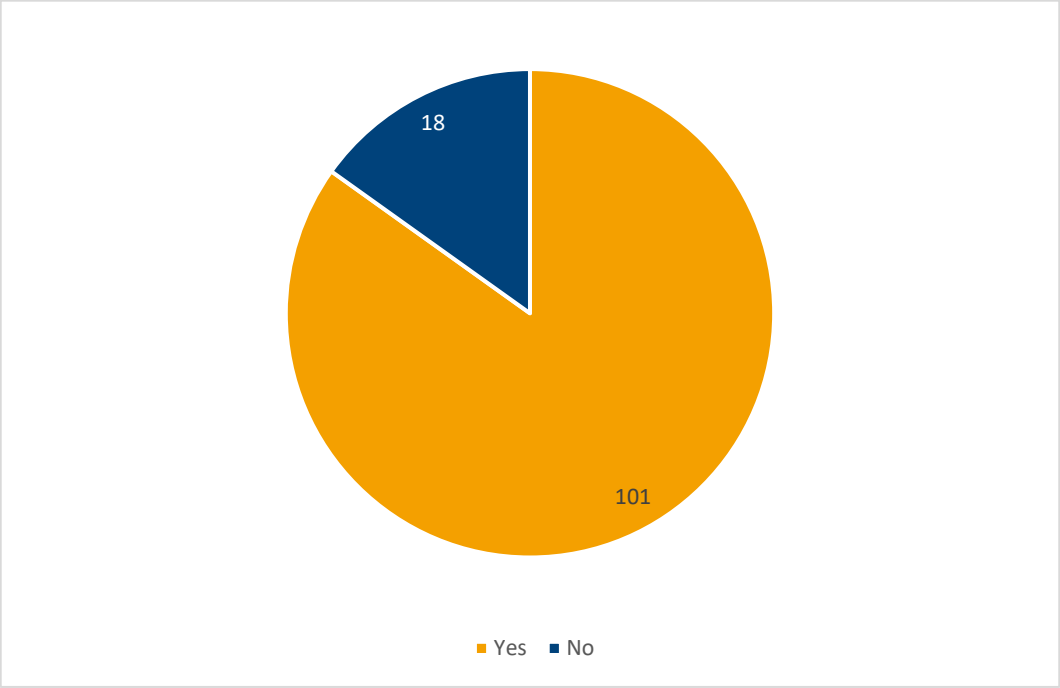


Figure 14 – Do you have a set of performance targets for the management of your network?

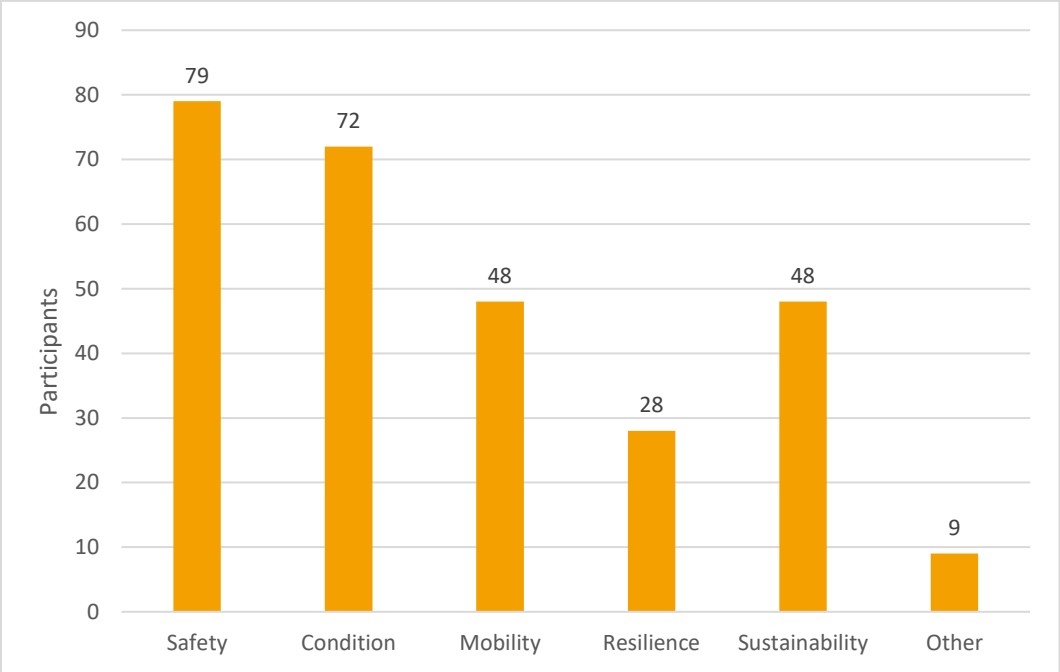


Figure 15 – Performance targets for the management of networks

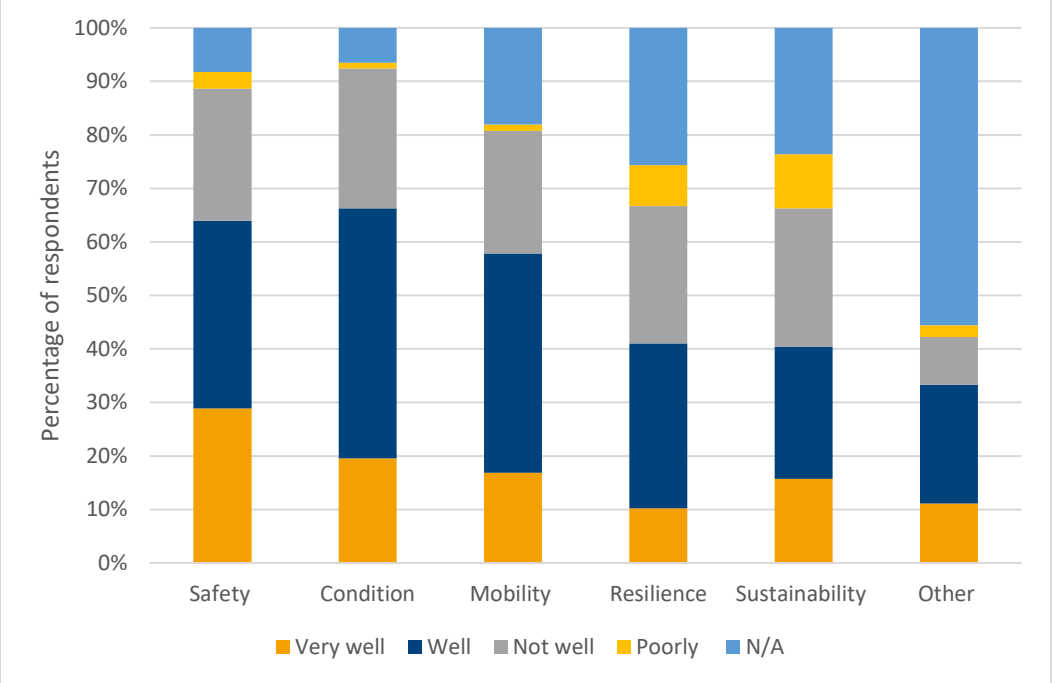


Figure 16 – If so, how is your network currently performing against those targets?

3.4. CASE STUDIES

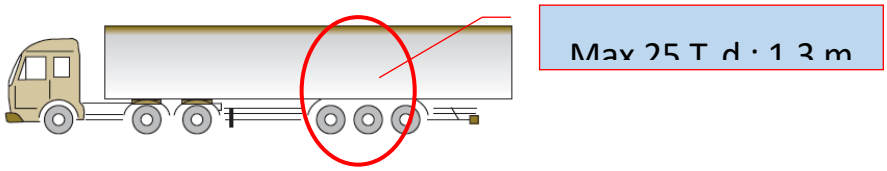
Authorised Vehicle Mass	**SPW Mobilité et Infrastructures** **Belgium (Wallonia), High Income Country**

Problem

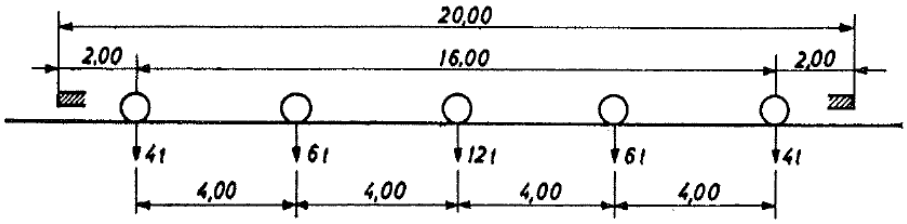
Changes in legislation can have a major impact for infrastructure owners. The Walloon Government Decree of March 29, 2018, amending the Royal Decree of March 15, 1968, on the general regulations on the technical conditions to be met by motor vehicles and their trailers, their components and safety accessories, sets a maximum authorized mass of 50 tons for

- articulated vehicles consisting of a three-axle towing vehicle and a three-axle semi-trailer;

- vehicle trains consisting of a motor vehicle with three or more axles and a trailer with three or more axles



Most of our road structures were calculated according to the NBN 5 standard, which was in force until 1993, with the following design load corresponding to 32-ton convoys with two-axle tractor units:



(a)

The increase in the maximum permissible mass of the vehicle trains increases the load on the structures. The load of a 44-ton vehicle with a 25.5-ton tridem can reach 113% of the mobile load for which the structures were designed. This figure rises to 124% in the case of a 44-ton vehicle with a 27-ton tridem.

The acceptance of 50-tonne vehicles on the Wallonia road network leads to a reduction in the safety coefficients for certain structures, thus increasing the risk of premature aging.

Solution

Monitoring the bridge stock and assessing its condition is key to better knowledge and understanding of aging structures. Frequent visual and systematic inspections must be enforced to trigger specific detailed inspections when required, in order to detect whether bridge components have prematurely deteriorated in condition.

Authorised Vehicle Mass	**SPW Mobilité et Infrastructures** **Belgium (Wallonia), High Income Country**

For instance, an increased attention should be conveyed to pre-stressed efforts in concrete structures. Loss of effort can lead to high instability or collapse. This type of monitoring requires openings and residual efforts measurement. Steel fatigue is also an element of concern for metallic structures.

Cracks, non-injected sheathes, water infiltration, chloride infiltration, corrosion, broken steel cables and more so evolving defects are different signs of advanced deterioration that lead to component replacement.

Bridges can therefore have shortened service lives and require rebuilding of some of its components sooner than expected.

Involving research to study actual deterioration and effort loss in deposited beams for instance will help improve deterioration models according to increased loads.

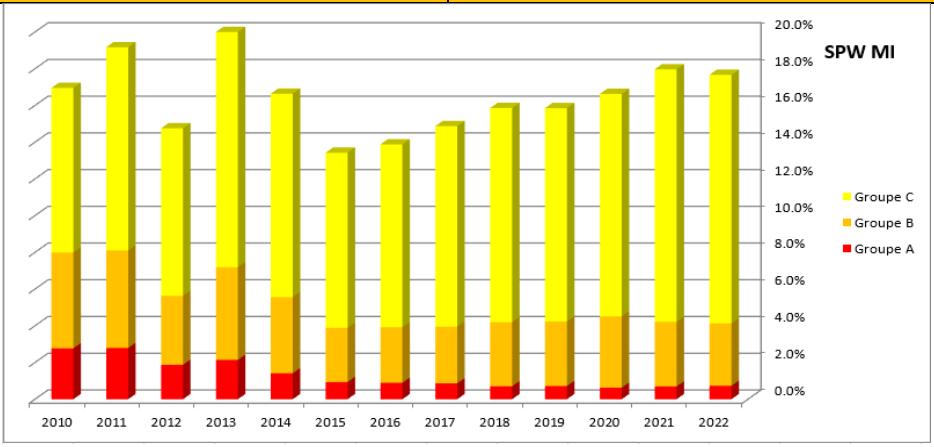
Adequate staff training is also necessary because bridge management in its inspection, calculation, repair aspects is a very specific topic and is not necessarily covered in the academic world.

So is knowledge sharing within the civil engineering world. Participating in and/or organizing specific events on bridge management allows to reunite the different stakeholders with their own experiences which can contribute to improving one's own processes.

Benefits

Regular bridge condition assessment allows to rank the bridge stock according to a condition index and therefore give a clear view on which part of the stock requires prioritized intervention. It also allows to monitor the overall bridge stock condition and therefore anticipate needs in skilled staff and in funding.

Authorised Vehicle Mass	SPW Mobilité et Infrastructures Belgium (Wallonia), High Income Country



Wallonia has one of the oldest bridge stocks worldwide. It faces the challenge of having many structures reaching the end of their lifecycle at the same time. It is therefore important to foresee the investment walls required in the following years. Premature condition deterioration will only increase probability of the need early intervention. It is therefore critical to be able to estimate and defend funding cases for Government investment plans.

3.5. KEY FINDINGS

The literature review and survey responses confirmed that the problem of aging infrastructure is affecting road administrations of both High Income Countries and Low- and Middle-Income Countries, across all geographical regions. However, variations were identified between different types of road network, with motorways primarily having issues related to structures, national roads having issues with structures and drainage, and regional roads facing significant levels of aging infrastructure for structures, drainage and pavements. This led to approximately a quarter of survey respondents rating their networks as performing “not well”.

A range of causes were identified, with certain road administrations facing different priority issues depending on the composition of their networks. Underinvestment is a major problem for virtually all administrations, which results in a growing backlog of maintenance. Traffic on roads has also been reported as significantly increasing across all modes for most road administrations, with particular growth coming from cars, HGVs and LGVs. This was particularly highlighted in Slovenia, with increases of up to four times the levels of HGV traffic compared to periods before joining the EU. However, there is also reported growth in cycling and micromobility, which will demand different levels of service from roads due to the more vulnerable nature of their users.

Loading from traffic also plays a part in increased deterioration and premature aging of assets, with reported increases in permitted axle loads for many countries, and the case study from Belgium detailing this more closely. Research by PIARC has also flagged that overweight vehicles are also a risk, particularly for LMICs with unpaved roads. Climate change was reported as an issue for HICs such as Slovenia, with issues related to increasing high water flood levels, plus LMICs in Africa, where the effects disproportionately impact on rural communities.

Finally issues related to construction were also flagged, with large volumes of assets built in similar periods in the past affecting countries such as Germany, by providing a wave of aging infrastructure in current times. Also, the construction of some assets in the past were noted as using lower design standards than are currently in place, plus some issues encountered when applying new construction techniques at the time, thus reducing the expected service lives of assets. The majority of survey responses indicated that standards are changing to accommodate innovation, but only a minority reported updates to standards to address the challenges of aging infrastructure.

These causes led to a number of reported consequences. Aging infrastructure typically suffers from more rapid deterioration that would be expected for newer assets, with the resulting need for maintenance work increasing year on year. This leads to a cycle of ever-increasing maintenance backlogs that are challenging to keep steady, with reduction in backlog simply seen as not feasible for most administrations. This is exacerbated by rehabilitation costs for aging infrastructure exceeding the costs that would be required to intervene at more optimal points in the asset lifecycle.

Addressing aging infrastructure is likely to require either increased frequency and/or duration of closures of lanes or entire roads, with knock-on effects for road users. Where maintenance funding and poor infrastructure condition get too extreme, permanent closures of assets may be required. Impacts on society can differ drastically depending on national income levels. Problems in High Income Countries may take the form of damage to vehicles, insurance claims and compensation payments, whereas in Low- and Middle-Income Countries the impact of aging infrastructure may

result in disruption to economies and essential services that may cost lives in addition to fatalities from road collisions.

The literature and case studies identified a number of needs to address such problems. These included a need to understand the condition of aging infrastructure, the ability to articulate the importance of investment in maintenance, the potential to manage risks associated with aging infrastructure, and the capacity and capability to plan and deliver all of this. These findings reconfirmed the proposed scope of this study, and the following sections develop these themes further.

4. MONITORING AND ASSESSMENT

4.1. INTRODUCTION

To effectively manage and improve aging infrastructure, it is critical to understand the condition, performance, and safety of it. As well as using established methods for capturing this information, road administrations are increasingly testing and implementing modern technologies to increase efficiency and depth of knowledge of their assets. The project compiled approaches used by road administrations in the selecting survey methods and how frequently these are commonly used, including assistance in bridge inspections with drones / unmanned aerial vehicles (UAVs) and the emerging use of Artificial Intelligence in processing video surveys.

Asset information systems are also vital to managing this knowledge, and supporting more informed decision making, with modern technologies, such as Building Information Management (BIM) providing new ways to organise and collect data. Better understanding of service lives can improve the optimisation of maintenance scheduling and management of risk, based on asset data and engineering knowledge. Furthermore, safety audits are also an important method of assessing how well aging infrastructure is performing.

A key issue in monitoring and assessment is adequate control of data quality. This needs attention at all stages of data collection, storage and use. Especially, if data collection is outsourced, data quality requirements need to be clearly defined to ensure acquisition of reliable data.

4.2. LITERATURE REVIEW

4.2.1. PIARC Special Project – Road related data and how to use it [8]

In 2020, PIARC commissioned a special project to investigate the use of data by road administrations to improve services in both High Income Countries and Low- and Middle-Income Countries, and the final report is freely available on the PIARC website. The study reviewed over 200 sources of literature to provide an overview of both existing “business as usual” and the state-of-the-art data collection and analysis technologies, and also to assess the Technology Readiness Level of each technology. Examples included the use of social media not only as a communication platform but also as a source of information such as reporting of defects on the road network, and the application of smartphones to continuously provide information related to road surface condition.

An online survey was also conducted, with responses from over 80 organisations in 46 countries covering all geographical regions and income levels. The survey investigated a range of technologies and approaches related to road inventory and condition data, such traditional human surveys, road sensors, machine learning and computer vision, satellite imagery, vehicle telematics and data from third parties or other organisations.

The report also includes a set of 24 recommendations based around 6 themes: strategy – ensuring that the use of data is aligned with the objectives of the administration; data sources – the use of existing data, new data, and unconventional data; organisation and management approach – how data analysis and functions are organised within road administrations; partnerships – different ways of setting up data sharing agreements, legal and technical aspects, and resulting services; enablers – the skills, systems and processes required to become more data-driven; and making the case – the justification of investment in data and the evaluation of its benefits.

4.2.2. PIARC Report – State of the Art in Monitoring Road Condition and Road / Vehicle Interaction [9]

The report comprehensively reviewed the current state of technology and techniques for monitoring road conditions and interactions between vehicles and roads. The document discussed various sensing technologies and their applications for road condition monitoring, including visual inspection, acoustic sensing, vibration sensing, and imaging using cameras or lidar sensors. The paper also highlighted the importance of incorporating weather data and environmental conditions in road condition monitoring systems.

The document also explored different methods for monitoring road/vehicle interaction, including measuring tire-pavement friction, vehicle dynamic response, and road roughness. The paper discussed using sensors, such as accelerometers, gyroscopes, and GPS, to gather data on vehicle behaviour and road conditions. The review also addressed the current challenges in road monitoring, such as the need for reliable and accurate data and the integration of data from multiple sources. The document concluded by discussing emerging technologies and trends, including using big data and artificial intelligence for road monitoring and developing connected and automated vehicles.

Overall, the document provided valuable insights into the state of technology and research in road condition monitoring and road/vehicle interaction, highlighting the potential for improving road safety, reducing maintenance costs, and enhancing transportation efficiency.

4.2.3. PIARC Special Project – The Use of Unmanned Aerial Systems for Road Infrastructure [10]

The report explored the potential applications of unmanned aerial systems (UAS) in road infrastructure, and highlighted the following key points:

- UAS can collect high-resolution images, videos, and other data on road infrastructure, including bridges, highways, and tunnels, for inspection, maintenance, and repair.
- UAS can also be used for surveying and mapping road infrastructure, providing accurate and up-to-date information on the condition of the road network and potential hazards.
- UAS can improve safety and reduce costs in road infrastructure management by allowing for more efficient inspections and maintenance, reducing the need for manual labour, and minimizing the risk of accidents.
- The report also noted that using UAS for road infrastructure management is subject to regulations and restrictions, including pilot training and certification requirements, airspace restrictions, and privacy concerns.

Overall, the report concluded that UAS have significant potential for improving road infrastructure management, but their use must be carefully managed to ensure safety and compliance with regulations.

4.2.4. PIARC Collection of Study Cases – Advancement of Inspection Techniques / Technologies as a Part of Bridge Management Systems [11]

The report is a collection of case studies published by PIARC in 2022. It highlights the advancements in inspection techniques and technologies used in bridge management systems. There are 28 case studies that have been gathered from 10 countries mainly in European countries, Chile and Japan.

The case studies demonstrate the use of various non-destructive testing methods such as ground-penetrating radar, ultrasonic testing, and acoustic emission monitoring to detect defects in bridges. Additionally, the collection showcases the integration of digital technologies such as drones and artificial intelligence to enhance the efficiency and accuracy of inspections.

The inspection techniques are presented based on structural type and damage type.

The use of these advanced techniques and technologies has enabled bridge managers to conduct more frequent and detailed inspections, leading to better maintenance and increased safety of bridges as well as the inspectors.

4.2.5. UK – National Highways standard – CS 450 Inspection of highway structures [12]

National Highways, the road administration responsible for the English strategic road network, provides a suite of technical standards that are freely available for reference and use by all. The latest version of standard CS 450, “Inspection of highway structures”, was published in 2021 and covers the use of the UK’s Inspection Manual for Highway Structures. The objectives of the standard include the detection of any defect that may cause an unacceptable safety or serviceability risk or a serious maintenance requirement, in order to safeguard the public, the structure and the environment and to enable appropriate remedial action to be taken. It also seeks to provide information that enables the management and maintenance of a stock of structures to be planned on a rational basis in a systematic manner, and to ensure that inspections are undertaken by suitably experienced and competent staff.

Topics covered include general requirements for inspections, as well as definitions and frequencies for different inspection types – safety inspections, general inspections, principal inspections, special inspections and inspections for assessment. The standard outlines requirements for the management and planning of inspections, including record keeping and access measures. The standard supports the use of risk based principal inspection intervals and provides a procedure to assess these consistently. It also puts a focus on the competence of inspectors and notifies practitioners of a separate Bridge Inspector Certification Scheme that has been developed in the UK in accordance with National Highway Sector Scheme 31. Finally, the standard covers health and safety, including an illustrative list of potential hazards and an extensive list of relevant legislation for UK practitioners to comply with.

4.3. SURVEY FINDINGS

Most road managers now systematically assess and monitor road condition. This concerns, firstly, the condition of the carriageway and engineering structures and, secondly, road equipment, drainage, earthworks, and road lighting.

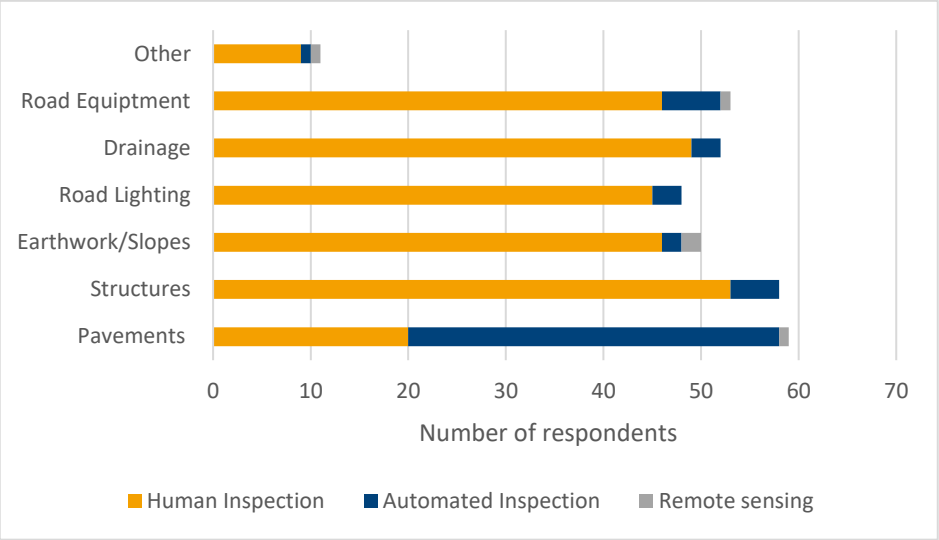


Figure 17 – For which assets do you regularly and systematically survey and assess condition?

This monitoring is carried out on an annual or even multi-annual basis for most countries, not forgetting a few countries that assess their roads on a half-yearly, quarterly or monthly basis.

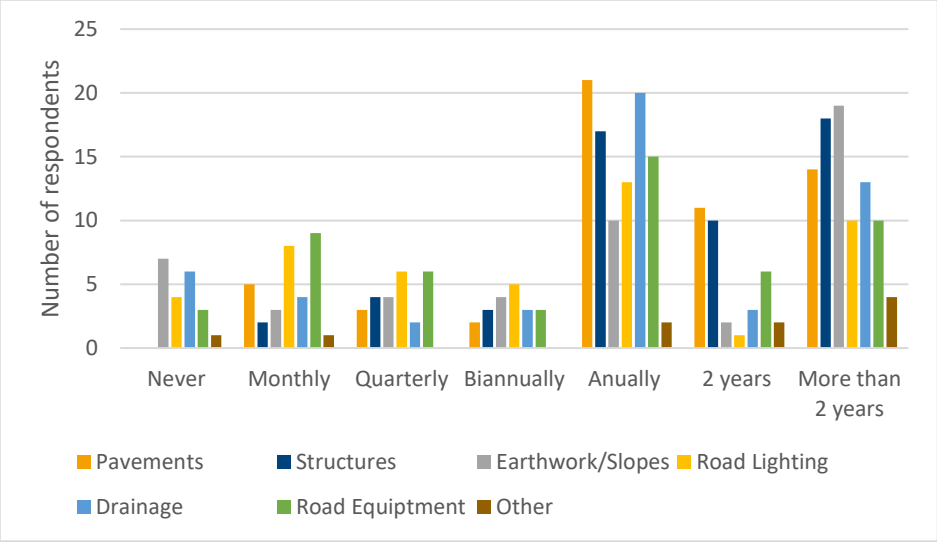


Figure 18 – Frequency of survey and assessment of assets

Most of the resources used are human, except for the monitoring of pavement condition, which is carried out by automatic means with a high level of data collection efficiency.

More than two thirds collect data on the condition of infrastructure regardless of its age, and not only those that are beginning to age.

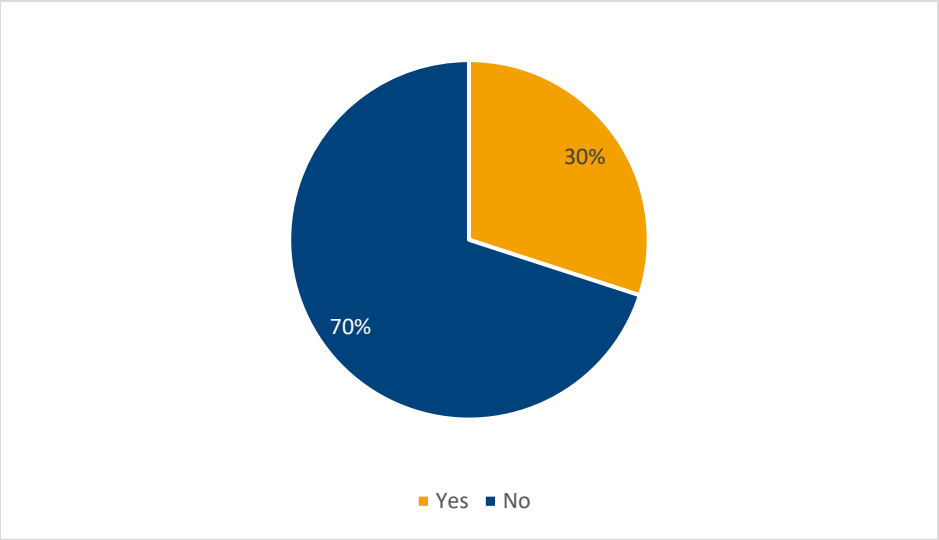


Figure 19 – Does the age of the asset influence how frequent you collect this data?

The structural survey and assessment of pavement bearing capacity are the main methods of data collection, along with the use of maintenance histories from the time of construction and high-performance condition assessments. Then, there are the more scientific and innovative methods, such as assisted bridge inspection using drones, and the use of artificial intelligence (AI). These latter methods will be used more and more in the near future. The data collected is stored and managed by IT systems in 66% of countries.

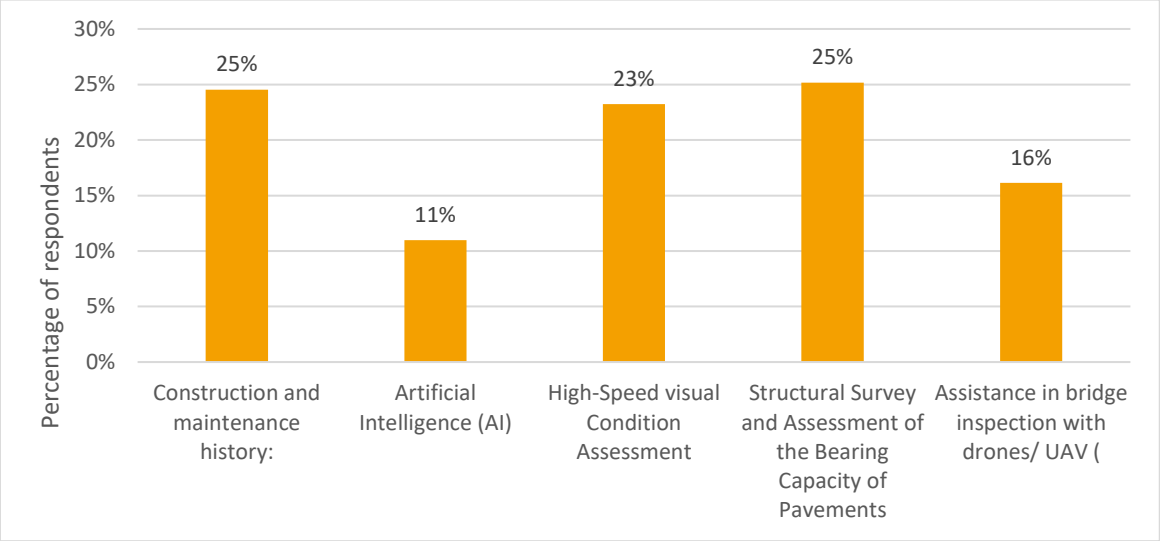


Figure 20 – What innovative scientific methods and cutting-edge knowledge do you apply to collect data and assess the condition of your aging infrastructure in particular?

The majority of countries confirm that each road asset has a residual lifespan: road equipment from 0 to 9 years, flexible pavements from 10 to 19 years, rigid pavements from 20 to 39 years, engineering structures more than 40 years and does not apply to drainage and public lighting.

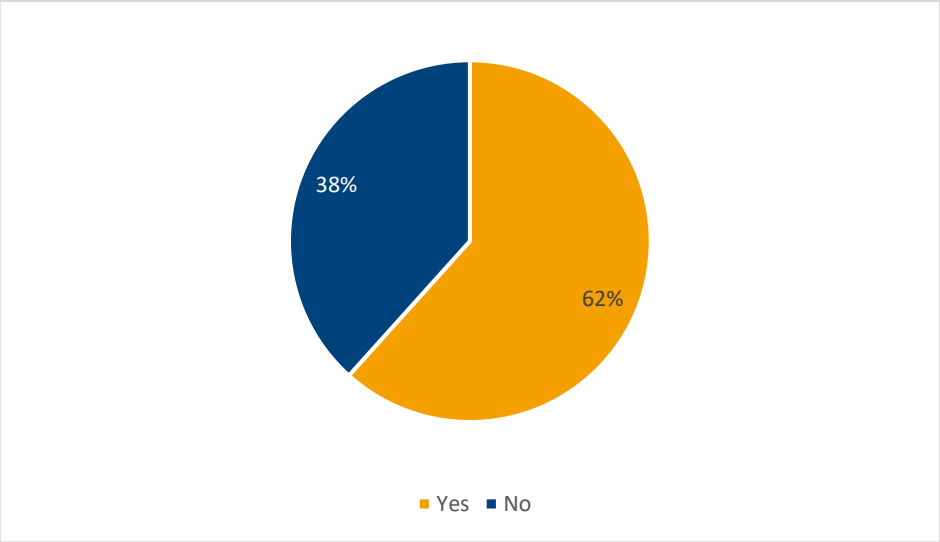


Figure 21 – Do you have standard service lives (residual life) for road assets?

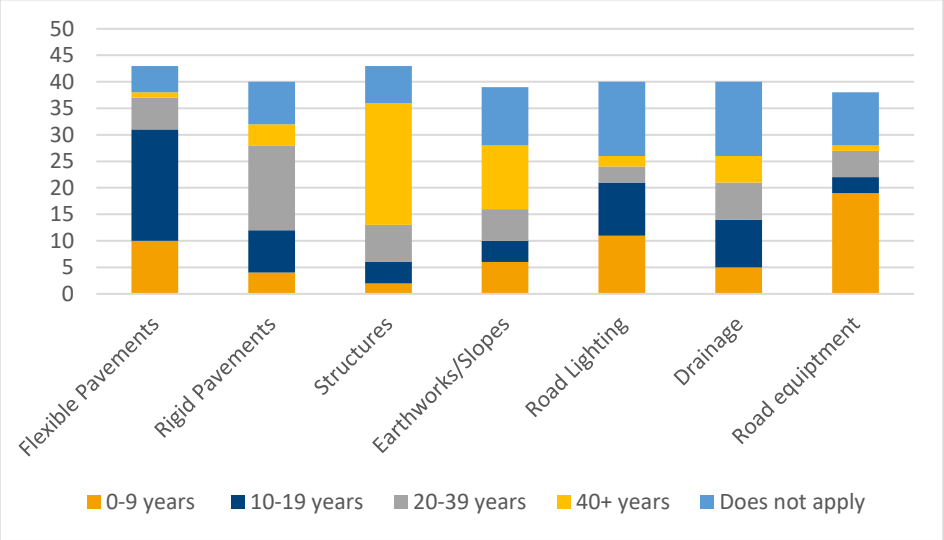


Figure 22 – If yes, what is your standard service life used in your monitoring and assessment?

In terms of the safety aspects of the current infrastructure, the majority of countries do not undertake safety measures, but 40% do so annually within 3 years.

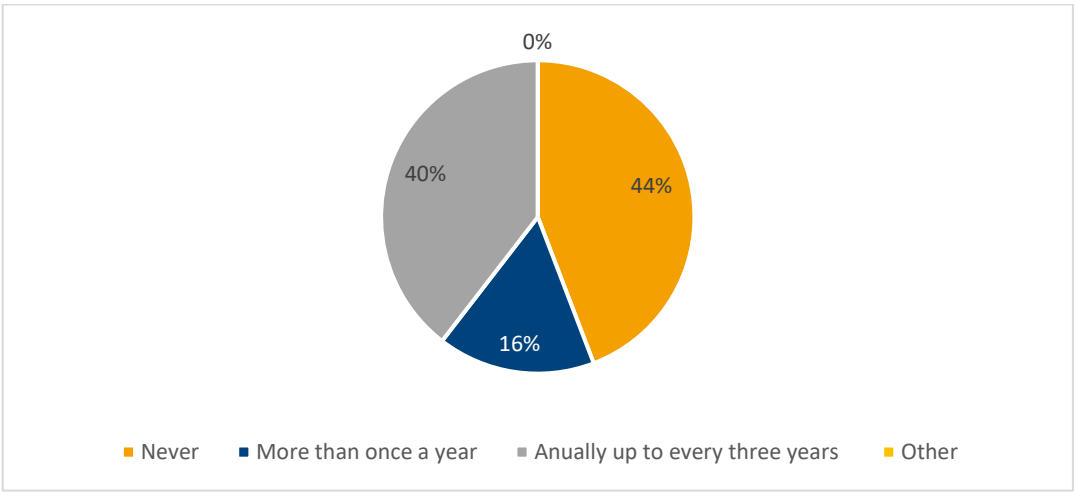


Figure 23 – How frequently does your organization undertake a safety audit of the current infrastructure?

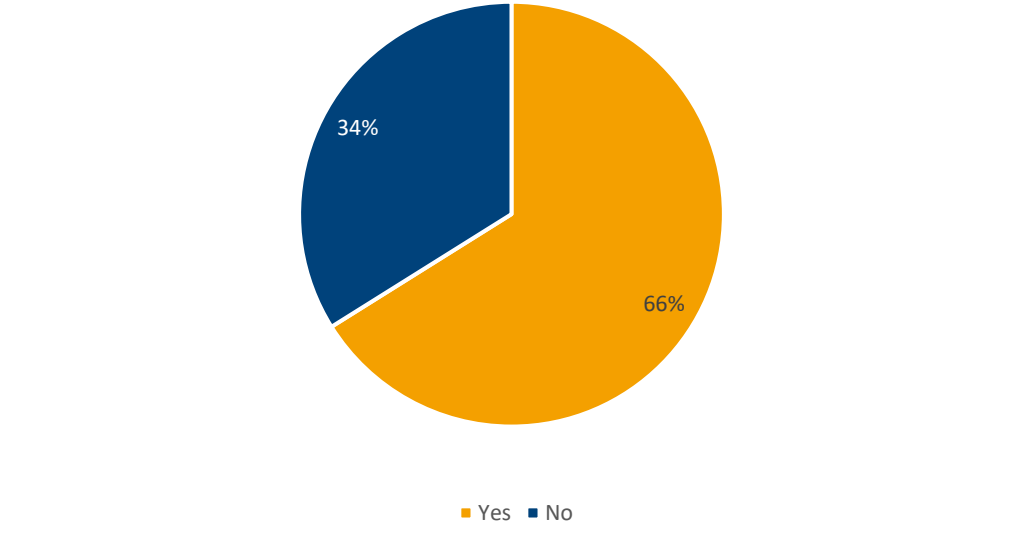


Figure 24 – Do you use a Road Asset Management System to store and manage data?

4.4. CASE STUDIES

Smart Infrastructure Asset Management System on Metropolitan Expressway	**Metropolitan Expressway Company Limited** **Japan**

Problem

In Japan, aging infrastructure that was developed during the high economic growth period has progressively deteriorated. As a result, the numbers of structural damages and inspection work are increasing. However, there is a shortage of inspection and maintenance engineers due to a reduction of working-age population, which causes one of major social issues.

Solution

Concerning the above-mentioned issues, the Metropolitan Expressway Co., Ltd. has developed an innovative maintenance and management system (i-DREAMs: intelligence-Dynamic Revolution for Asset Management system) in order to enhance efficiency and effectiveness in maintenance and management work for achieving sustainable road infrastructure. This system has been developed by adopting innovative technologies that have made remarkable progress in recent years, such as ICT, AI, IoT and Robotic Technology.

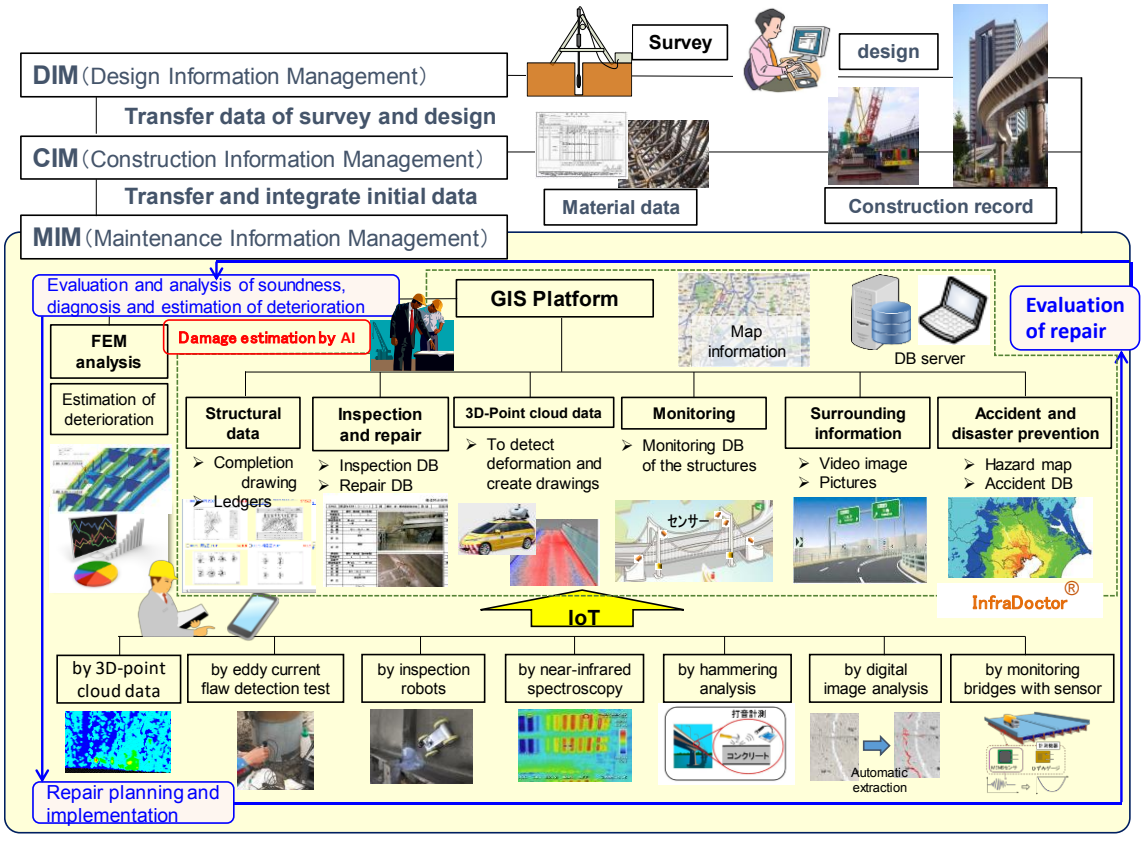


Figure 1 - Overall concept of smart infrastructure management system (i-DREAMs)

The core technology of i-DREAMs is InfraDoctor, which can integrate various data obtained from each work process such as maintenance work and utilize 3D point cloud data for various stages of maintenance work on GIS platform. The scope of InfraDoctor is inside of the dashed line box

Smart Infrastructure Asset Management System on Metropolitan Expressway	**Metropolitan Expressway Company Limited** **Japan**

in Figure 1. This system can support an efficient maintenance and management work of road infrastructure. In addition, by utilizing technologies such as image processing analysis and AI, it enables a comprehensive evaluation and assessment of structural deterioration and damage, thus allowing the condition of infrastructure to be visibly checked. By repeating and conducting the required processes in a maintenance cycle, an advanced and innovative infrastructure maintenance and management can be implemented.

Benefits

Since the practical operation of smart asset management system (i-DREAMs) in Metropolitan Expressway Co., Ltd. in 2017, some beneficial effects are beginning to appear such as a reduction of lead time for site condition check, which is the basis of maintenance and management work. Furthermore, the measured 3D point cloud data by MMS without any necessity of work zone traffic control can be efficiently utilized in maintenance and management work. This can significantly reduce the time required for work zone traffic control, thus leading to a decrease in social and economic losses due to such traffic control. With the results of practical operation in the actual maintenance work, the system will be further improved and developed for efficient maintenance and management of infrastructure. It is expected that this system can be utilized not only for highway structures in the Metropolitan Expressway but also for other infrastructure such as railway structures and can contribute to the development of safe and secure social infrastructure not only in Japan but also in various countries around the world in the near future.

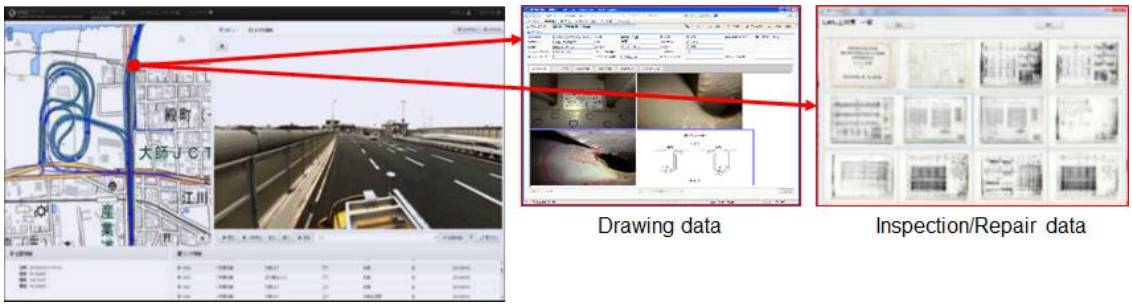


Figure 2 - Operation screen of GIS platform

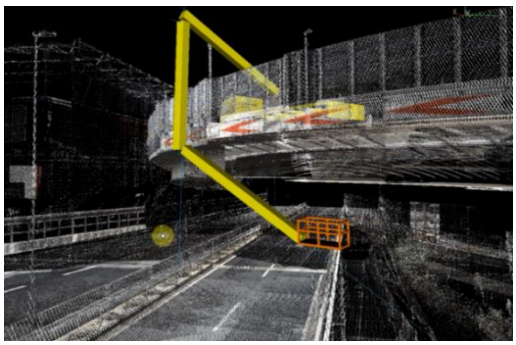


Figure 3 Simulation of construction machinery

Figure 4 Simulation of work zone traffic control

Moving towards proactive maintenance of the paved road network	**Finnish Transport Infrastructure Agency and Roadscanners Oy, Finland** 

Problem

The decline in Finnish budgets for paved roads has caused increasing pavement deterioration rates that has led to increasing problems on national network. Falling budgets and prioritisation of main roads have led to the fact that low traffic volume roads are now suffering from inadequate funds. In addition, trends towards heavier truck total weights and maximum allowed axle loads have exacerbated this, as have the newer generations of tyre types with smaller footprints. Climate change is also likely to have an effect through the impact of seasonal changes on road networks. All these cause extra stresses on pavements as well as unbound pavement structures. To counter this, research on new methods and policies is now needed to address the growing problems.

Solution

Road asset management policies have globally been mainly based on reactive maintenance, where corrective measures have been initiated only after clear pavement damage or another types of deficiencies in structural or functional condition have been identified. The problem with this policy is that, for instance, cracked asphalt can have already lost its tensile strength and the service life of new coatings can be significantly lower, and life cycle costs higher, than if the asphalt had been repaired before the damage became visible. In these circumstances, monitoring pavement distress only measures how late the needed maintenance actions are.

However, in the philosophy of proactive maintenance, the root causes of premature damage are always determined prior to repair, and the chosen corrective actions focus on eliminating, or at least diminishing, the causes of these problems. The central theme of proactive maintenance is to extend the service life of roads, in accordance with the following principles: 1) repairs are not carried out if nothing is wrong, i.e. for safety's sake, 2) damage must never become the acceptable "normal," and 3) the approaching damaged condition is monitored and responded to in a timely manner.

Since 2015 the new technologies and policies, including proactive maintenance in road asset management, have been tested in "full scale" in the 10-year PEHKO project in Finland. The project´s goal is to improve practices and policies in paved road maintenance and management and thereby improve the condition of the paved road network, or at least keep it at the current level using less resources. This is being done by focusing on four targets:

1) Improving daily maintenance, especially drainage and snow removal,

2) Applying new non-destructive testing (NDT) methods in the diagnostics of paved roads. These techniques allow engineers to focus rehabilitation measures exactly on the problem sections and address the root causes,

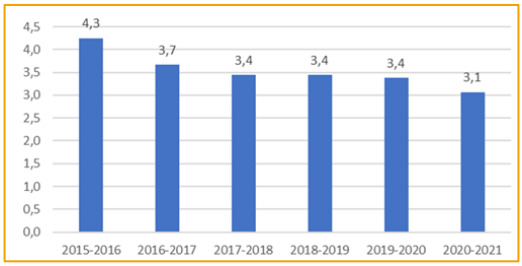
Moving towards proactive maintenance of the paved road network	**Finnish Transport Infrastructure Agency and Roadscanners Oy, Finland** 

3) Changing maintenance policies from reactive to more proactive maintenance, allowing maintenance crews to fix the potential problem sections before serious pavement damages appear, and

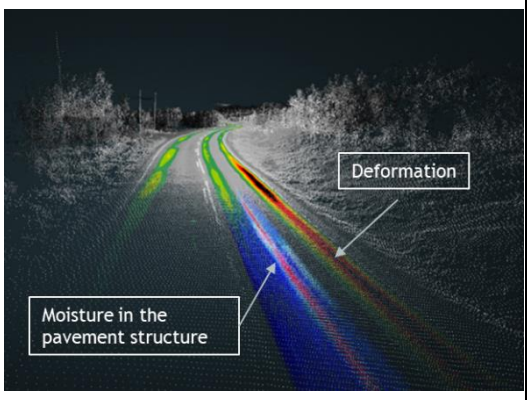
4) Developing co-operation between daily and periodic maintenance planning and execution.

Benefits

The PEHKO project has been in place for eight years in two pilot areas and three years in one area. The gains in annual calculated life cycle costs are already between 20-35%. Results show clearly that improving the productivity of road asset management by using new road condition monitoring techniques based on diagnostics, focused rehabilitation and proactive maintenance can lead to major savings in annual paving budgets. This means that in the future available budgets can be effectively spent, and more of the limited resources can be allocated to low volume rural roads also.



Development of calculated annual paving costs



In the future, road users' demands will continue to increase, as will traffic and number of vehicles, and maintenance must keep up with these changes as well. Maintenance measures need to be based on continuous road structural and functional condition monitoring and data analysis, and be focused on solving the actual problems developing in the road structure. These results need to be also properly visualized so that they can be understandable to everyone in the maintenance process chain.

Survey and Assessment of the Bearing Capacity of Pavements in a state-wide Road Network	**Bavarian Road Administration** **Germany, High Income Country**

Problem

In Germany, projects are currently being carried out in several areas to survey the substance and structure of road pavements and to integrate this information into the maintenance management system. The present case study is on a pilot project of the Bavarian Road Administration on network-wide surveying and assessment of the bearing capacity using TSD.

Until now, road maintenance management in Germany has mainly been based on the results of the Condition Survey and Assessment (in German: Zustandserfassung und-bewertung - ZEB), which is carried out every four years. However, the ZEB is limited to the assessment of the superficial condition of the road. Within the framework of an efficient maintenance management, however, knowledge of the structural substance of road pavements is essential for many issues, both at the strategic and the operational level. The measurement of bearing capacity is an important element in the assessment of the structural substance of pavements.

Solution

The Bavarian Road Administration (a part of the Bavarian State Ministry for Housing, Construction and Transport) is responsible for almost 6,000 kilometres of federal trunk roads, about 14,000 kilometres of state roads and more than 3,000 kilometres of county roads in the federal state of Bavaria.

In 2019, the Bavarian Road Administration carried out in a pilot project the first network-wide survey and assessment of the bearing capacity of the Bavarian state roads with Traffic Speed Deflectometer (TSD). Within this pilot project, this measuring system was used for the first time in Germany to record the bearing capacity of an entire road network. The Federal Highway Research Institute BASt accompanied this project with scientific and consulting support.

The Traffic Speed Deflectometer (TSD) is a high-speed measuring system that measures the load-bearing capacity of asphalt pavements.

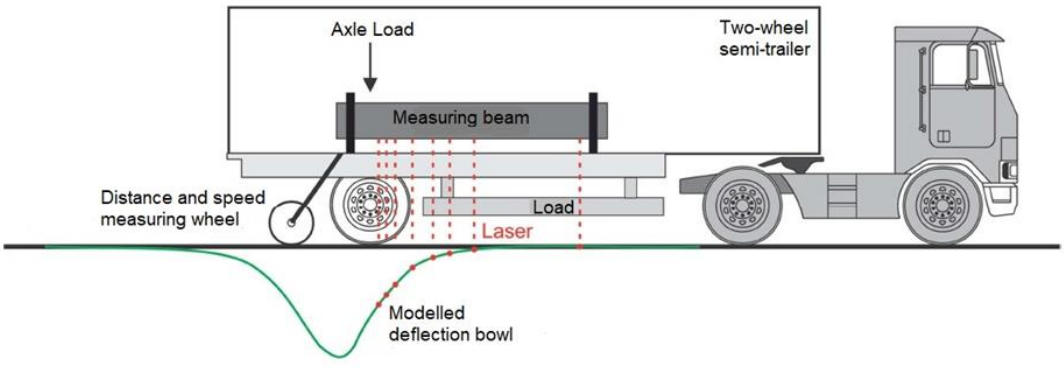


Figure: Schematic diagram of the TSD measurement vehicle [© Bavarian State Ministry of Housing, Building and Transport. Bavarian Road Administration]

The TSD consists of a two-wheel semi-trailer, which applies a defined load to the road pavements with its static axle load of 10 ton. Inside the semi-trailer, there is a measuring beam

Survey and Assessment of the Bearing Capacity of Pavements in a state-wide Road Network	**Bavarian Road Administration** **Germany, High Income Country**

in the right-hand wheel track, to which laser sensors are attached. These laser sensors continuously record the deformation speed caused by the axle load. From the deformation speed and the driving speed, the slopes of the deformation can be determined at each measuring point. Deflections (deformations) can again be derived from these slopes.

The results are available to the Bavarian Road Administration since autumn 2020 for planning maintenance measures.

Benefits

The results help, for example, to optimize the planning of maintenance measures for the coming years. The available budgetary funds can thus be used even more economically. With this pilot project, the Bavarian Road Administration is taking a pioneering role on the way to a new valuable tool for maintenance management in Germany.

More information

Kressirer, Birgit: Pilotprojekt Tragfähigkeitsmessung in Bayern als Baustein des Erhaltungsmanagements (Pilot project on bearing capacity measurement in Bavaria as a component of maintenance management), Journal “Straße und Autobahn” (“Road and motorway”) October 2020. Abstract (Retrieved 11 September 2023): https://www.strasse-und-autobahn.de/strasse-und-autobahn/heftarchiv/sta-102020.html#c9928

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4.5. Key Findings and Recommendations

4.5.1. Key Findings

Knowing the road inventory – whether new or aging - and understanding its condition, functionality, and safety is essential for managing and enhancing it. Road administrations are progressively exploring and deploying new technologies and employing established methods for gathering this data to boost efficiency and deepen their understanding of their assets.

The survey conducted by the working group shows that the collection, assessment, and regular monitoring of conditions has become a systematic task for most road authorities. There are even specific standards for inspecting road bridges in the UK and other countries. The survey shows that pavements and engineering structures are inspected regularly and systematically. Road equipment, drainage, road lighting, earthworks, and slopes are surveyed and assessed less frequently but still by a fair number of respondents. This work is mainly done annually or at slightly longer intervals for core assets such as pavements and engineering structures. Regarding the frequency of condition surveys and assessments, most respondents in the survey indicate that this is not related to age. This could be verified in more detail in interviews in a follow-up cycle.

The automation degree in condition surveys is very high for the pavements and predominates over human inspections. Whereas for the other assets, the human factor predominates, and automated procedures or remote sensing are used only to a limited extent. Road administrations are increasingly exploring the use of new technologies in addition to the established data collection methods. PIARC has conducted a Special Project to investigate the potential applications of unmanned aerial systems (UAS) in road infrastructure, highlighting, among other things, that they are an improvement and efficiency gain for inspecting and maintaining engineering structures or tunnels. The survey shows that several countries already use drones to support bridge inspections. A report published by PIARC 2022 provides further case studies of modern inspection techniques in bridge management.

In most road administrations, road databases are used for organising and making data available for various applications. In order to expand the data stock, especially for aging and historically grown road networks, methods are being explored to record this data efficiently. The introduction of BIM will likely increase the need to capture data on existing infrastructure even further.

The survey shows that in the context of aging infrastructure, many road authorities have recently started to use cutting-edge methods to obtain knowledge about the structural substance of road pavements or other assets and to incorporate this knowledge into maintenance planning. An example of this is the survey and assessment of the bearing capacity of road pavements in a state-wide road network from the German federal state of Bavaria.

Knowledge about the causes of damage is essential for the new path being taken in Finland. Here, there is a move away from reactive maintenance in which measures for improvement are only initiated when damages have occurred. Proactive maintenance aims to identify and eliminate the causes of potential damage in advance. The findings allow us to expect efficiency benefits in the asset's life cycle.

4.5.2. Recommendations

Optimise the collection and utilisation of asset data

Knowledge of aging infrastructure's condition, functionality, and safety is crucial to its management and improvement. The data can be used for various tasks across the full range of a road administration's activities. However, it only makes sense to collect and process data that can be used beneficially for the tasks of road administration. Data capturing or digitisation for its own sake is useless and inefficient.

Exploit innovative methods for condition assessment and inspection

The development of technology and digitalisation continues beyond the road asset management. Modern techniques allow innovative ways of monitoring and gathering data. These can potentially be more efficient and effective than traditional methods. Further research should be conducted in this area. However, these methods must meet the requirements of the road administration for the respective data and its quality.

Enhance information on the structural substance

Particularly in historically grown road networks, road authorities have only limited information on the substance of road pavements (e.g., structure and load-bearing capacity). For overall maintenance management, the knowledge of the structural substance of road pavements is likely to be relevant, both on a strategic and operational level. In addition to recording superficial characteristics, recording the substance with non-destructive and high-speed methods should also be considered.

Use a risk-based approach to collecting data

Aging infrastructure is expected to have greater risks than new assets, so they should not be treated the same in terms of how they are inspected, assessed and monitored. Frequencies of data collection should be adjusted to take into account the age of assets, their condition, their location and the potential consequences of failure.

5. RISK MANAGEMENT

5.1. INTRODUCTION

Road administrations do not typically have sufficient funding to address all risks related to aging infrastructure. On the other hand, due to the critical role they play in supporting the economic and social well-being of their countries, the assets themselves need to operate as normally as possible. Therefore, the project researched the various approaches used to minimise risks where renewal or rejuvenation has not yet been completed (or cannot be completed). For example, how do administrations deal with the risks such as ensuring the stability of assets or safety of traffic, when aging infrastructure has not yet been updated.

Methods include increased frequency of inspections for assets or sections of higher risk, or the use of remote sensors to gain near real-time understanding of performance and thus early warning of any problems. Alternatively, the use of signage and / or speed limits helps minimise risks related to vehicles, with restrictions such as weight limits or even closures of assets (either partially or fully) where required. Accident incidence and road safety on the network should also be systematically monitored and evaluated in order to be able to take remedial action at an early stage. The funding of emergency maintenance has also been investigated, as there may be instances where specific risks that suddenly arise simply cannot be managed safely or where the impacts of mitigations will have too negative an impact on society.

5.2. LITERATURE REVIEW

5.2.1. International – Aging Infrastructure – More than just a bump in the road? [13]

Produced by Willis Towers Watson in 2020, this provides a risk management and insurance perspective of issues related to aging infrastructure. The authors start by introducing the bathtub curve, a graphic that breaks the lifecycle of an asset into three distinct stages – early life, useful life and wear out. The model outlines how failures of in the early stages of an asset's life cycle are oftentimes attributed to defects in design or construction. In the useful life stage, failure is essentially random, and risk is minimised through consistent inspection and maintenance. Risk of failure towards the end of the asset life increases as inspections and maintenance become all the more important and limitations on use may become necessary.

The document highlights the changing landscape that we live in and how we are seeing heavier vehicles on our roads alongside overall higher use. Assets designed for traffic 40 years ago are now facing very different loads compared to back then. Many assets used today were built to comply with less stringent safety standards and bringing those assets up to date carries inherent risks.

It references a study by McKinsey that estimates $49trn will need to be spent by 2030 on infrastructure, for both construction of new assets but also maintenance of existing assets, and highlights that maintenance budgets are typically uncertain, something that could be mitigated through long term contractual arrangements such as Public Private Partnerships (PPPs).

The article concludes by highlighting several areas of interest to risk engineers. These include competency of organisations involved, depth and complexity of supply chain and sufficiency of lifecycle funds.

5.2.2. PIARC Report – Estimation of load carrying capacity of bridges based on damage and deficiency [14]

This PIARC report investigates how and when an estimation of bridge load carrying capacity is carried out by road authorities based on state of damage and deficiency. It gives an analysis of bridge inspection practice, methodologies for load carrying capacity evaluation and traffic restriction measures within 16 countries in order to determine ways to improve the quality and efficiency of road infrastructure through effective management.

Bridges are a major concern for road authorities to garanty public safety and to maintain road capacity. Assessing load carrying capacity of bridges is therefore highly important. The process starts with bridge inspections. Mostly, main routine visual inspections are carried out every 5 to 6 years. Special in-depth inspections are performed according to the results of the routine inspections. Bridges hence receive a state condition index. Good practice shows results of routine tests and bridge element indexes are used in equations or models to determine the load carrying capacity. Mostly though, re-calculation of load carrying capacity is done when the bridge rehabilitation is planned.

This allows to manage risk and enforce proper mitigation actions. The report underlines how decisions are made to restrict traffic on bridges. The main traffic restriction methods are bridge closure, lane closure and limiting maximum tonnage of truck axles.

A key finding is that all road authorities rely on engineering judgment to apply deterioration and damage to the load carrying capacity evaluation. Training, knowledge and efficient program management are therefore essential to road owners to implement this risk based approach and to provide safe bridges for the users.

5.2.3. Slovenia – guidelines for planning and implementing measures to improve traffic safety and flow on Slovene motorways [15]

The document provides guidelines and instructions for planning maintenance activities on Slovenian motorways. The document was produced by the Slovenian Motorway Company (DARS). One of the main issues addressed in the document is the increase in truck traffic on Slovenian motorways since the country joined the EU. This increase in traffic has resulted in the pavements on large parts of the motorway network being under-designed. Additionally, maintaining the motorways has become more difficult as it is not possible to reduce the number of lanes from two to one when performing maintenance. The existing motorways are too narrow for the closure of one direction of the motorway while not reducing the number of lanes.

The document also notes that there has been an increase in traffic accidents due to the emergency lane's width being too narrow at 2.5 meters. Furthermore, the safety barriers on Slovenian motorways were not built according to EN standards, and their assumed level of protection is too low. The guidelines and instructions in the document are meant to address these challenges.

For motorway sections where the pavement needs to be reinforced by more than 5 cm, the guidelines recommend designing pavements for a 20-year design life. Safety barriers are also replaced with new ones, and the median barrier is paved to avoid the need for mowing the grass and equipped with concrete safety barriers that require less maintenance after the traffic accidents. The emergency lane is widened to 3.5 meters to increse safety of stoped vehicles and to allow closures of the one directional carriageway without reduction of the traffic lanes.

If the increase in investment due to the implementation of these measures is more than 30%, some measures can be avoided.

On other motorway sections where the pavements are reconstructed, the design life is 10 years, and there is no change in the motorway's width. Safety barriers are only replaced at hazardous locations.

Overall, the document emphasizes the importance of proactively addressing the challenges caused by increasing traffic on Slovenian motorways, particularly with regard to implementing safety measures and considering the impact on traffic flow when allocating funding and making decisions regarding maintenance activities.

5.2.4. UK – National Highways standard – CS 470 Management of sub-standard structures [16]

National Highways, the road administration responsible for the English strategic road network, provides a suite of technical standards that are freely available for reference and use by all. The latest version of standard CS 470, "Management of sub-standard structures", was published in 2020 and covers the requirements for the management of highway structures that have either been assessed to be sub-standard according to the requirements of CS 454 ("Assessment of highway bridges and structures") or have been deemed to be sub-standard by other methods. As assessments of this type are typically based on theoretical calculations, and the identification of sub-standard structures without completed assessments are typically based on engineering judgement, such structures do not necessarily pose an immediate and unacceptable risk to safety.

The document includes information management processes such as document and records management, which is vital to providing a clear and auditable way of managing such structures. It also covers more technical issues such as assessing whether structures pose an immediate risk to public safety, and if so, what emergency interim measures should be applied. The document also covers the management of provisionally sub-standard structures, including lower risk structures, and a process for identifying appropriate interim measures to manage safety risks.

The range of interim measures outlined by the document include load mitigations such as vehicle weight restrictions, lane restrictions, propping of the structure, use of a temporary structure and closure of the structures to all users or classes of vehicles. It also covers reviews of existing weight restrictions and monitoring regimes, the importance of emergency response and communications plans, and a technical appendix providing further information on examples of particular types of sub-standard bridges.

5.3. Survey Findings

When assets cannot be repaired, most countries apply restrictions either by limiting weights or limiting speeds and increasing inspection frequency to ensure good risk management. The majority of countries (53%) state that they have no mechanism for funding emergency maintenance.

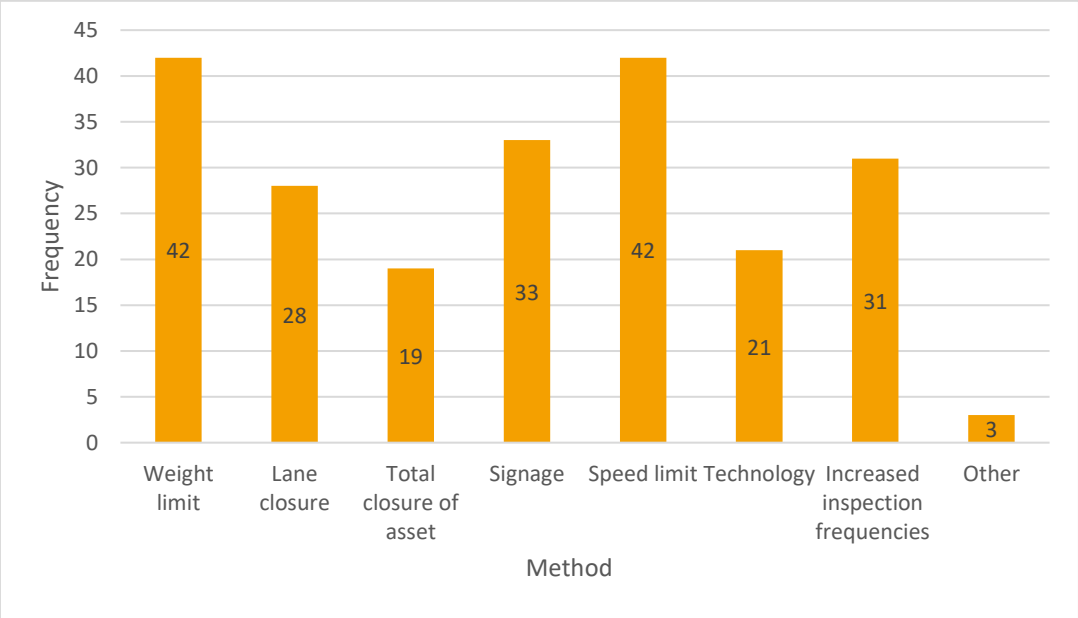


Figure 25 – Risk management approaches used whilst infrastructure elements have not been repaired

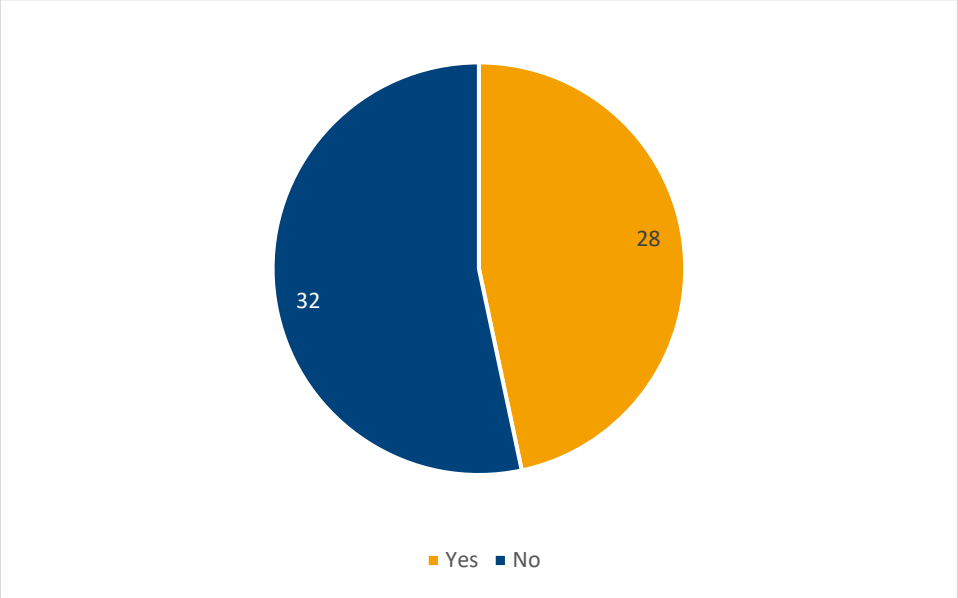


Figure 26 – Do you have any funding mechanisms for emergency maintenance?

5.4. CASE STUDIES

Evaluation of bridges in Slovenia	**DRI Investment management Ltd.** **Slovenia** 

Problem

In most infrastructural systems, it is neither possible nor optimal to inspect all system elements regularly. An optimal inspection-repair strategy controls deterioration processes and repairs or replaces damaged elements in a timely manner. This has to be done with limited financial resources and acceptable reliability. A review of the available literature shows that an integral risk-based optimization procedure for an entire infrastructural system is not available as existing risk-based inspection methods and decision support systems are limited to optimizing inspections and/or decisions element by element.

In general, the greatest risks for bridge failures are posed by the following bridge characteristics: shallow foundations, brittle static design and damage in vulnerable zones (such as high shear and high moment zones). If these issues are properly addressed, the risk of bridge failure is significantly reduced.

Solution

The Slovenian bridge management system for motorways (BMS DARS) consists of two parts: 1. Periodic inspections and 2. Data analysis on structural and network level. For any decision-support system to be used in practice the following condition must be met: the data used for the decision making must be available for all the elements considered, in this case bridges. To address the above-mentioned possible causes of failure, among other data, the bridge static design as well as the location, intensity and extent of each damage needs to be known.

The data regarding damage is gathered during the inspection. Slovenia's bridge condition assessment methodology is based on a quantitative approach. That means every damage type on every element ($ID_{i,j}$) is assessed individually using the following equation:

$$ID_{i,j} = \sum_{l=1}^{p_j} \underset{k=od\ 1\ do\ o_l}{maks} (B_l \cdot K_{1,j} \cdot K_{2,j,l} \cdot K_{3,l,k} \cdot K_{4,j,k,l})$$

where i is bridge component, j is component element, p_j is the number of damages l on the element j, B_l is damage type characteristic value, $K_{1,j}$ is significance of damage type to element j, $K_{2,j,l}$ is intensity of damage l on element j, $K_{3,l,k}$ is extent of damage l on location k and $K_{4,j,k,l}$ is intervention urgency due to damage l on element j and location k.

During the inspection special attention is paid to vulnerable zones and in case of detected irregularities or damage in these zones the value of the $K_{4,j,k,l}$ factor is increased earlier than it would be in cases of the same damage being recorder on other locations. When later analysing the whole bridge stock at the network level it is much easier to detect potentially dangerous damage by filtering damage with a high value of the $K_{4,j,k,l}$ factor. The described method reduces the risk of overlooking potentially dangerous damage.

Evaluation of bridges in Slovenia	**DRI Investment management Ltd.** **Slovenia** 

The robustness of static design is also addressed at the network level. For example, the rigid frame bridge can in general withstand more damage than precast beam or truss bridge. When prioritizing remedial measures, bridges with a less robust static design are selected first among similarly damaged bridges.

Shallow foundations pose the third risk for bridge failure. On Slovenian highways all bridges are designed and built with deep foundations, therefore there is no risk of scour. However, bridges on Slovenian state roads are mostly built with shallow foundations. The issue of how to systematically eliminate this shortcoming with acceptable costs is still being addressed. Currently, during the periodic inspections bridges with local scour are being identified and when the condition of the foundations is assessed as hazardous, remediation is carried out.

Benefits

The benefit analysis is performed at the network level and is not risk based, as this issue is already addressed at the structural level during the periodic inspections and individual bridge assessment where bridges with higher risks get lower bridge condition (BC) value.

Benefits are calculated with a so-called target function. Maximizing the average condition of bridge stock is the road authorities' goal. The users' goal is not exactly the same as for them it is also important which bridges are in good condition and which in bad. Bridge in a good condition (low risk of failure) and a high traffic load is certainly worth more than a bridge in the same condition and low traffic load. To take into account the users' benefits, the parameter Average annual daily traffic (AADT) is embedded in the target function. Users' benefits are defined as higher safety and driving comfort as well as avoided detour costs because of partial or complete bridge closures due to their poor condition. The value of the target function is calculated:

$$f(BC, AADT) = \sum_{i=1}^{N} (BC_i \cdot \sqrt[p]{AADT_i} \cdot A_i)$$

where *BC* is bridge condition, *AADT* annual average daily traffic, *N* number of bridges in the network, *A* bridge floor area and *p* selected potency that limits the AADT impact on decision process.

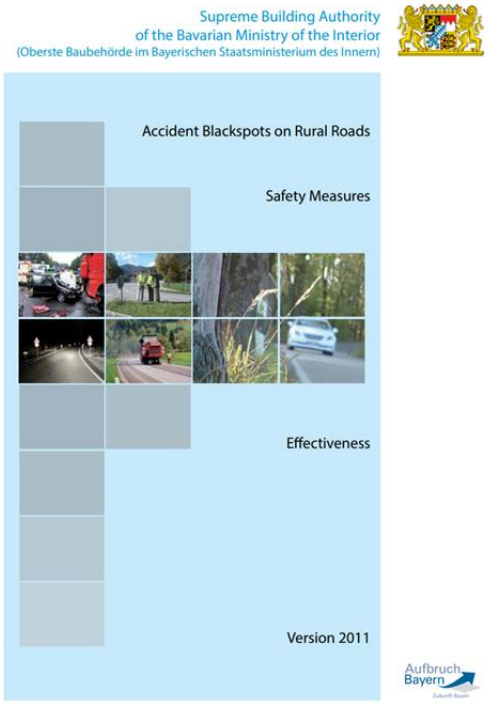
Systematic Road Safety Activities on existing Roads - Expert system for accident commissions	**Bavarian Road Administration** **Germany, High Income Country**

Problem

In order to achieve a sustainable improvement in road safety on their road network, the Bavarian Road Administration relies on systematic road safety activities. Due to the historically grown road network, the analysis and elimination of safety deficiencies on existing roads is of crucial importance.

Solution

The 107 accident commissions in Bavaria (consisting of the road traffic authority, the road administration authority and the police) continuously investigate the accident clusters (so-called “accident blackspots”) identified by the Central Office for Road Safety in Road Construction of the Bavarian Road Administration (in German: Zentralstelle für Verkehrssicherheit im Straßenbau - ZVS) on interurban roads (federal trunk roads, state roads, county roads). Based on this, the Bavarian accident commissions have initiated and realised a large number of improvement measures on accident blackspots since their establishment in 2000. In order to be able to better analyse the complex interactions between the incidence of accidents, accident causes and remedial measures including their effectiveness, all relevant information relating to accident blackspots is being collected by the accident commissions and stored in a central database (UHP) since 2000.



The UHP contains essential basics for the analysis of accident blackspots (e.g. individual accident lists, maps, photos), information on traffic volume, the road inventory (e.g., road curvature, gradients, carriageway width), the road condition (e.g. results of skid resistance measurements), the current accident situation and partially speed analyses. By means of the Web GIS of the Bavarian Road Information System (BAYSIS) this can be combined with further specialised information. All process steps from the time of identifying the accident blackspot to the completion of the work, i.e., the completion of the last measure, are continuously documented by the accident commissions at the UHP.

The information in the UHP and in BAYSIS is the basis for a Bavarian-wide success control of the improvement measures realised at accident blackspots. On this basis, effective measures can be identified depending on the type of accident and the traffic facility. In a first large-scale evaluation in 2011, the results of the network-wide effectiveness analysis for roads (based on

Systematic Road Safety Activities on existing Roads - Expert system for accident commissions	**Bavarian Road Administration** **Germany, High Income Country**

3,864 investigated accident blackspots with 4,647 safety measures implemented) were compiled in the compendium "Accident blackspots on rural roads - safety measures".

The accident commissions are assisted in their work via a web application. Due to the continuous documentation of the measures and their effectiveness, the suitability of the planned measure can be checked online in an effectiveness prognosis. Besides, the application enables a comparison of different alternative measures. Furthermore, detailed descriptions of realised projects are available there.

Benefits

Evaluating the effectiveness of measures at accident blackspots in a centralised and standardised way state-wide and making the information obtained usable for the planning of future remedial measures has proved to be successful and is being consistently continued in Bavaria. With the help of the expert system designed for this purpose, improvement measures at accident blackspots can be implemented more specifically and thus more effectively than before. In the meantime, the BAYSIS expert system has become established in the daily work of accident commissions in Bavaria and is therefore often used as argumentation aid for planned measures at accident sites.

More information

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Tame Valley Viaduct – Bridge Monitoring	**Birmingham City Council** **UK, High Income Country**

Problem

The Tame Valley Viaduct forms part of the A38(M) Aston Expressway, the primary route connecting Birmingham to the M6 motorway and the wider strategic road network, carrying more than 90,000 vehicles a day. As such, the use of the structure to carry traffic is critical to the economy of Birmingham which contributes over £40bn to the UK economy each year.

The 22-span composite viaduct was built in the early 1970s, and is 620m long and 25 metres wide, operating under a tidal flow system during the peak morning and evening periods.

The structure needs to be appropriately managed following an assessment which showed its carrying capacity to be less than that required by modern standards.

Solution

To date the need to restrict or close the viaduct to normal traffic has been avoided through the implementation of a comprehensive structural management strategy involving real time monitoring, inspections, assessments and testing aimed at ensuring the viaduct's operational safety.

The monitoring system comprised over 1,100 sensors, which was one of the largest bridge monitoring systems in the United Kingdom at the time. This innovative approach not only managed operational risks for traffic on the viaduct, but also reduced risks to the workforce working inside the box girders.

The monitoring system used instantaneous temperature correction to provide actual dynamic strains and carry out continuous threshold checks in real time using collected data. This process provided accurate strain readings to input into structural analysis calculations, and acted as a real time safety system alerting engineers if the strains exceed variable seasonal thresholds.

This was essential for satisfying both operational and safety requirements required by the management process. Infrared (IR) cameras were distributed at key critical locations within the viaducts box girders (connected to the monitoring system) to allow remote visual inspection inside the structure to support engineering decision making and mitigate the time required for expensive internal access.

In addition to strain monitoring, a low power IT network was designed and installed to support the 13 IR cameras and 5 computers inside the bridge which connected to a central website control panel coordinating review of data and system operation. A detailed structural strengthening scheme that could be constructed whilst the viaduct remained open to traffic was designed to address the capacity deficiencies identified by the assessment.

Benefits

Tame Valley Viaduct – Bridge Monitoring	**Birmingham City Council**  **UK, High Income Country**
This use of innovative monitoring technology pushed beyond design codes to sustain Birmingham city's accessibility to and from the national motorway network whilst a strengthening scheme was designed and constructed at the viaduct. The deployment of the management strategy enabled long-term plans for the strengthening and maintenance of the viaduct to be devised. A well-planned investment programme is currently underway to strengthen the viaduct’s superstructure via the addition of steel plates welded in position. In addition to strengthening, anti-corrosion paint will be applied to the structure, alongside other refurbishment works to help preserve the viaduct’s longevity and minimise the need for future work.	

5.5. KEY FINDINGS AND RECOMMENDATIONS

5.5.1. Key Findings

Risk management allows road infrastructure owners to address the impacts of aging infrastructure assets in an optimised way, since resource constraints frequently limit the rejuvenation or renewal of all affected assets. Aging infrastructure can lead to risks such as stability or collapse risks or traffic safety risks. Failures in infrastructure assets follow the bathtub curve, a curve that breaks the lifecycle of an asset into three distinct stages: early life, useful life, and wear out. Failures in the early stages of an asset's life cycle are often attributed to defects in design or construction. In the useful life stage, failure is essentially random, and risk is minimized through inspection and maintenance. The risk of failure towards the end of the asset's life increases. In this phase, inspections and maintenance become even more important, and limitations on use may become necessary.

An important issue is being able to identify sub-standard assets, which allows focusing on potentially higher risk-level assets. Monitoring and analysing accident blackspots and accident occurrences in general help identify potentially sub-standard roads, such as too narrow lanes or emergency lanes, or inappropriate road equipment such as under capacity safety barriers. Road design, layer thicknesses, may no longer be suited for current increased heavy truck traffic. Similarly, brittle static design or shallow foundations are inherent vulnerable zones for bridges. Second, frequent inspections are compulsory to assess asset condition. But another key is to optimize inspections by breaking down systems into elements and focusing on vulnerable elements more regularly. This allows gaining efficiency in the inspection process. Adding an emergency intervention weight to the condition calculation when damage is detected on vulnerable zones such as high shear or high moment zones highlights the most dangerous damages when analysing bridge stock at a network level.

After asset condition assessment is made, further analysis can be carried out, such as load-carrying capacity calculation for bridges, to determine and trigger the appropriate mitigation measures. Risks can indeed be mitigated until renewal or repair is prioritised in the road owner's investment program. Main mitigation measures are used worldwide, as suggested by the results from the survey. These measures include weight limitation, speed limitation, lane closures, or asset closures, for example. Another type of interim measure can be propping the bridge or even the use of temporary structures. The condition index values are considered in the decision process to prioritise investment projects to repair and renew the different assets of the road network. But condition alone is not the only factor. Traffic levels, strategic importance, user benefit, risk impact in case of risk occurrence, are but some of the criteria needed to select the highest priority assets to be renewed. In some cases, an inspection may lead to the discoveries of defaults or damages that need to be addressed immediately. Organising an emergency maintenance fund or even reserving part of the budget allocated to maintenance for emergency interventions is good practice. The survey shows, though, that less than half the respondents have such a funding program. These considerations will be further discussed in the following chapter.

To reduce the risk related to the failure of aging infrastructure, it is essential to keep it in the useful life stage as long as possible and to consistently inspect the infrastructure in the end of the asset's life phase to be able to identify the critical and sub-standard assets and apply detailed inspections

to the critical parts. The identification of critical parts of aging infrastructure can already be incorporated in the monitoring phase, or it can be addressed in the later phases.

5.5.2. Recommendations

Shift maintenance policies from a reactive approach to a more proactive one

Shifting from a reactive approach to a proactive one means addressing issues before they escalate into major problems. Renewal measures should be applied before the asset's load-bearing capacity is significantly compromised.

Prevent overloaded vehicles through strong enforcement (monitoring, detecting, and applying severe penalties)

Overloaded vehicles can cause accelerated wear and tear on infrastructure. Strong enforcement, including monitoring and imposing severe penalties, can deter such practices and protect the integrity of the assets.

Target inspections where there is greatest risk

Focusing on critical elements during inspections ensures that vulnerable areas are thoroughly assessed and prioritised for maintenance or repair. More frequent inspections during the end of an asset's life phase help identify potential issues early on and allow for timely interventions, whilst ensuring the safety of road users.

Have rapidly available funding for emergency repairs

Establishing emergency maintenance funds allows quick access to resources for urgent repairs when critical infrastructure is at risk.

Develop policies on how to deal with sub-standard assets and focus on structural maintenance and selected improvements

Having clear policies in place for handling sub-standard assets ensures a consistent and effective approach to addressing risks associated with these assets. To optimise resources, maintenance policies can be adjusted to prioritize critical structural maintenance and safety improvements over meeting the latest technical standards for the entire road network.

Impose limitations on use (weight limit, lane closures, signage, speed limit, total closure of the asset)

Temporarily or permanently restricting certain uses or applying speed limits can mitigate risks and protect vulnerable infrastructure until repairs or replacements are carried out, especially in areas with higher risk or traffic impact.

6. PRIORITISATION, PROGRAMMES AND FUNDING

6.1. INTRODUCTION

Given the scale of challenges in managing aging infrastructure, it is vital that there are robust processes to develop investment plans, deliver works programmes and communicate these for greatest effect. For instance, how can road administrations evaluate the risks and prioritise strategies for rehabilitation, repair or replacement? Criteria that can influence this include network hierarchies, safety deficits, reliability, condition, environmental impacts, level of service, economic efficiency etc. These can be applied either based on asset types, routes or other means. This type of prioritisation can be supported by special software. As well as reviewing needs from an engineering perspective, it is increasingly important to understand and consider road user needs and expectations. In this context, it is important to communicate management and maintenance decisions to the public in an understandable way.

Special programmes may be in place to modernise and rejuvenate aging infrastructure, but key to all of this is the ability to finance urgent interventions to the network and the reduction of any maintenance backlog. Various sources of funding are available, either through government, the private sector, international banks and / or innovative funding models. Once asset needs are clearly understood and funding options are identified, then it is critical that the case for investment is clearly articulated to decision-makers, politicians and the public to convince them that this is worth doing.

6.2. LITERATURE REVIEW

6.2.1. Germany – How can we communicate better on road asset management [17]

During a presentation at the 2018 “Pavement Preservation and Recycling Summit” (PPRS) in Nice, France, Dr.-Ing. Thomas Linder (former Chair of PIARC TC Asset Management) gave an overview of the steps taken by the Bavarian Road Administration (Germany) from 2011 to 2018 to improve funding through better communication. The article was published in French in: RGRA Revue générale des routes et de l’aménagement, No. 957, September 2018, Paris

The Bavarian Road Administration – at that time responsible for more than 25,000 km of federal motorways (Bundesautobahnen), federal roads (Bundesstraßen), state roads (Staatsstraßen) and district roads (Kreisstraßen) – was and is faced with ever-growing road traffic, with the increasing relevance of roads as the most important mode of transport and with aging infrastructure. The preservation and maintenance of this network is therefore becoming more and more important. Asset Management is the keyword. To ensure the high infrastructural standard of the Bavarian Road network, adequate funding for road maintenance is imperative. In order to enhance funding, the Bavarian Road Administration is focused - among other things - on improved communication.

In order to convince decision-makers, several steps were taken during the above-mentioned period:

- Step 1: Professional Asset Management: the entire maintenance activities during the life cycle must be carried out with profound technical expertise.
- Step 2: Professional Communication: It is crucial to translate the engineering language into a language that is easily understandable by decision-makers.
- Step 3: Convince the boss! It is crucial that your boss is on your side. For a state administration the boss is the minister, the Prime Minister and the State Cabinet. The fact

that the boss is on the side of the road administration and its asset management strategy is impressively shown in the preface of the publication of the maintenance strategy: There, the minister and the state secretary show that the maintenance of roads is their great concern (first edition in German: 2009, first edition in English: 2011):

https://www.stmb.bayern.de/assets/stmi/vum/strasse/bauunderhalt/42_maintenance_management_201108.pdf (retrieved 11th September 2023)

- Step 4: Convince the financier! For a state administration the financier is the Parliament. Therefore, you have to convince the members.
- Step 5: Do good and talk about it! At the end, the achieved success shouldn't be hidden. An active public relation is essential.

6.2.2. Mexico – New Schemes for Road Maintenance [18]

This article mentions the various contracting schemes between the private sector and the public sector, for the maintenance of the federal highway network. In particular, the Multiannual Road Maintenance Contract (CPCC) is described. The purpose of the CPCC was to standardize the User Service Levels and guarantee their preservation over time.

They were implemented to improve the service provided to users, give long-term budgetary certainty to road maintenance, modernize the management of the maintenance of the federal highway network, and promote the development of companies specialized in comprehensive and multi-year maintenance of roads.

There were previous programs to fund the road maintenance such as "Road Fund", which was created through a tax on gasoline.

Subsequently, Mexican government created the "Pilot Project For Integral Maintenance, PROPIMI", which was a multi-year project that includes in one single contract all the activities necessary to maintain the toll-free federal highway infrastructure.

Some years later, it was developed the "Integral Maintenance Program, PROMAI", that had as main goals to lower the economic, social, and environmental cost, to intensify reconstruction, periodic and routine maintenance work, and to improve the quality of reconstruction, periodic and routine maintenance works.

The "Multi-Year Road Maintenance Contracts, CPCC". tried to capitalize previous experiences in road maintenance funding. Its purpose was to standardize User Service Levels and guarantee their preservation over time, through the Pluriannual Contracting Regime, with private companies.

The main objectives of the CPCCC were to improve the service provided to users, to provide long-term budgetary certainty to road maintenance, modernise the management of the conservation of the federal highway network, and to promote the development of companies specialized in integral and multi-year highway conservation.

It can be summarized benefits for both Users of road and government with the CPCC Program:

USER BENEFITS	GOVERNMENT ADVANTAGES
Telephone Assistance	Multi-year contract for 7 year
Permanent road assistance	Cost reduction, timely attention to maintenance and greater efficiency in the resource scheduling
Optimum conditions	Permanent attention for emergencies
Reduction of accidents	Constant updating of studies and executive projects
Horizontal and vertical signalling in perfect condition	Construction and maintenance opinions, saving costs helping the Agency
Comfort and safety	Identification and exploitation of basaltic material banks
Toll-free roads	New pavement structuring techniques that are more economic and structurally improved

Table 1 Summary of user benefits and government advantages of CPCC

Nevertheless, the CPCC scheme had some disadvantages, such as short time for implementation of management systems, generation of executive projects and permanent facilities, non-compliance with annual programmed allocations, obsolete technical data of the road network, and vandalism and permanent damage to the urban road package.

6.2.3. Mexico – Evolution of Toll-Free Federal Highways Maintenance [19]

This article mentions the evolution of the contracting schemes between the private sector and the public sector in terms of maintenance of federal road network. The first maintenance contract models were the “Integral Maintenance Pilot Project” (PROMPIMI) Implemented in 2003 with financing from the World Bank.

In 2010, the CPCC contracts (Multi-year Highway Maintenance Contracts) emerged. Contract pay-outs were contingent on maintaining the tranches within performance standards.

PPP (Public Private Partnership) contracts are currently being implemented. They were developed since 2013. They propose a long-term relationship between the Public and Private sectors. These contracts can develop new infrastructure or address the existing one.

As many counties, the Mexican government faced several challenges in the 21st Century such as to increase budget allocation, eradicate problems obtaining budget authorization, to promote private sector participation and risk sharing, and performance standards implementation.

The evolution of Toll- Free Federal Highways Maintenance tried to improve roads through public actions such as Routine maintenance, Periodic maintenance, Reconstruction of sections and bridges, Road signs and Attention to conflict points.

Some of these Programs were:

PROMPIMI (Integral Maintenance Pilot Project) | 2003	Implemented with The World Bank financing, it proposes a single contractor to be responsible for the road section
PROMAI (Integral Maintenance Program) | 2007 - 2013	This program was developed after PROMPIMI's external financing ended
CPCC (Multi-year Road Maintenance Contracts) | 2010	7-year contracts: Development 3 years, Maintenance 4 years. Payments depended on preserving and maintaining the condition of the sections within performance limit
APP (Public-Private Partnership) | 2012 - Current	Long-term relationship between the public and private sectors to increase the social welfare and investment levels of the country. Its Application Fields were Transportation, Electricity, Social infrastructure and Water

Table 2 Summary of Public-Private sector contracting schemes in Mexico.

PPP (Public Private Partnership) had as main features to improve existing infrastructure trough Service agreement, and not by concession. It had Three stages: a) Preliminary stage (2 months), b) Initial rehabilitation (28 months), and c) maintenance (Up to 10 years from the preliminary stage).

Private sector recovered its investment with monthly payments and deductions, coming from government, depending on the performance of maintenance activities, which are measured all time.

The APP have helped to improve communication roads in Mexico through a program that ensures funding and the continuity of the maintenance.

6.2.4. Belgium – Plan Infrastructures 2019-2024 [20]

The Plan Mobilité et Infrastructures 2019 – 2024 report details Wallonia's (Belgium) pluriannual investment plan. Particularly, it explains how the government's FAST vision for improving mobility in terms of trafic flow, accessibility, security and modal transfer is implemented within the road infrastructure development and renewal plan and how the plan was actualy devised.

The project selection process is described. The idea behind the process is to choose the best projects which meet the needs of road users and local stakeholders while in line with the governement strategy. It involves different steps which guarantee objectivity throughout the process. Starting with the identification and rough cost estimate of all needs by the territorial operational road departments as well as expertise or support services. The report adresses the cost estimation method based mainly on the type of activity, road surface and length of network. A need isn't a project yet, it is the simple expression of a particular infrastructure need, i.e. the solution to a problem, which can be a dangerous area, a poor condition, etc.. These needs are then categorized in different themes such as structures, pavement, public transportation, bicycle paths, stormwater basins, noise reduction, security etc.. The budget allocated to each of these themes is defined by the Minister, based on his political will and on the recommendations from the administration.

For each of these themes, included needs are rated according to specific criteria such as health indexes for structures or pavements, presence of high accidentology zones for security, high trafic rates, etc.. This delivers a selection of prioritized needs which is then challenged by local operational

departments to discriminate needs which would not necessarily translate a correct priority via the algorithm.

Prioritised needs are then presented within their category and an investment plan proposal which takes into account the expected global plan budget is submitted to the Minister for review. Once the selection is validated, the next steps can begin with the pre-study phase which will allow a selected need to become a better defined project with a perimeter, budget and time frame. Then the planification phase can take place. The investment plan becomes a pluriannual works program.

6.2.5. UK – State of the City [21]

London's highway network infrastructure is facing many challenges, current (highly congested, aging asset, designed in 60's and central London being built on a floodplain) and future (climate change and limited resilience within the city).

LoTAG (London Technical Advisors Group) developed the 'State of the City' report to highlight the challenges impacting London and the consequences of underinvestment in the highway network.

'State of the City' is an annual report for Greater London, which aims to build up an objective picture of the extent of the highway infrastructure asset, its condition, maintenance spend, and the networks need. The purpose of the report is to communicate to stakeholders (the public, politicians, etc) in layperson terms the current status of London's highway network and future consequences, plus making the case for sustainable long-term funding.

'State of the City' has evolved to highlight the risks against UK Government and London Mayoral Strategic Objectives, the promotion of Active Travel and adaption to climate change, plus also considering the Social Value provided by the Highway Infrastructure and the impacts due to degradation of the asset condition.

'State of the City' has gained national interest and assisted in raising the awareness of London's Highway Infrastructure challenges and the impacts to the UK Government. Since publishing the 'State of the City' report, DfT has become actively engaged with LoTAG, looking into the future and collaborating to find solutions manage future risks.

6.2.6. France – Maintenance Audit of National Network [22]

The State is responsible for nearly 21,000 km of roads: 9,000 km of motorways granted through 19 contracts and 12,000 km of motorways and national roads managed by 11 interdepartmental road directorates (DIR). The modal share of the road in France exceeds 85% whether for the transport of people or goods. Even if it represents only 2% of the total length of roads in France, the State network supports more than a third of the total traffic, the non-concessioned national road network (RRN NC) nearly 20%. Concerning the network maintenance, the national road network not under concession is made up of roadways, civil engineering works and various equipment (such as signalling) whose quality of service deteriorates more or less rapidly under the effect mainly of aging of the equipment concerned, the level of traffic by light vehicles and heavy goods vehicles or even the severity of winter weather conditions. The network maintenance policy designates the objectives, strategy and means that the State adopts to maintain normal traffic and safety conditions on the network.

Conducting an external audit aims to help the State improve its road network maintenance policy. It is not a technical audit consisting in inspecting the state of the network and the works, but a

methodological audit relating to the way in which the assessment of the state of the network and the policy of road maintenance by the competent State departments, in particular by comparing them with international practices.

The study aimed to help the State define and optimize the maintenance strategy to guarantee the best condition of the non-conceded national road network in the next five, ten and twenty years.

With regard to security and availability, the models and simulations carried out by the design offices have integrated two priorities: maintaining security and avoiding serious attacks on the network; control the availability of infrastructure, in particular the most sensitive road sections in socio-economic terms (traffic, type of connections).

6.2.7. Morocco – Management and financing of road infrastructure in Morocco [23]

Morocco has a paved road network of more than 41,000 km including 750 km of express roads. The motorways put into circulation have a length of 1416 km, those in construction are 252 km.

For the management and operation of this network, the Direction des Routes du Maroc has set up well-adapted services and a well-defined management system. The databases on roads in Morocco are considered among the oldest in Africa: road traffic since 1977, accident statistics since 1968, the management system since 1990.

In addition, for the financing of road projects in Morocco, the Road Administration draws on various sources such as the general State budget, the Special Fund roads, the Fund for Road Financing, donations, partnership, concessions public. The purpose of this communication is to share the Moroccan experience in terms of management and financing of road projects.

6.2.8. Ivory Coast – Financial and commercial management of roads in West Africa [24]

Benefiting from reliable, high-quality road infrastructure at all times is an important matter for governments and populations. However, after decades of implementation of road funds, a bitter observation of the advanced deterioration of road transport infrastructure is still required, mainly in developing countries.

In Côte d'Ivoire, a country in sub-Saharan Africa, the will of the authorities to deal effectively with the alarming situation of road infrastructure which had reached and even exceeded the age limit, prompted the introduction of tolls. The announcement of the cost of toll has resulted in the anger and grumbling of carriers and users, threats of increases in the cost of public transport, criticism of authorities). Which says a lot about the willingness of the different parties to accept and appropriate the concept of road tolls.

This article is intended as a contribution to the understanding of a cross-cutting concept. The results of this study are supported by a survey of the populations regarding the perception, relevance and sustainability of road tolls. Overall, it is a practice to be gradually integrated into habits but above all to be put into perspective regard to costs.

6.2.9. PIARC Report – Assessment of budgetary needs and optimisation of maintenance strategies for multiple assets of road network [25]

The report was produced by Technical Committee 4.1 Management of Roads Assets. The subject of the report was defined in the PIARC Strategic Plan 2012-2015. It provides a detailed analysis and discussion of data gathered from interviews with public road administrations and private sector

concessionaires on good practices in budgetary assessment and optimisation of maintenance strategies. The study lasted 4 years and the aim was to formulate recommendations for an improved or better asset management of actual or planned road infrastructure assets.

The investigation found that many road authorities have some sort of long-term strategic plan, based on performance indicators, that is relevant to prioritisation in budgetary allocation. All administrators face budgetary and construction quality constraints. A way to cope with these budgetary constraints is to present choices in the strategic plan and/or comparison of business cases. For instance, by presenting the ideal situation and alternative strategies to show expected results and consequences in terms of spending, impacts and/or risks.

The findings underline the importance of realistic strategic targets and requirements (safety, comfort, pavement structure issues). Comparison of the actual situation and these targets has an essential impact on decision-making. A subsequent straightforward and reproducible process for monitoring and assessment against those targets is needed.

The report highlights the importance of harmonization of maintenance and construction programs of different road assets. Thus, it is important to provide asset-specific data and maintenance needs in a cross-asset-specific form so that engineering judgement and assessment are possible. A combination of a bottom-up and top-down approach is recommended here. Most countries currently use cross-asset management for coordination and prioritisation. Most road administrators use engineering judgement while developing an optimisation process. The main difficulty in the development is the complexity of the universal ranking scale for all assets allowing for a holistic process.

There is a shift from a technical asset management plan to a more detailed argumentative version such as explicit business cases in support of budget allocation. These are more interesting for the public and politicians. Also, external auditing of reported obtained results is starting to become more common. The report concludes that risk management should be an integral part of asset management business cases. The assessment of risks based on the probability and consequence of failures enables a better understanding of decisions and their effects. Risk assessment should be included at the project and network levels.

Finally, many road authorities have an interest in knowing where they stand in performance relative to other authorities. However, the benefits of comparison between road management authorities (benchmarking) are vague. The asset base and the way costs are accounted for within an organisation need to be considered when comparing benchmarking results.

6.2.10. PIARC Report – Best Practices in Funding and Financing of Road Infrastructure [26]

The PIARC Collection of Case Studies on Best Practices in Funding and Financing of Road Infrastructure is a compilation of case studies from different countries around the world that showcase innovative approaches and strategies for financing road infrastructure projects. The report covers various types of funding sources, including public and private financing, and explores different mechanisms for raising revenue such as tolling, taxes, and public-private partnerships.

The case studies highlight the importance of developing a clear and comprehensive funding strategy that aligns with the country's overall transportation policy and economic goals. They also emphasize the need for effective project management and risk management to ensure the successful implementation of road infrastructure projects.

Overall, the report provides valuable insights and practical examples of how countries can fund and finance road infrastructure projects in a sustainable and efficient manner.

6.3. SURVEY FINDINGS

Of the 60 respondents that answered as to whether they had a specific financial strategy in place for aging infrastructure, nearly 2/3 answered yes. The vast majority of respondents that do have a financial strategy in place specifically for aging infrastructure do so in the form of government funding, with international funding as the second most popular response.

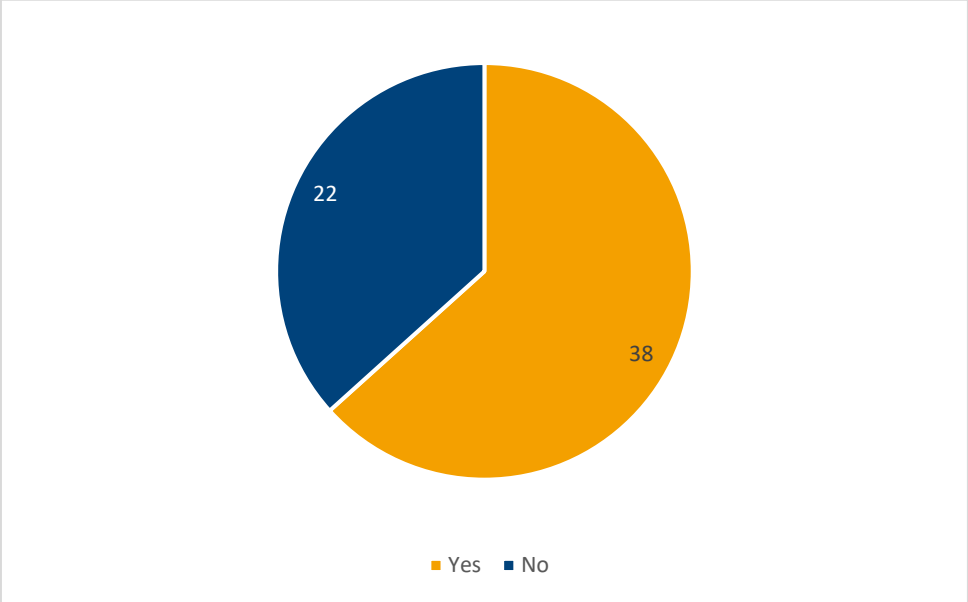

Figure 27 – Is there a specific financial strategy for aging infrastructure?

When considering prioritisation strategies for the modernisation and renewal of the aging infrastructure, there was a much more overwhelming majority that answered yes as depicted in the graphs below. Of the 48 respondents which answered yes, the majority of them communicated that the prioritisation programmes refer to route sections as opposed to asset types or segments. However, that is not to say that programmes were not constructed on an asset type/ segment basis, as shown in the below graph.

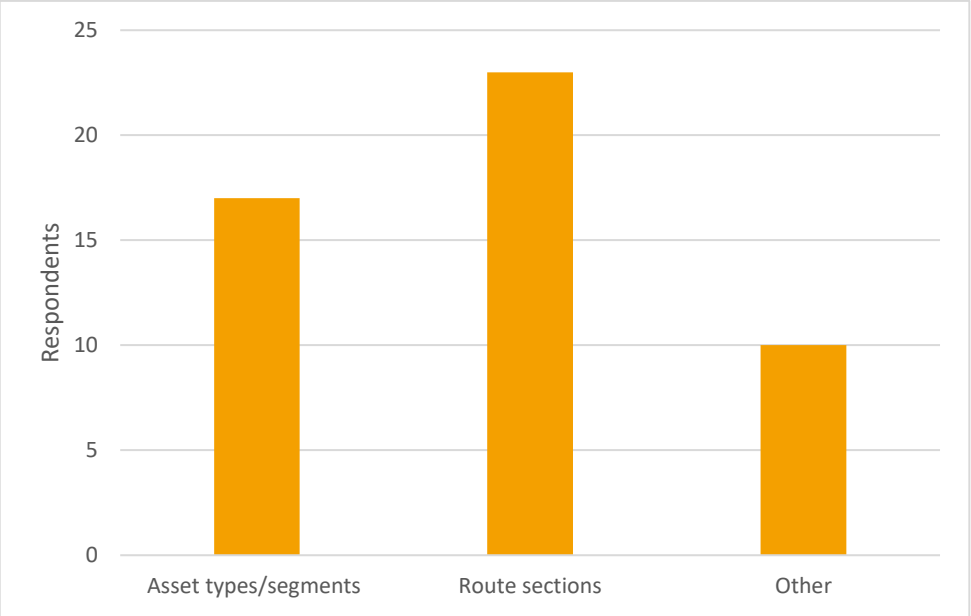

Figure 28 – If yes, does this prioritisation strategy only refer to individual asset types/road segments or route sections?

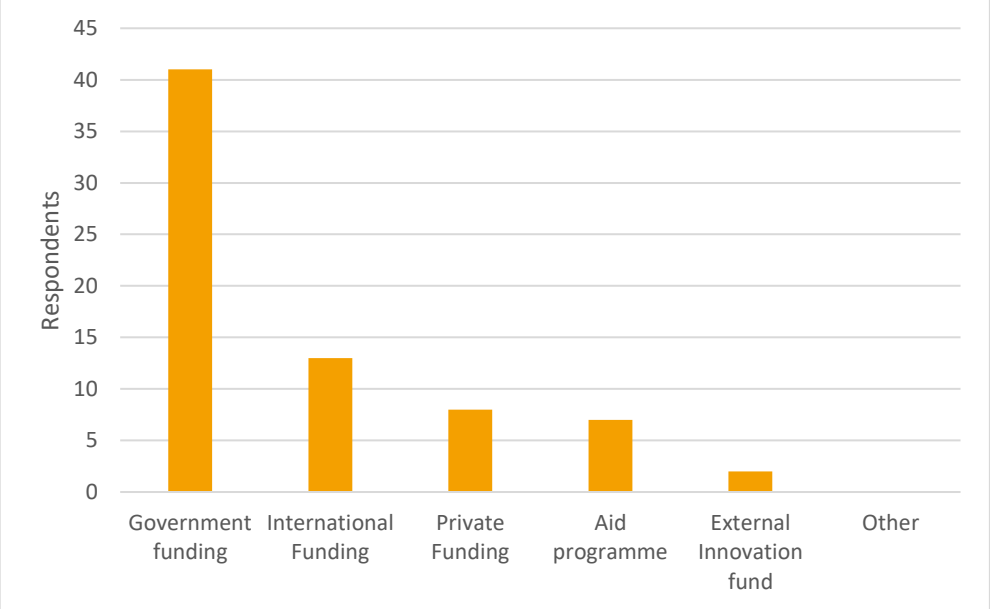

Figure 29 – If yes, which programmes or plans do you have for the financial strategy of aging infrastructure?

When considering prioritisation criteria of these programmes, a range of criteria were identified as shown by Figure 30. Asset condition and safety defects were highlighted as the most common criteria. Environmental impact and public perception were amongst the least popular responses. Despite the pressing climate crisis that the global community is facing, environmental impacts are not viewed as equal importance to safety. This is of particular prevalence when funding is limited and sourced from governments. Interestingly, just over half of the respondents said they do not use a software system or tools to support the decision-making process for fund allocations. This means that the majority of prioritisation decisions undertaken by respondent countries are done so completely at human discretion.

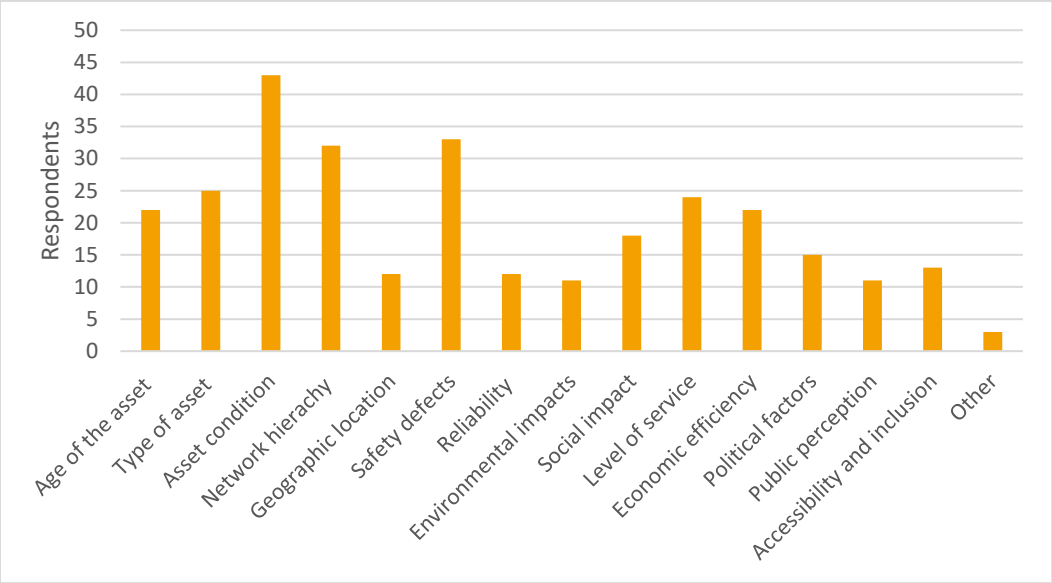

Figure 30 – If yes, which prioritisation criteria do you use?

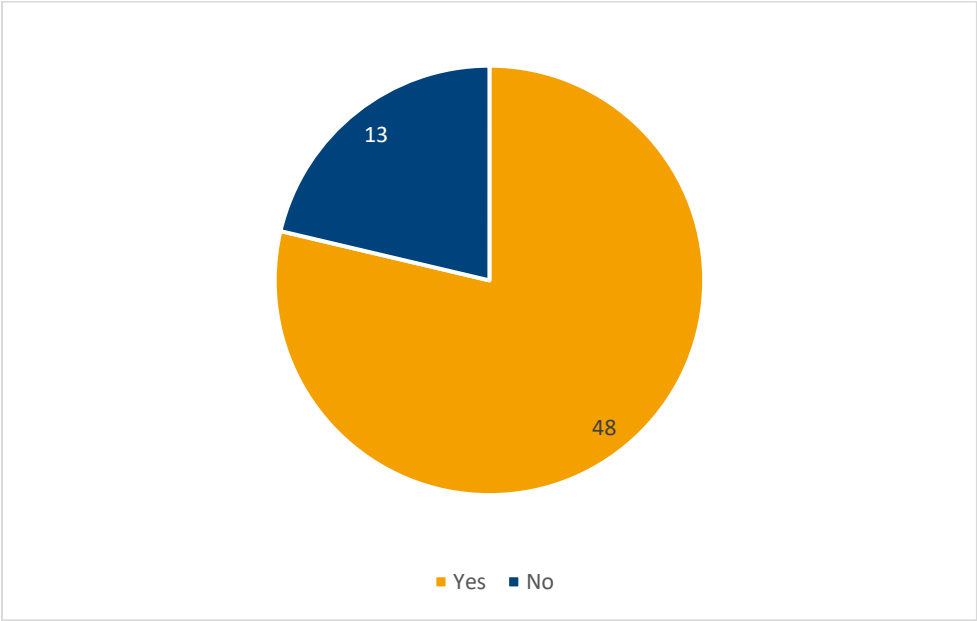

Figure 31 – Do you have a prioritisation strategy for the modernisation and renewal of the aging infrastructure?

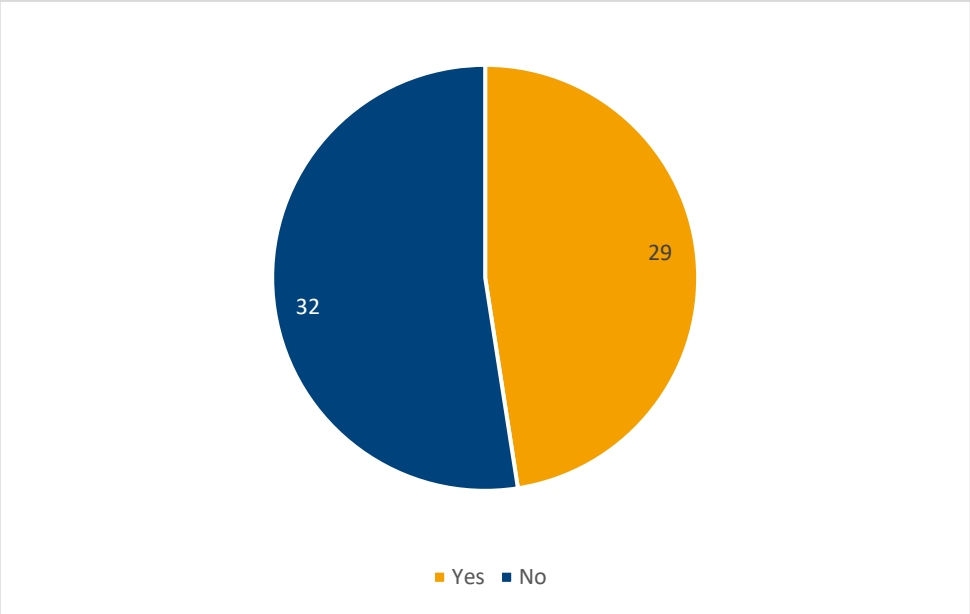

Figure 32 – Do you use a software system or other tools to support Prioritisation, Decision making and fund allocations?

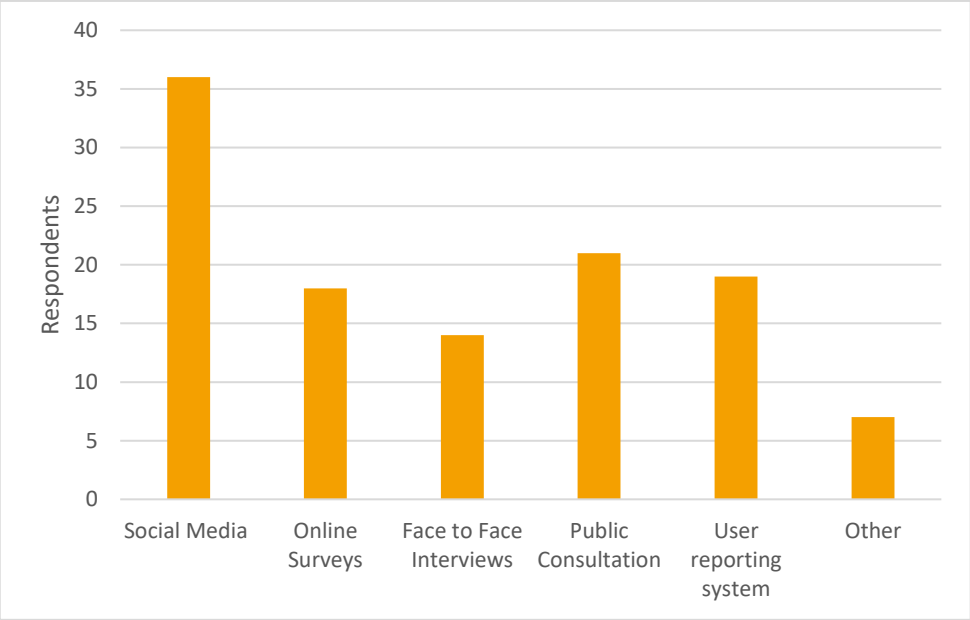

Figure 33 – Which measures are you taking to understand the road users' perception of the road infrastructure?

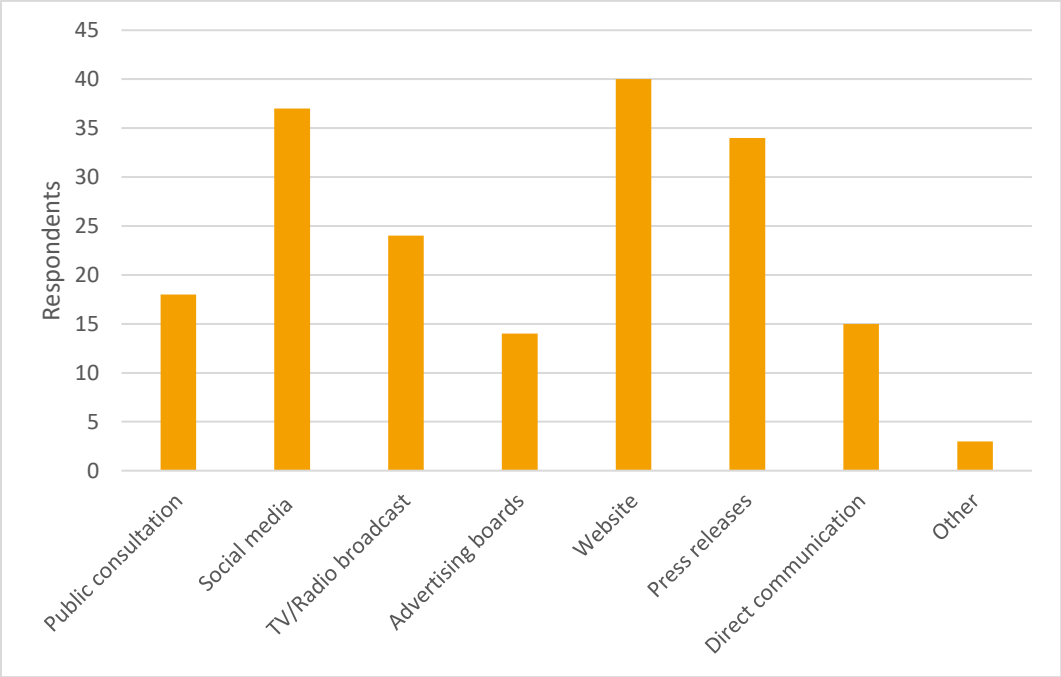

Figure 34 – What are the current methods to communicate issues around asset management to public road users?

6.4. CASE STUDIES

Strategy for modernisation existing bridges on federal trunk roads	**Germany, High Income Country** 

Problem

Ensuring mobility in the long term is an essential requirement for economic growth and employment, as well as an important contribution to the citizen's quality of life. The federal trunk road network is essential for managing freight and passenger transport. Besides tunnels, bridges are the most expensive road assets in terms of investment and follow-up costs. Due to an aging structure, a rapid development of the traffic volume as well as an increasing total weight of heavy traffic, the load-bearing reserves of older bridges are increasingly exhausted.

Solution

Against this background and based on current traffic forecasts, the German Federal Ministry for Digital and Transport initiated the need to upgrade older bridges on the federal trunk roads to make them fit for the future. Therefore, the German Federal Ministry of Transport, together with the Federal Highway Research Institute (BASt) and in coordination with the responsible road administrations of the federal states, has developed the "Strategy for strengthening existing bridges on federal trunk roads", in which the nationwide approach, the object-related static recalculations and the systematic bridge modernisation planning was defined.

This strategy is integrated into the structured maintenance planning of the federal trunk road network. The aim is to prevent extensive traffic restrictions, including bridge closures, as far as possible.

Bridge modernisation - a contribution to a powerful infrastructure
[© German Federal Ministry for Digital and Transport (BMDV)]

Based on the realisation that bridges are the critical points in the road network and that restricted or even interrupted use leads to traffic relocation in the network, traffic jams and time-consuming detours, as well as an increase in climate-damaging emissions, the strategy for modernising bridges was updated in 2016. In order to reduce traffic jam for regional and supra-regional passenger and freight transport, not only important and particularly critical individual structures are included in the analysis. Rather, the focus will be on entire traverses and long-distance corridors. This "bridge modernisation network" has been defined in consultation with the federal states and stakeholders in the transport industry.

Against this background of several years of experience with bridge recalculations, the bridges of the entire existing network of federal trunk roads were re-evaluated in 2022 with tightened technical criteria. With the load bearing index, the prioritization of modernization measures can be updated in a meaningful way. The urgency with regard to necessary modernization measures can therefore be derived.by identifying bridges with technical deficiencies or minor load bearing

Strategy for modernisation existing bridges on federal trunk roads	**Germany, High Income Country** 

capacity very easily and quickly. In recent years, thanks to the investment run-up, over 1,000 of modernised structures has been achieved.

In line with the maxim "preservation before new construction", the German Federal Ministry for Digital and Transport has provided the necessary maintenance and renewal funds for the federal trunk roads (pavements and bridge) have been substantially increased in recent years. A total of EUR 4.5 billion is allocated for 2022, which will gradually increase to around EUR 5.7 billion in the budget by 2026. A growing part of this is allocated to bridges. While the annual portion of total maintenance and renewal funds for engineering structure was less than 25 % in 2011, it will rise to over 35 % by 2022. The German Federal Ministry of Transport reports regularly (every year) to the German Bundestag (German Federal Parliament), on the status of bridge modernisation, most recently in March 2022.

Benefits

The bridge modernisation programme has accelerated the implementation of the necessary strengthening and modernisation measures. The appropriation of funds for the modernisation of bridges has led to a nationwide increase in planning and realisation activities in recent years.

More information – German Federal Ministry for Digital and Transport, Brücken an Bundesfernstraßen - Bilanz und Ausblick (Bridges on federal trunk roads – balance and outlook). (Retrieved 11 September 2023)

https://bmdv.bund.de/SharedDocs/DE/Anlage/K/presse/bruecken-an-bundesfernstrassen-bilanz-und-ausblick.pdf?__blob=publicationFile

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On questions of specific implementation in the area of the Bavarian Road Administration: Bayerisches Staatsministerium für Wohnen, Bau und Verkehr – Bayerische Straßenbauverwaltung

(Bavarian State Ministry of Housing, Building and Transport – Bavarian Road Administration): Abteilung-4@stmb.bayern.de

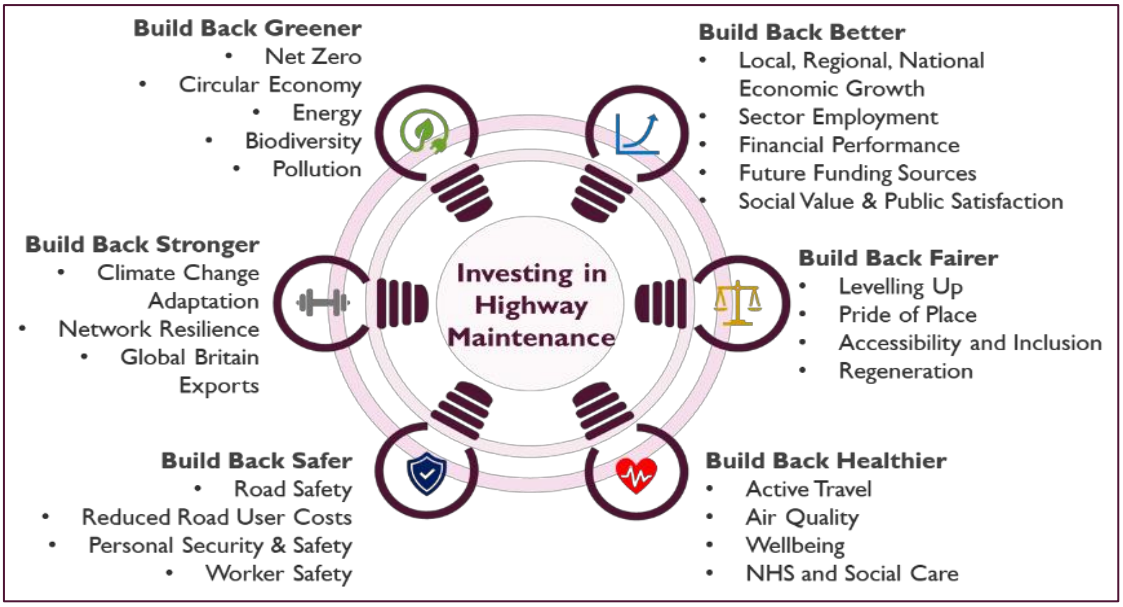
The Case for Investing in Highway Maintenance	UK Roads Leadership Group UK, High Income Country

Problem

The UK Roads Leadership Group (UKRLG) Asset Management Board needed to describe the investment needed for the English local road network (outside of London), to support the Department for Transport's submission to Treasury for the 2021 Governmental Spending Review. This needed to cover both current and future requirements, and articulate the significant benefits of investment in highway maintenance that are aligned to all Government's core policy objectives.

Solution

The local road sector prepared a comprehensive response that summarised the context of historical funding for local highway maintenance and the impact the underinvestment has had on road conditions, road users and network resilience. Potential investment scenarios were developed along with a rating of the contribution each had towards UK Government Policy objectives and socio-economic growth. This was visualised through a new model linking Government's Build Back Better themes with benefits of investing in local highway maintenance.



The report included over 40 case studies that were compiled to "make the findings tangible" and provide confidence to HM Treasury. Robustness was ensured through the review of almost 200 potential evidence sources, with over 100 referenced in the report. Real world data was utilised to frame the different investment scenarios. Clarity was critical, with targeted messaging that avoided technical jargon, to ensure that it was accessible to the audience.

The investment case was developed through contribution from a wide range of stakeholders and highways practitioners from across the country. Close dialogue with DfT was critical to ensure that the UKRLG work was addressing DfT's key themes and any feedback they were receiving from HMT. Please note that the content within the investment case does not necessarily reflect the views of DfT.

The Case for Investing in Highway Maintenance	UK Roads Leadership Group UK, High Income Country 

Benefits

The project not only provided a robust evidence pack for DfT to consider when making the case for Spending Review 21, but the report has been openly published online to support wider implementation of the outputs – it is intended to be used as evidence to support the case for funding by any highways organisation, as they can access this freely and make use of the extensive information, evidence and references.

The project has improved visibility of the many strands across the sector and supported enhanced relationships, both during the task itself and perhaps more importantly looking ahead too. A key success reported was that officials in HM Treasury have now got a far better understanding of the importance of maintaining local highway networks, and this was seen to have helped stabilise highways maintenance funding when Government spending was under pressure.

The report clearly highlighted the need to drive forward development of the workforce, and, partnering between UKRLG and professional institutions such as the Chartered Institution of Highways and Transportation (CIHT), will be key to delivering increased professional competence and qualifications.

The findings also articulated the potential gains in carbon impact from any increased investment in the network, through reduced whole life carbon of more programmed maintenance programmes, increased energy efficiency of upgraded assets, and less emissions from private sector confidence to invest in new technology and plant.

Overall, it was demonstrated that funding for local road maintenance provides good to very good return on investment, with much lower risk than major projects to construct new infrastructure, and the ability to quickly gear up to spend money and generate benefits via “shovel ready” schemes. Longer term certainty of funding will also help maximise the proven benefits provided by good quality local roads.

More information – https://ukrlg.ciht.org.uk/uk-rlg-news-listings/the-case-for-investing-in-highway-maintenance/

6.5. Key Findings and Recommendations

6.5.1. Key findings

With funding for renewal and rejuvenation of aging infrastructure limited to differing degrees across the countries surveyed, a robust process to develop and deliver investment plans efficiently is of upmost importance. The vast majority of respondents to the survey rely on government funding for their financial plans surrounding aging infrastructure. Government budgets are notorious for being stretched and therefore, succinct planning and processes are of great importance to maximise limited budgets available. Just over 1/3 of respondents to the survey did not have a specific financial strategy in place for aging infrastructure, whereas only around 20% of respondents were from lower/ lower – middle income countries. This shows that lacking a specific financial strategy for aging infrastructure is not a problem only faced by lower income countries. Considering the case of Germany, we can see the importance of convincing decision makers and financiers on the benefits of asset management.

More promisingly however, across the surveyed countries, a higher emphasis has been placed on prioritisation strategies for modernisation and renewal of aging infrastructure. With almost 80% of respondent countries indicating that they do have prioritisation strategies in place, there is a split of approaches to the prioritisation strategies. Most prioritisation strategies are developed for certain route sections as opposed to at the asset level. For the example of Belgium, their approach is slightly more complex than simply allocating funds based on route sections or specific assets. Here, needs are categorized in different themes who then have budgets allocated to them based in political will of the minister as well as recommendations from the administration. This again links back to the findings which highlight the importance of getting key advocates on board such as ministers and financiers as well as talking about success stories.

Over 50% of respondents did not use a specific software system or other tools to support prioritisation, decision making and fund allocations. Instead, such authorities may largely depend on political will and expert opinion to make decisions on investments and fund allocation. This highlights how it is not only the Low- and Middle-Income countries that are not utilising the full potential asset management benefits that technology can provide in the decision making process.

6.5.2. Recommendations

Consider prioritising maintenance and preservation over new construction

This means focusing on maintaining and preserving existing assets rather than building new ones when resources are limited. By prioritising maintenance, the useful life of the infrastructure can be extended and number of assets in backlog is decreased.

Integrate technology and software into the decision-making process

Research shows that there is significant potential for the integration of software systems to support the prioritisation, decision making and fund allocations process. There are efficiency gains to be made through the introduction of software systems to provide a succinct asset management process that is less influenced by political factors.

Communicate in the right way to the right audience

The case for funding may be strong, but this will lack impact unless it is understandable and meaningful to the right audience, which includes technical, political and financial stakeholders.

Getting them onside is of high importance when drawing together an asset management plan and the necessary funding to deal with aging infrastructure. Having clear examples of success can aid this process of convincing key stakeholders to agree to something that oftentimes can incur high start-up costs. It is therefore important that active public relation takes place to keep taxpayers, financers and other key stakeholders on board.

Consider a range of commercial options

Different contract models such as PPPs or tolling concessions may support longer term commitment to good maintenance and service to users. However, careful engagement with users and stakeholders is needed to ensure any change in arrangements does not result in unforeseen issues.

Use a consistent prioritisation process

When prioritising work, it is crucial that decisions support strategic objectives of the road administration. This includes factors such as what problem needs to be addressed, how is this categorised, what budget allocations are available, and how are needs rated by criteria. Ideally, cross-asset review should be carried out. Once this process is done, findings should be challenged with local knowledge.

Make the case for investment

Evidence exists to support a strong case for maintaining existing assets ahead of building new infrastructure. However, this case needs to be made clearly, with a focus on the consequences of underinvestment and consideration of socio-economic factors as well as the asset itself.

7. TECHNICAL SKILLS AND SKILLED STAFF

7.1. INTRODUCTION

Formal training in the roads sector has predominantly focused on design and construction of new infrastructure, however, addressing the needs of aging infrastructure requires additional skills and experience. This may apply to new recruits to the roads sector, and also upskilling of more experienced workers already within the industry. Some countries also need to contend simultaneously with the challenge of a shortage of skilled workers as well as aging infrastructure, which applies even greater pressure on resources to deliver a safe and effective network. The project investigated challenges and limitations related to the workforce, along with emerging skillsets that are required, such as mobility and digitalisation. Also, it reviewed levels of awareness and take up of training in maintenance techniques across different asset types, along with various methods of delivering this. Finally, it reviewed the development and application of special standards or guidelines for the renewal of aging infrastructures, especially against the background of the challenges of aging assets and simultaneously limited resources.

7.2. LITERATURE REVIEW

7.2.1. Laos – Capacity building [27]

Produced by the Japan International Cooperation Agency (JICA), the purpose of this paper is to present the proposed Climate Resilient Rural Infrastructure Improvement Project. This Project was only rolled out to two provinces – Vientiane and Savannakhet. To realise a full roll out, the road management data base has been expanded but more funding is still needed across the board.

The road transport in Laos is reported to carry 80% of total domestic cargos and 85% of total passengers transported in entire Laos. The Lao Government heavily channels its investment to development of national trunk roads, and, accordingly, 70% of 7,200 km national roads have already been paved.

In the last decade, the World Bank, together with other multi-lateral and bilateral donors, has been making great efforts for capacity development of the road maintenance and management in Laos. The objective of the project is for the World Bank, along with other donors, to support the development of financial and institutional capability of road maintenance in Laos due to the limited budget for road maintenance and fragile institutional framework with the ultimate goal of a self-reliant road maintenance cycle.

The project took several measures to ensure resilience of Laos' rural infrastructure in the long term. For instance, GIS training was rolled out to highways workers so that up-to-date road network data can be used to inform decision making for the network. Additionally, the vehicle weighing station was replaced to support capacity building for overload control which poses a grave risk to the road network in Laos.

The results of the project carried out in Vientiane and Savannakhet were gauged via the means of a feedback survey, the results of which showed fairly high effectiveness, impact and efficiency as well as high relevance and fair sustainability.

7.2.2. PIARC Report – General Concept and Requirements for Asset Management Training Courses [28]

The efficient and effective management of road infrastructure is a major challenge for all road authorities. Due to limited financial resources and other constraints, maintenance and operations need to be optimised. Asset Management provides valuable approaches and the necessary tools. However, it is essential to raise awareness among authorities of the need for broad implementation of these new procedures. In order to achieve the maximum benefit from Asset Management, it is necessary that all employees of the organisation – not only strategic management – "live" Asset Management at every workplace and that all employees are aware of it. Therefore, PIARC has taken up this issue and the Technical Committee (TC) D.1 "Asset Management" has prepared the report "General Concept and Requirements for Asset Management Training Courses" in 2019. The report presents a general concept for supporting education in the field of Asset Management and prepares examples of short courses on selected topics. The courses aim to disseminate the asset management approach as widely as possible in order to get the broadest possible benefit from this new discipline. Three main forms of education are recommended: short courses, long courses and self-education.

The document begins with outlining the challenge of insufficient and/or inadequate technical skills within road asset management. It also outlines the discipline of asset management and the description of the term "asset management".

A fundamental aspect of asset management training is the standards which are covered in the document, referencing ISO 55000 and PAS 55, by the Institute of Asset Management and the British Standards Institute respectively.

As part of the 2016-2019 cycle, PIARC's TC working group D.1.2 developed a series of short courses contributing to asset management education worldwide as covered briefly in the PIARC report. These short courses are designed to be delivered in 30 mins each and the course documents are provided in the form of PowerPoint slides to participants to support their learning.

Short courses and long courses differ where the short courses provide a basis of asset management knowledge and are provided by several educational institutes, courses last 1 to 3 days. Long courses are primarily offered by universities and normally cover 30 hours of learning across 1 semester (15 weeks) covering a greater level of detail and experiences of professors delivering the course. Self-education relies on individuals to support their learning by referring to manuals, publications in specialist journals, conference contributions and articles on specialist websites.

The appendices contain the result of a survey of existing Asset Management courses from around the world. It was completed by the Technical Committee D.1 which showed educational institutions successfully providing training, however, in delivering so, training is only provided on selected topics with a disconnect between single themes. Supporting activities are available on the PIARC website such as the Road Asset Management Manual which provides additional support to existing learning for participants and for their teachers.

Overall, the report provides an outline of the training courses available to a wide range of professionals to further develop their understanding of asset management. There is a great emphasis of how such courses can contribute to increased learning, however, there is a lack of acknowledgement of financial implication of these courses on the participant. Encouragingly the

courses are available worldwide. There needs to be a better understanding on how the participants can be supported if they cannot afford to attend fee-paying courses.

The findings of the report and of the report will be incorporated into the PIARC Asset Management Manual.

7.2.3. UK – Bath College / TMS – BTEC qualification in highway maintenance [29]

In the UK, Bath College (an academic institution) and TMS (a training consultancy) have collaborated to produce a qualification in highway maintenance. The course offers a BTEC Level 4 Certificate of Achievement for students, which is equivalent to the first year of an undergraduate degree, and is taught as four separate modules, with one day of classroom-based tuition for each module, totalling four days. At the end of each module, an assignment is set to assess learning outcomes. As well as providing a qualification in itself, the course can also contribute to the achievement of a Professional Diploma in Highway Engineering by further study of highways and transportation topics.

Topics covered include an introduction to highway maintenance, such as relevant Codes of Practice, the concept of designing for maintenance, and carriageway assessment and condition surveys, plus more technical content focusing on specific assets. For flexible roads, this includes typical faults and causes, along with planning and processes for surface dressing, resurfacing, recycling of materials, patching and reinstatement of pavements and finally reconstruction. For rigid roads, the course again outlines types of faults and causes, along with more specific guidance on inspections, repairs to surfaces, joints and structural elements, and routine maintenance. The course also covers issues around cyclic maintenance, emergency works, winter maintenance, footways and signs and markings. For highway structures, subjects covered include a summary of components that constitute such structures, inspections techniques, routine maintenance, construction and major maintenance.

7.2.4. Germany – BMDV Network of Experts [30]

(https://www.bmdv-expertennetzwerk.bund.de/EN/Home/home_node.html)

The transport infrastructure of the 21st century is facing diverse challenges which will have a decisive impact on mobility in the future. The challenges such as climate change, environmental protection or aging infrastructure do not only affect the road transport mode, but also other sectors such as rail or waterways. There is a considerable need for research on these future issues and their impact on transport and infrastructure. In order to coordinate research work and make it more efficient and effective, to put competences onto a broader common basis, to network intensively among each other and thus to promote knowledge and technology transfer, the Federal Ministry for Digital and Transport (BMDV) launched the BMDV Expert Network in 2016. The BMDV Expert Network consists of the following federal authorities:

- Federal Logistics and Mobility Office (BALM)
- Federal Maritime and Hydrographic Agency (BSH)
- Federal Institute of Hydrology (BfG)
- Federal Highway Research Institute (BASt)
- Federal Waterways Engineering and Research Institute (BAW)
- Deutscher Wetterdienst (DWD, German Meteorological Service)
- German Centre for Rail Traffic Research (DZSF) at the Federal Railway Authority (EBA)

The BMDV Network of Experts builds a bridge between research and its application and thereby involves all relevant stakeholders and respective resources. By applying a cross-modal perspective, new research approaches as well as innovative and problem-solving methods are developed.

The BMDV Network of Experts has elaborated a long-term Research Strategy 2030, which describes how the BMDV Network of Experts will address current challenges such as climate change, environmental protection and aging infrastructure.

In the first phase (2016-2019), research in the BMDV expert network was divided into five thematic areas:

- Adapting transport systems and infrastructure to climate change and extreme weather events
- Environmentally appropriate design of transport systems and infrastructure
- Increasing the reliability of transport infrastructure
- Consistent development and application of digital technologies
- Tapping the potential of renewable energies for transport and infrastructure to greater extent

The findings of the 2016 - 2019 research phase of the BMDV expert network are published on the internet: https://www.bmdv-expertennetzwerk.bund.de/EN/Publications/Publications_node.html

The second research phase (2020-205) is currently underway, in which the cooperation between the participating authorities will be further intensified and the dialogue with the users of the results will be intensified.

7.3. Survey Findings

Considering technical skills and skilled staff, the results of the survey identified that the road lighting sector had the largest proportion of staff that felt they were never trained or informed of the latest innovations regarding the maintenance of aging infrastructure. Pavements and road equipment were found to have some of the lowest levels of staff feeling like they were never trained in or informed of the latest innovations with regard to aging infrastructure. Pavements was the asset class which had the highest proportion of staff feeling as though they were always informed of the latest innovations, this translated into the highest level of staff feeling like they were always trained in the latest innovations. Graphs 35 and 36 both highlight the link between being informed of the latest innovations and being trained in them.

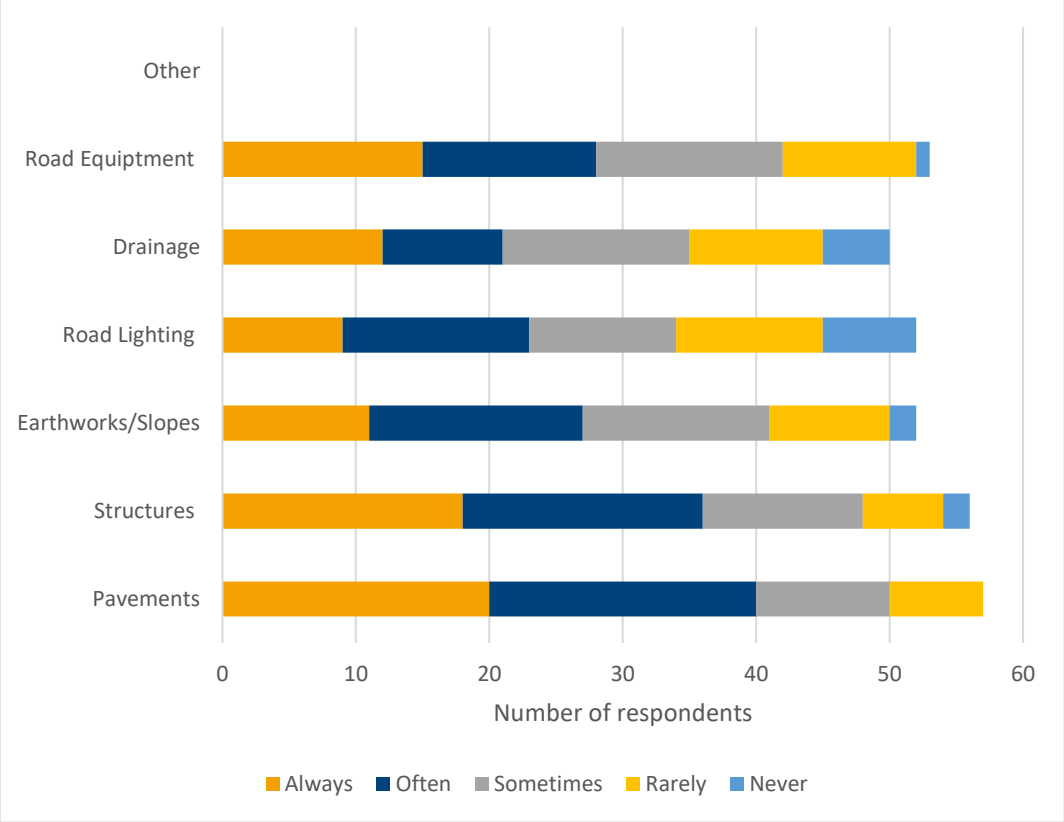


Figure 35 – Are you or your staff trained in the latest innovations regarding the maintenance of aging infrastructure?

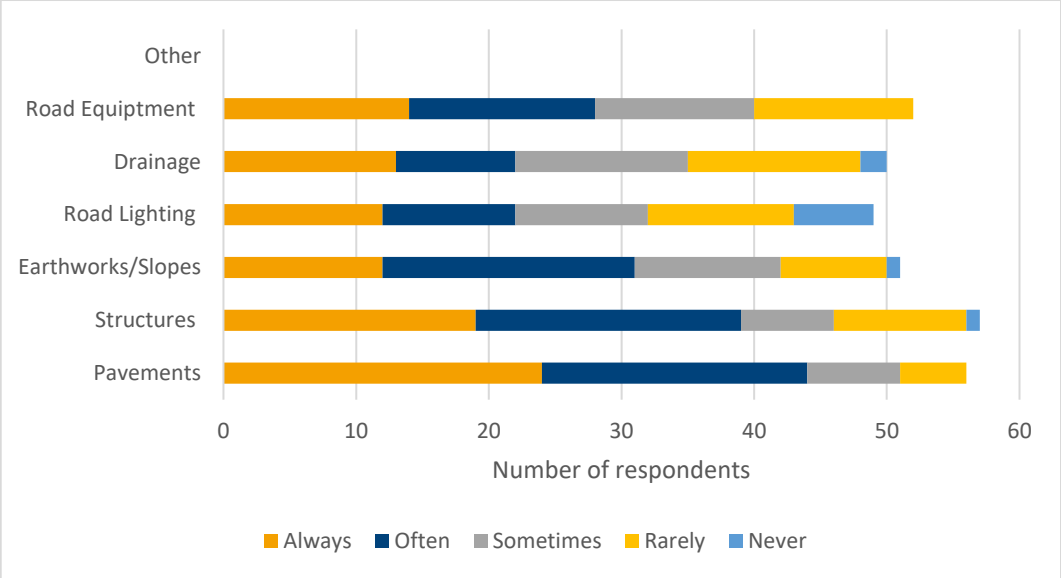


Figure 36 – Are you or your staff trained informed of the latest innovations regarding the maintenance of aging infrastructure?

Generally, respondents that were informed on the latest innovations in managing aging infrastructure were also trained on the implementation of these innovations.

When asked surrounding the availability of appropriately trained staff, only 24% of respondents felt like they had enough skilled personnel to meet the demands of managing aging infrastructure. The specific workforce challenges that lead to not having sufficient availability of skilled staff that were

faced by respondents varied. The most common ones being funding and recruitment. A full breakdown of these challenges is outlined in Figure 38.

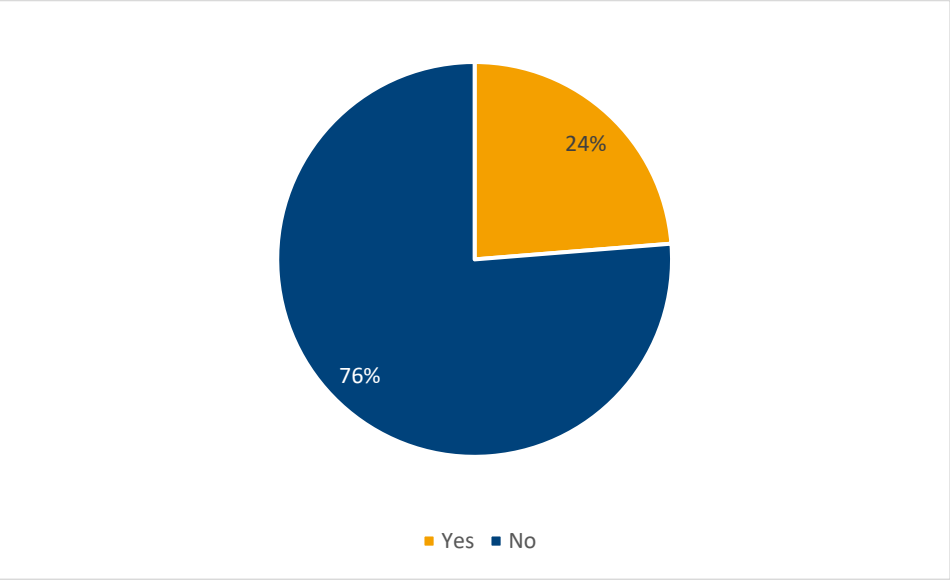


Figure 37 – Are there enough skilled people available to withstand the demands to manage aging infrastructure?

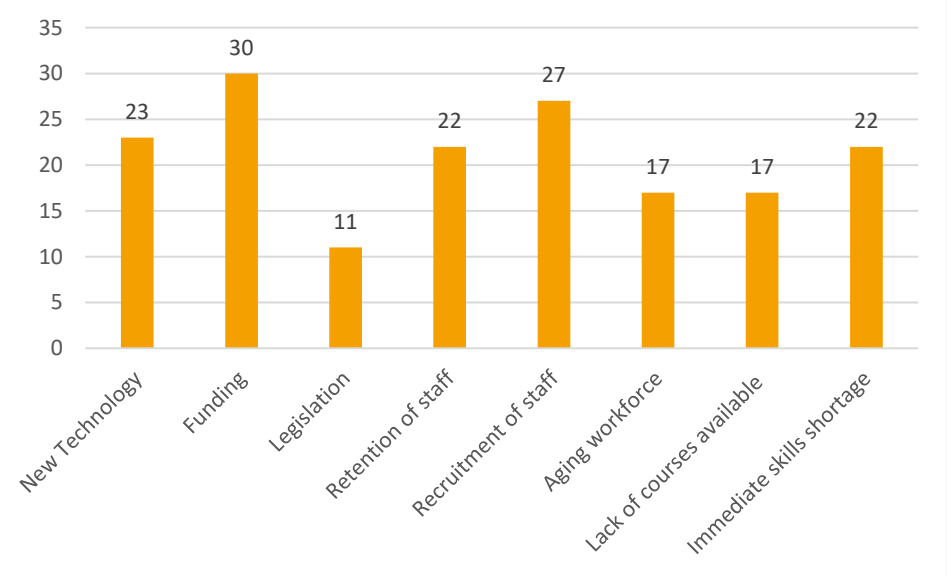


Figure 38 – If no, select appropriates challenges faced in the workforce available (Please select your top 3)

Thinking forward to the future, Figure 39 outlines the new skill demands that are being placed on employees. This is indicative of the general approach to asset management moving into the future. We see a heavy emphasis on maintenance techniques and digitalisation as well as environmental skills. This is expected with the rapidly developing technology landscape as well as the global push to net zero. The least common skills that are being demanded of employees by the respondents are sociology behavioural skills, perhaps taking a back seat given the strong push for net zero and restricted budgets.

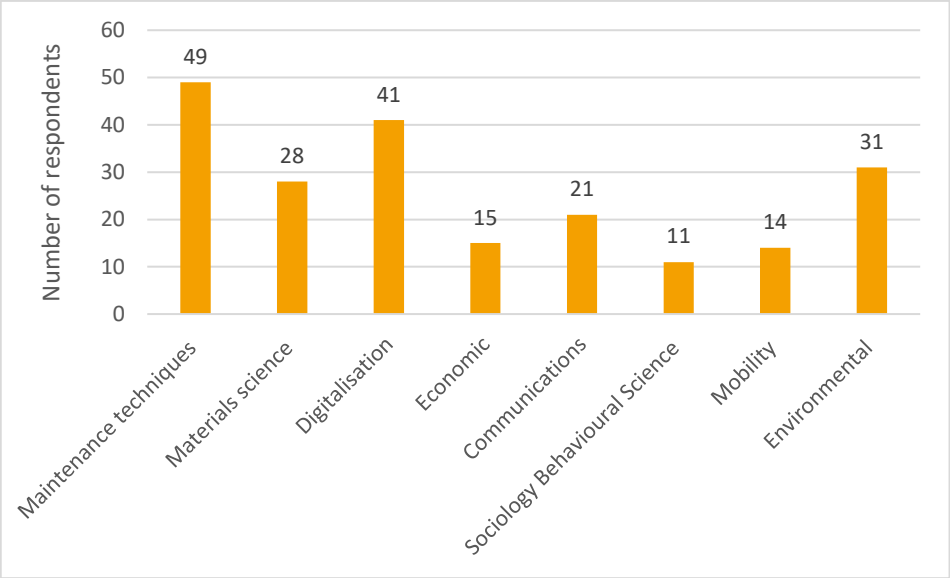


Figure 39 – What new skill demands are being made on employees?

Figure 40 highlights the variation in approaches to training and knowledge transfer. There is not one clear front runner in terms of technique for training and knowledge transfer, but technical manuals and conferences are shown to be common practice within the industry.

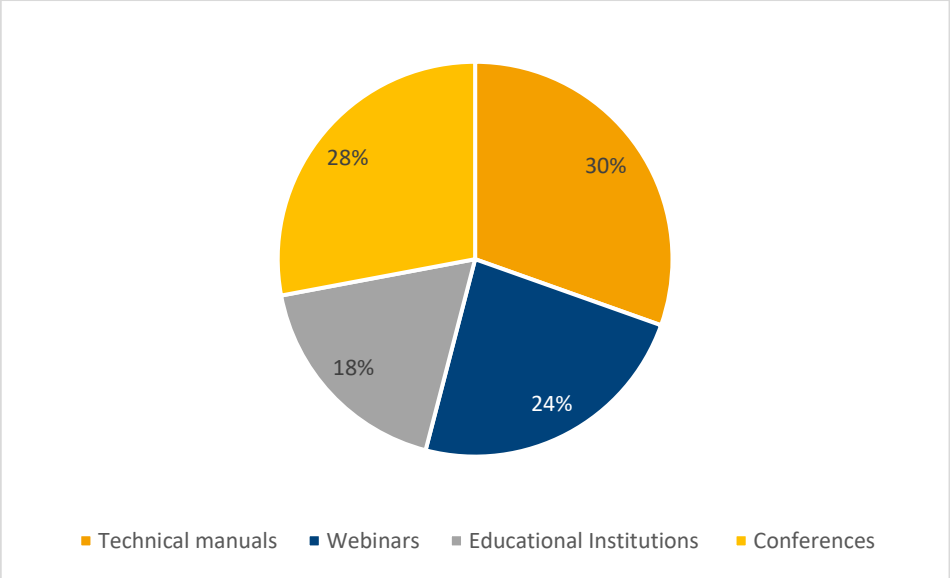


Figure 40 – How do you currently support training and share knowledge?

7.4. CASE STUDIES

Asset Management and Highway Inspection Competence Frameworks	**UK Road Leadership Group** **UK, High Income Country** 

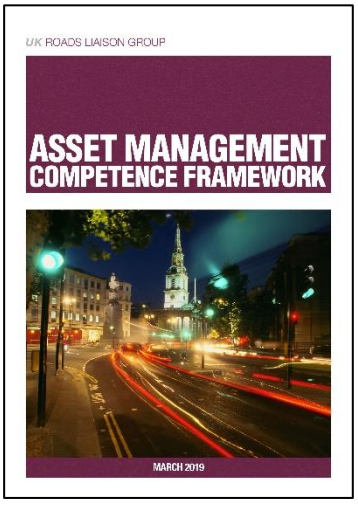
Problem

The UK Roads Leadership Group (UKRLG) Code of Practice for Well-managed Highway Infrastructure (WMHI) is the reference document for Asset Management for Local and Highway Authorities in the UK and is endorsed by the Department for Transport (DfT). It promotes a risk-based approach to managing network and provides non-prescriptive guidance and recommendations. This meant that a variety of approaches were being used by different highway authorities to manage the skills, competences and training requirements of their staff, with no single body auditing these or ensuring they were fit for purpose.

This created a need for further guidance, specifically a consistent but adaptable competence framework. The right balance had to be struck between providing a document which was sufficiently robust to stand scrutiny but at the same time completing the framework could not be too onerous, due to time constraints faced by most asset management staff.

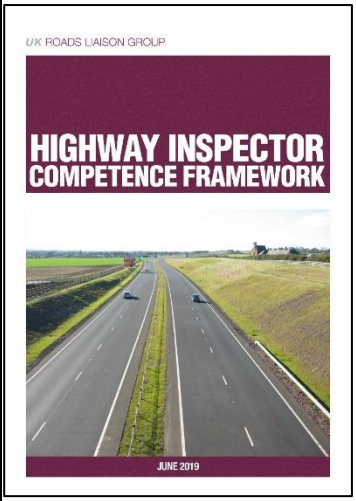
Solution

An Asset Management Competence Framework (AMCF) has been developed to address the varying needs and organisational structures across the full range of UK Highway Authorities, from national road operators to small local authorities. It also covers the full scope of roles within a highway authority which contribute to asset management – not just specialist roles. This includes senior decision makers, on-the-ground operatives and risk/legal/insurance colleagues, and thus supports true embedding of asset management principles and a joined-up approach to delivery throughout each organisation.



The AMCF has been developed to be an easy and free-to-use product that can help Highway Authorities quickly and easily assess competence, either confirming appropriate levels or alternatively identifying competence gaps and supporting training of staff. It can be applied to assess both overall organisational and individual competences and, supporting personal development planning.

Asset Management and Highway Inspection Competence Frameworks	**UK Road Leadership Group** **UK, High Income Country** 



To facilitate this, an Excel tool was also produced, that users can populate to monitor competence levels which provides a useful visualisation depicting competence gaps, if any, and recommending areas for additional training based on the identified gaps.

While the AMCF covers the full range of asset management activity, UKRLG has also created a Highway Inspector Competence Framework (HICF). This complements the AMCF, providing specific competence guidance for a key role in managing highway assets and the network as a whole, with a particular focus on the adoption of a risk-based approach to highway inspection. The HICF enables authorities to undertake quick and consistent evaluation of staff competences and training needs and address gaps, better defend against compensation claims for network defects and use risk-based inspections to make efficient use of funds.

Benefits

Both frameworks are publicly available to the highways sector, enabling good practice to be shared in a cost effective and accessible manner, and providing the following benefits:

- Assessing whether a sufficient level of competence exists amongst all the staff in the authority.
- Allowing staff to identify progression routes and any gaps in training or experience.
- Assessing whether staff are suitable for the role they have; or alternatively provide an indication of the training or experience which may enhance their capabilities.
- Providing an assessment of whether staff in the team can contribute to another part of the organisation.
- Enabling succession plans for the workforce; and
- Enhancing staff's employability and enable freedom of movement within the industry.
- Flexibility to align the generic AMCF to any Highway Authority's specific needs.

More information – https://ukrlg.ciht.org.uk/ukrlg-home/guidance/competence-frameworks/ and https://www.theihe.org/wp-content/uploads/2022/04/highway-inspector-competence-framework-final-document-june-2019.pdf

Guidance for renewal of roads with reduced standards	**Bavarian Road Administration** **Germany, High Income Country**

Problem

The Bavarian Road Administration is responsible for almost 23,000 kilometres of interurban roads (federal trunk roads, state roads, county roads) in the federal state of Bavaria.

Especially in the network of state and county roads, many stretches of road have grown historically and do not meet today's requirements as formulated in the relevant regulations or as demanded by the traffic volume. The Bavarian Road Administration is working continuously on adapting the road network to today's requirements. The basis is the “develop plan for the state roads” (in German: “Ausbauplan für die Staatsstraßen”) and the results of a regularly condition assessment and evaluation. The Ausbauplan contains new roads – e.g., bypass roads – and widening existing roads. It was approved by the Bavarian State Government and thus represents the task of developing the road network for the road administration. However, there is still a considerable proportion of sections with various deficits (structural, safety, etc.) that could not be included in the plan and therefore cannot be fully upgraded in the foreseeable future. Hence, only structural maintenance or selected improvements can be carried out there. Besides, renewal with reduced technical standards and financial expenditure, i.e., upgrading using existing facilities, are permissible.

Solution

In order to support the road construction authorities in the planning and construction of such road projects, the manual "Cost-conscious planning and construction - planning aids for the renewal roads using existing facilities" were already established in 2012. This manual provides practical suggestions and advice on possible solutions for using the available budget funds as economically, sustainably and effectively as possible. The technical regulations in road construction and design do not prescribe a rigid application of design parameters, but rather offer scope that allows reasonable and appropriate deviations in individual cases. It is the responsibility of all those involved in the planning process to make use of this leeway or, in exceptional cases, to deviate from standard parameters. The manual provides practical guidance on this, depending on the traffic volume and composition (e.g., proportion of heavy good vehicles).

Guidance for renewal of roads with reduced standards	**Bavarian Road Administration** **Germany, High Income Country** 
The manual has recently been updated against the background of the social debate on the considerate use of resources and the demands for solutions that are as land-saving as possible. The manual is intended to provide planning information for an environmentally friendly, resource-saving, appropriate and economical standard of renewal existing roads. This must, however, be accompanied by a noticeable improvement in road safety, although possibly at a lower but still acceptable level. Any safety deficits identified must be eliminated before people are harmed.	
Benefits The manual provides guidance for planners on how to use the limited financial resources available for the renewal and rejuvenation of the existing road network efficiently and effectively, in order to develop an appropriate and tailored solution for as many road sections as possible. However, the manual offers numerous ideas not only for planners, but also for all those who have responsibility in the field of road construction and road management, on how to handle the resources environment, land use and costs in an optimal way.	
More information The manual is available for free download in the internet (only in German): https://www.stmb.bayern.de/assets/stmi/vum/strasse/planung/49_kostenbewusstes_bauen_2021.pdf	
Contact details Bayerisches Staatsministerium für Wohnen, Bau und Verkehr – Bayerische Straßenbauverwaltung (Bavarian State Ministry of Housing, Building and Transport – Bavarian Road Administration): Abteilung-4@stmb.bayern.de	

7.5. KEY FINDINGS AND RECOMMENDATIONS

7.5.1. Key findings

It is evident that skilled personnel are considered essential for the successful management of road infrastructure - and especially aging infrastructure - worldwide. Human resources, their skills, experience, and knowledge are given high importance in the examples found by the working group.

However, the survey carried out by the working group shows that more than three-quarters of the respondents do not have enough qualified staff in their organisations to cope well with the challenges arising from the aging infrastructure. The main reason given for this is insufficient funding. This may be an indicator that the importance of human resources in asset management is unfortunately not yet sufficiently recognised by organisations or financiers, and that their importance for effective and efficient management of road infrastructure continues to be underestimated. But also, the loss of established and proven staff due to retirement and the difficulties in recruiting new employees were mentioned by about half of the respondents. In some regions, e.g., in many European countries, this shortage of skilled workers is due to demographic developments. In these countries, many workers from the “baby boomer” generation are currently retiring, while too few young people are following to replace them.

Since it is not the number of people but their skills and experience that are crucial, the survey asked how well informed and trained staff are regarding the challenges that arise from aging infrastructure. It shows that two-thirds of the institutions surveyed stated that their employees are always or often well informed and trained in the core assets "pavement" and "structures". However, even in these important assets, there is room for improvement, as between one-tenth and one-fifth of the respondents indicated that there is rarely or no knowledge transfer. For the other assets, the figures were even more moderate. Against the background of climate change and the increasing importance of efficient and functional drainage in this context, the potentials in the asset "drainage" should be particularly emphasised. About the type of knowledge transfer, it can be noted by now that webinars are almost as important as the "classic" formats, such as technical manuals or conferences. Respondents from Switzerland and Germany also stated that they have an internal transfer of information and knowledge between specialists in the different areas as well as staff-to-staff training.

With special training and education courses, future employees can be made fit for the tasks of road maintenance and asset management, as the example of the "Highway Maintenance" course from the UK shows. But appropriate knowledge transfer is also urgently needed for the field of asset management in general. PIARC has recognised that technical progress and the dissemination and implementation of modern management techniques and skills are fundamental to increasing efficiency and getting the maximum benefit from the road infrastructure asset. Therefore, PIARC published a report in 2019 that formulates a general concept and requirements for training courses in asset management, useful for the organizations and academia.

However, in terms of employee qualifications, it is not only technical specialist knowledge that is important, but also other competences. The survey shows that the use of digital media, but also communication, will play an increasingly important role in the future. Against the backdrop of advancing digitalisation, the ever-greater complexity of issues - in the technical area, but also in the framework conditions (e.g., legal framework) - this seems reasonable, perhaps even imperative.

But qualification should not end with the beginning of a professional career or the entry into a new job. Against the background of staff shortage, the related “competition for the best brains”, the ever-increasing specialisation and new challenges, human resource development is becoming increasingly important. Here it is essential to proceed more effectively and efficiently. An example from the UK shows that a competence framework, e.g., for highway inspectors, has been developed for this purpose. This defines requirements and competence levels. With the help of this framework, it is possible, to evaluate the competence level of the staff and consequently to recognise potentials or to identify training needs. Human resource development should not be limited to upper management or engineers. An example from Laos shows that technical manuals are developed for the operational level, considering the country-specific characteristics, and staff are trained accordingly in practice. Experience gathered in practice is then integrated into the update of the manuals.

In education at universities and colleges, road engineers-to-be are taught optimal planning from a technical point of view. But due to financial constraints, it is not possible to upgrade or improve the entire road network (immediately or in a timely manner) in accordance with the relevant guidelines. Solutions need to be found that enable the renewal and rejuvenation of existing roads at lower cost without compromising significantly on road safety. This requires engineers with excellent engineering knowledge and skills, who know the scope of the regulations and understand their fundamentals. To support those involved in this task, the road administration of the Free State of Bavaria (Germany) has developed a guidance document that enables planners to renew and upgrade existing roads with reduced standards, but still keep the road safe. In addition, these guidelines provide planners with advice and recommendations on how to deal with new social and legal challenges - such as the sparing use of resources and the demand for land-saving solutions.

But efforts are not only being intensified in the areas of education and training. Special attention is also given to research. Challenges such as climate change, environmental protection or aging infrastructure do not only affect the road transport mode, but also other modes such as rail or waterways. The issues and challenges here are partly identical. A cross-transport expert network of federal authorities was established in Germany, to organise research in a coordinated, efficient, and effective manner, to place competences on a broader common basis, to network intensively among each other and thus to promote the transfer of knowledge and technology.

7.5.2. Recommendations

Provide the necessary financial resources

No well-functioning road infrastructure without a qualified workforce. This applies to both new and aging road infrastructure. Qualified personnel, with their skills, experience, and knowledge, are imperative throughout the life cycle of a road and its components. Adequate and skilled human resources are crucial in addressing the vast and complex challenges of aging infrastructure. The public and especially the financiers need to be made aware of this. The road network can only be managed and maintained as well as renewed and modernised in line with demand if it is staffed with adequate and skilled personnel. The necessary financial resources must be made available for this purpose. It is important to promote this with the financiers.

- **Increase the focus on human resources development**

The importance of human resource development is increasing against the background of the shortage of staff, the related competition for the best brains, the ever-advancing specialisation and new challenges. Shortage of skilled staff is a fundamental problem in some countries due to demographic development. There is competition for the best brains. Efforts to attract these "best brains" must be increased. For this purpose, the attraction of working in the road sector needs to be increased and promoted. The qualification of staff should not be limited to the beginning of a career or a new job. Lifelong learning and training are necessary throughout a professional life, and it must be improved with education and training.

- **Consider aging infrastructure and new challenges in education and training**

In education and training, the issues related to aging infrastructure and its renewal need to be better embedded and their challenges need to be considered more deeply and comprehensively. In this regard, topics that are gaining importance in the context of climate change and resilience (e.g., drainage) must also be given adequate consideration. It is important to identify the skills and strengths of the individual employees and to develop the necessary competences in a targeted manner. Thereby, each employee should be considered individually. In principle, the individual employee should be accompanied by targeted training and further education throughout his or her entire professional life. Ultimately, the right person with the right skills should be on the right position.

- **Recognise that engineering judgement and experience are as important as technical guidelines**

For the renewal and renovation of existing or aging road components, it is often insufficient to make use of a "kit of building blocks", as mostly provided by the guidelines. Instead, it is important to identify the causes of deficiencies and defects in the road or structure and to draw appropriate conclusions on how to deal with them. This applies to the construction and traffic engineering sector as well as to road design and road safety. As financial resources are usually limited, it may be necessary to find solutions that enable the upgrading and improvement of existing roads at low cost without compromising road safety. For both, it is necessary that engineers in charge have in-depth engineering knowledge, know the scope of regulations and understand their fundamentals.

- **Promote knowledge sharing**

Against the background of increasing labour turnover, the transfer of knowledge is also important. However, this knowledge transfer is not only important for the change of staff, but also for the transfer of practical experience and case studies. It is valuable to share knowledge and lessons learned in dealing with aging infrastructure. Best practice examples can also help to ensure that the issue is appropriately dealt with. It may be possible to develop specific standards for dealing with aging infrastructure. It is not necessary that everyone reinvents the wheel.

- **Collaborate and coordinate research**

It is necessary to collaborate in the area of research and to link research activities across all transport modes, but also internationally, and to coordinate them if applicable.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. CONCLUSIONS AND LESSONS LEARNED FROM THE PROJECT

The key findings from this study have confirmed the challenges that aging infrastructure provides to road administrations of all income levels, plus it has identified a range of evidence and good practice related to the themes listed above. However, the work has also confirmed that there is little formal existing research dedicated to the specific issue of aging infrastructure, and there may be opportunities to address this better.

The topic of renewal and rejuvenation of aging infrastructure was a new theme for TC3.3 this cycle, and as such, it took extensive time and effort to review and agree the scope and approach. However, this effort was invaluable, as it resulted in a strong basis for the work and help create a sense of co-creation across the Working Group members. This was despite the implications of Covid measures that disrupted meetings and building of relationships within the Working Group.

Whilst the Working Group was agreed in our definition of aging infrastructure, it was not always been easy communicating this more widely, as the term can mean different things to different people. There is a need to distinguish this work from broader asset management, and several times the Group needed to refocus efforts to ensure that the scope was maintained, and the objectives remained achievable.

The Working Group has also gathered a significant amount of evidence and data that both supports this report and also provide information for further research. This includes the response to the survey, which was considered to be very good both within the TC and also in wider PIARC. A particular strength was that the survey responses had good coverage of Low- and Middle-Income Countries. This was balanced with some challenges related to collecting LMIC case studies, and also arrangement of follow-up interviews.

The Working Group continually improved its working arrangements, and also welcomed new members during the course of the cycle, diversifying the membership from initially being a majority of High-Income Country / European representatives, to being more balanced across national income levels and geographical spread.

8.2. RECOMMENDATIONS

A series of recommendations have been developed against each of the themes listed above, and these are described within each respective chapter. A number of recommendations have also been developed for PIARC's consideration, especially as "renewal and rejuvenation of aging infrastructure" is likely to be a topic of interest to road administrations for the foreseeable future – this report is just the first step to helping roads professionals address its challenges more comprehensively.

8.2.1. Monitoring and Assessment

Optimise the collection and utilisation of asset data

Knowledge of aging infrastructure's condition, functionality, and safety is crucial to its management and improvement. The data can be used for various tasks across the full range of a road administration's activities. However, it only makes sense to collect and process data that can be

used beneficially for the tasks of road administration. Data capturing or digitisation for its own sake is useless and inefficient.

Exploit innovative methods for condition assessment and inspection

The development of technology and digitalisation continues beyond the road asset management. Modern techniques allow innovative ways of monitoring and gathering data. These can potentially be more efficient and effective than traditional methods. Further research should be conducted in this area. However, these methods must meet the requirements of the road administration for the respective data and its quality.

Enhance information on the structural substance

Particularly in historically grown road networks, road authorities have only limited information on the substance of road pavements (e.g., structure and load-bearing capacity). For overall maintenance management, the knowledge of the structural substance of road pavements is likely to be relevant, both on a strategic and operational level. In addition to recording superficial characteristics, recording the substance with non-destructive and high-speed methods should also be considered.

Use a risk-based approach to collecting data

Aging infrastructure is expected to have greater risks than new assets, so they should not be treated the same in terms of how they are inspected, assessed and monitored. Frequencies of data collection should be adjusted to take into account the age of assets, their condition, their location and the potential consequences of failure.

8.2.2. Risk Management

Shift maintenance policies from a reactive approach to a more proactive one

Shifting from a reactive approach to a proactive one means addressing issues before they escalate into major problems. Renewal measures should be applied before the asset's load-bearing capacity is significantly compromised.

Prevent overloaded vehicles through strong enforcement (monitoring, detecting, and applying severe penalties)

Overloaded vehicles can cause accelerated wear and tear on infrastructure. Strong enforcement, including monitoring and imposing severe penalties, can deter such practices and protect the integrity of the assets.

Target inspections where there is greatest risk

Focusing on critical elements during inspections ensures that vulnerable areas are thoroughly assessed and prioritised for maintenance or repair. More frequent inspections during the end of an asset's life phase help identify potential issues early on and allow for timely interventions, whilst ensuring the safety of road users.

Have rapidly available funding for emergency repairs

Establishing emergency maintenance funds allows quick access to resources for urgent repairs when critical infrastructure is at risk.

Develop policies on how to deal with sub-standard assets and focus on structural maintenance and selected improvements

Having clear policies in place for handling sub-standard assets ensures a consistent and effective approach to addressing risks associated with these assets. To optimise resources, maintenance policies can be adjusted to prioritize critical structural maintenance and safety improvements over meeting the latest technical standards for the entire road network.

Impose limitations on use (weight limit, lane closures, signage, speed limit, total closure of the asset)

Temporarily or permanently restricting certain uses or applying speed limits can mitigate risks and protect vulnerable infrastructure until repairs or replacements are carried out, especially in areas with higher risk or traffic impact.

8.2.3. Prioritisation, programmes and funding

Consider prioritising maintenance and preservation over new construction

This means focusing on maintaining and preserving existing assets rather than building new ones when resources are limited. By prioritising maintenance, the useful life of the infrastructure can be extended and number of assets in backlog is decreased.

Integrate technology and software into the decision-making process

Research shows that there is significant potential for the integration of software systems to support the prioritisation, decision making and fund allocations process. There are efficiency gains to be made through the introduction of software systems to provide a succinct asset management process that is less influenced by political factors.

Communicate in the right way to the right audience

The case for funding may be strong, but this will lack impact unless it is understandable and meaningful to the right audience, which includes technical, political and financial stakeholders. Getting them onside is of high importance when drawing together an asset management plan and the necessary funding to deal with aging infrastructure. Having clear examples of success can aid this process of convincing key stakeholders to agree to something that oftentimes can incur high start-up costs. It is therefore important that active public relation takes place to keep taxpayers, financers and other key stakeholders on board.

Consider a range of commercial options

Different contract models such as PPPs or tolling concessions may support longer term commitment to good maintenance and service to users. However, careful engagement with users and stakeholders is needed to ensure any change in arrangements does not result in unforeseen issues.

Use a consistent prioritisation process

When prioritising work, it is crucial that decisions support strategic objectives of the road administration. This includes factors such as what problem needs to be addressed, how is this categorised, what budget allocations are available, and how are needs rated by criteria. Ideally, cross-asset review should be carried out. Once this process is done, findings should be challenged with local knowledge.

Make the case for investment

Evidence exists to support a strong case for maintaining existing assets ahead of building new infrastructure. However, this case needs to be made clearly, with a focus on the consequences of underinvestment and consideration of socio-economic factors as well as the asset itself.

8.2.4. Technical skills and skilled staff

Provide the necessary financial resources

No well-functioning road infrastructure without a qualified workforce. This applies to both new and aging road infrastructure. Qualified personnel, with their skills, experience, and knowledge, are imperative throughout the life cycle of a road and its components. Adequate and skilled human resources are crucial in addressing the vast and complex challenges of aging infrastructure. The public and especially the financiers need to be made aware of this. The road network can only be managed and maintained as well as renewed and modernised in line with demand if it is staffed with adequate and skilled personnel. The necessary financial resources must be made available for this purpose. It is important to promote this with the financiers.

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cost without compromising road safety. For both, it is necessary that engineers in charge have in-depth engineering knowledge, know the scope of regulations and understand their fundamentals.

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Against the background of increasing labour turnover, the transfer of knowledge is also important. However, this knowledge transfer is not only important for the change of staff, but also for the transfer of practical experience and case studies. It is valuable to share knowledge and lessons learned in dealing with aging infrastructure. Best practice examples can also help to ensure that the issue is appropriately dealt with. It may be possible to develop specific standards for dealing with aging infrastructure. It is not necessary that everyone reinvents the wheel.

- **Collaborate and coordinate research**

It is necessary to collaborate in the area of research and to link research activities across all transport modes, but also internationally, and to coordinate them if applicable.

8.3. RECOMMENDATIONS FOR PIARC TO CONSIDER

Whilst the previous recommendations are aimed at road administrations, the research has also identified a number of further recommendations that should be considered by PIARC, to disseminate the report and its findings, to enhance the scope of work for this theme in the next cycle (if the theme is to be continued) and to improve working practices across Technical Committees and Task Forces more generally.

- Case studies – greater focus on collecting case studies from Low- and Middle-Income Countries would enhance the coverage and relatability of future work on this theme.
- Risk management and technical skills – these two sections identified less source content than the other sections, thus there is potential greater gain in future work to focus more on these topics.
- Delivery of renewals schemes – the focus of this project has primarily been on the context and planning of renewal and rejuvenation of aging infrastructure. However, a number of case studies were collected related to the delivery of renewals schemes too. Future work should extend the scope of its research to cover delivery of schemes as a topic in itself.
- Interviews – a number of potential interviews were identified from the survey, but with limited success in arranging and holding any calls. For any future work, alternative routes to engage with potential interviewee organisations should be considered.
- Existing survey data – a vast amount of data was collected through the Working Group survey that is held in digital format. This should be reviewed for potential additional analysis at the start of the next cycle, to identify further relevant information.
- Webinar – due to time pressures in finalising the report, the Working Group has not delivered a webinar in advance of its publication. However, the group would like to propose that a post-launch, post-Congress webinar would be of use and value to PIARC members.
- Working Group delivery – other than the initial kick-off meeting Paris in early 2020, virtually all engagement for the Working Group has been via virtual Teams calls. In future, the group should ensure that there is a mix of face-to-face meetings and virtual meetings.
- Working Group membership – the Working Group comprised almost exclusively of representatives who were new to PIARC (first cycle), with a learning curve for how the

group was expected to operate and the typical scope / arrangement for research themes. It may be helpful to ensure that there is a balance between new members of PIARC and more experienced representatives when assigning Working Groups.

- Other PIARC TC work programmes – findings from the project may be valuable to inform programmes of work for next cycle, outside of TC3.3, e.g., challenging design standards within asset-focused Technical Committees.
- Survey best practice – a considerable amount of time and effort was applied to design and deliver the Working Group survey, along with necessary communications and analysis. A short guide to best practice may be useful for all future TC Working Groups and Task Forces, with advice on the process to follow and recommendations on which tool / platform to use.

9. GLOSSARY

Term	Definition
ALARM	Annual Local Authority Road Maintenance
AI	Artificial Intelligence
BIM	Building Information Management
CIHT	Chartered Institution of Highways and Transportation
DfT	Department for Transport
GPS	Global Positioning System
HIC	High Income Countries
ICT	Information Communication Technology
IoT	Internet of Things
i-DREAMS	intelligence-Dynamic Revolution for Asset Management system
JICA	Japan International Cooperation Agency
LMIC	Low- and Middle-Income Countries
LoTAG	London Technical Advisors Group
NDT	Non-destructive Testing
PPP	Public Private Partnership
TSD	Traffic Speed Deflectometer
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicles
UKRLG	UK Roads Leadership Group

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11. APPENDIX – FURTHER CASE STUDIES

Camera Inspection System and Automatic AI Damage Detection	**Metropolitan Expressway Company Limited** **Japan** 

Problem

In response to the demand for reliable maintenance and management of the vast aging social infrastructure, the shortage of engineers due to the decrease in the working-age population has become a major social problem. Therefore, it is necessary to actively utilize technologies such as ICT, IoT, and AI in road maintenance and management to improve productivity.

Solution

Recent technological advances have improved camera functions, increased the accuracy of captured images, increased the communication speed and capacity of captured images, and diversified GPS functions, resulting in the advanced use of captured images. The following is an overview of the camera inspection system developed in consideration of these trends in camera technology and issues with conventional methods.

(1) Three-cameras video acquisition and video confirmation function

The patrol car used for patrol inspections is equipped with three full high-definition cameras with a 60° angle of view to cover a 180° field of view, which are installed at the locations shown in Figure-1. Detailed images of the entire process of the patrol inspection are captured and recorded. The camera can be moved up 20 degrees and down 10 degrees for a total of 30 degrees, enabling patrol inspections tailored to each application, such as concentrated observation of road surface damage that could lead to third-party damage or management defects caused by falling facilities installed at high locations. The captured video data is recorded by synchronizing each frame with positional information from GPS and gyro sensors, etc., and the time of capture, making it easy to retrieve the data after acquisition. Therefore, as shown in Figure-2, detailed video and vehicle vibration records can also be linked to the system from any specified location and time on the map. This eliminates the need for re-running and re-photographing due to missed shots, and by storing the data on a cloud server, the system can also record sound sections and damage not yet reported, which can be used for various analyses such as predicting damage deterioration, whereas previously only damage was recorded by digital cameras.

Camera Inspection System and Automatic AI Damage Detection	Metropolitan Expressway Company Limited Japan

Figure-1. Overview of inspection Cameras

Figure-2. Observation System with linked to maps.

(2) Utilization for historical tracking of damage, etc.

Since the camera inspection system accumulates images of all the daily patrols, it is possible to go back in time and check the images. Therefore, when damage is found, it is possible to confirm the time of occurrence and its status from the accumulated images, and to perform follow-up checks after treatment. This reduces the time and effort required to go to the site and assess the situation, leading to increased work efficiency. In recent years, preventive maintenance and repair, in which the condition of road facilities is inspected, and any deterioration or damage is treated as early as possible, has been promoted. The camera inspection system is expected to contribute to "preventive maintenance" by accumulating information on the entire process of damages from when the structure was built. As shown in Figure-3, it can also be used to determine the progression of road surface damage, prevent third-party damage, and set the timing for repair.

Camera Inspection System and Automatic AI Damage Detection	Metropolitan Expressway Company Limited Japan

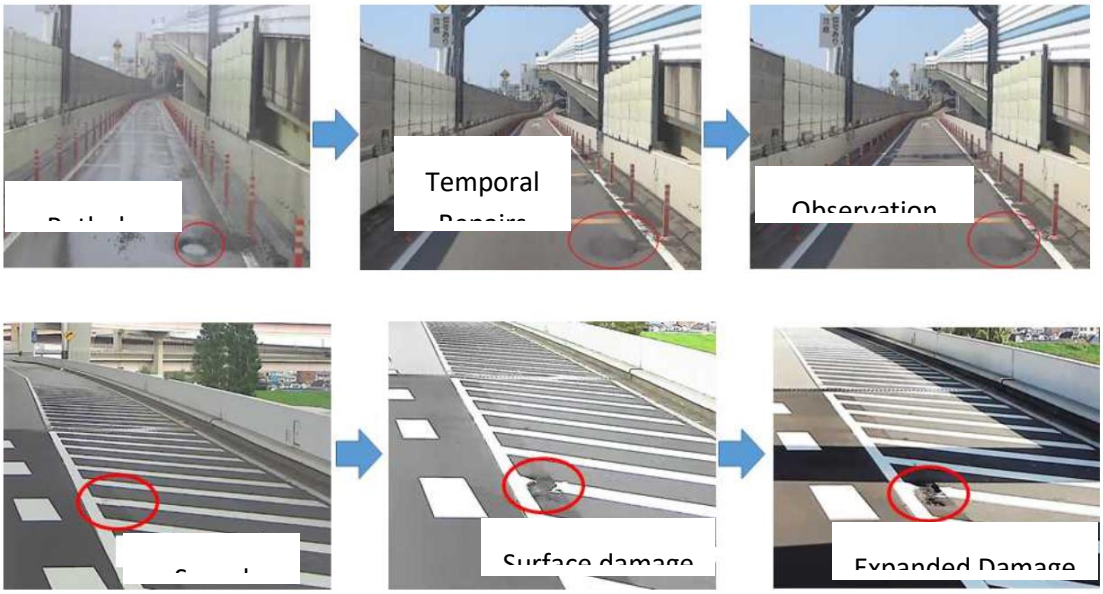

Figure-3. Detected images of road surface damages

(3) Details of trial of automatic damage detection using camera inspection system

Previously, when major damage is detected during a routine inspection, the inspection engineer contacts the company using the emergency call function and takes urgent action. However, since a camera inspection system acquires high-definition images of the entire process, if AI can automatically detect serious damage, it can be used as a complementary tool to ensure that nothing is missed, and in the future, it can take the place of inspection technicians, leading to further advancement and efficiency. The automatic damage detection targets pavement potholes, cracks, and expansion joint surface abnormalities. The automatic damage detection system that is being tested. As shown in Figure 4, the current automatic damage detection system is a trial system that detects damage by inputting images of any route or point from the camera inspection system images that are accumulated daily on the cloud into an automatic damage detection AI engine that utilizes Deep Learning techniques, and outputs a list of the detection results. And the teacher data is currently accumulated in order to improve detection accuracy.

Camera Inspection System and Automatic AI Damage Detection	Metropolitan Expressway Company Limited Japan

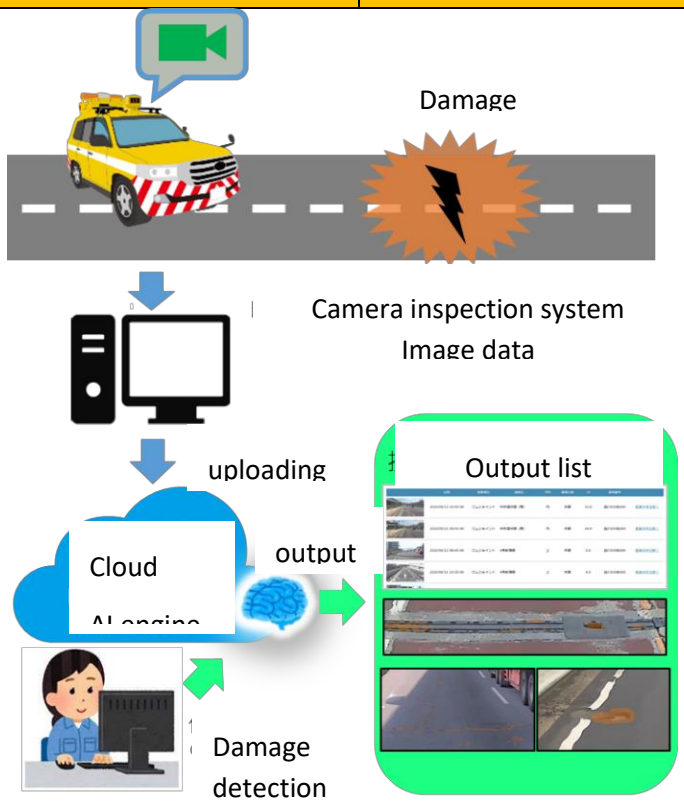

Figure-4. Automatic Damage Detection System

Benefits

The camera inspection system not only improves the efficiency and sophistication of highway patrol inspections, but also contributes to the overall efficiency and sophistication of maintenance and management operations by eliminating the need for conventional on-site inspections. In addition, an automatic damage detection system using AI can detect damage that is easily overlooked by humans and contribute to the safety and security for customers.

Survey of existing road assets with laser scanning and AI-supported object classification	Bavarian Road Administration Germany, High Income Country

Problem

Survey of existing road assets with laser scanning and AI-supported object classification	**Bavarian Road Administration** **Germany, High Income Country**

The Bavarian Road Administration (a part of the Bavarian State Ministry for Housing, Construction and Transport) is responsible for almost 6,000 kilometres of federal trunk roads, about 14,000 kilometres of state roads and more than 3,000 kilometres of county roads in the federal state of Bavaria.

A comprehensive knowledge of the existing road infrastructure is an essential basis for planning, construction and utilization processes. Especially due to the historical grown road network of the Bavarian Roads, the corresponding data is only available to a limited extent.

Solution

The Bavarian Road Administration uses increasingly kinematic 3D surveys by laser scanning to capture the road assets. The derivation of the required CAD objects from the point clouds obtained from the laser scanning has so far been carried out in a manual process, which is associated with high time and cost expenditures.

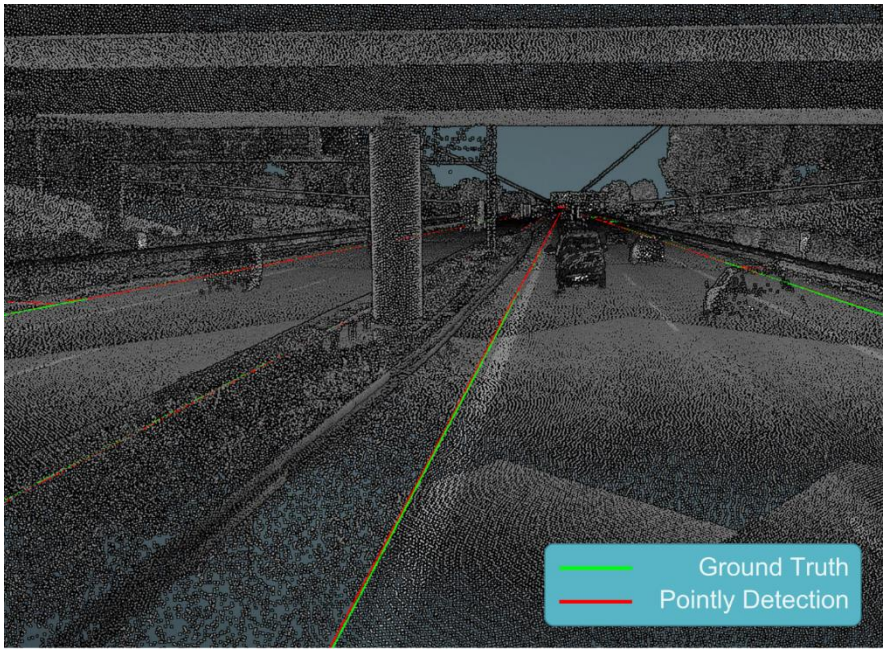

Figure: Motorway section with laser scan point clouds [© Supper & Supper GmbH, www.supperundsupper.com]

In a pilot project – that also included the federal motorway, which were manged by the Bavarian Road Administration until the end of 2020 - the possibility of automated object derivation from laser scan point clouds using methods of AI (3D neural network) was investigated.

Benefits

The automated, AI-supported derivation of infrastructure objects from laser scan point clouds enables an enormous increase in efficiency and cost reduction for the inventory of road

Survey of existing road assets with laser scanning and AI-supported object classification	**Bavarian Road Administration** **Germany, High Income Country**

infrastructure. The medium to long-term goal of the Bavarian Road Administration is the immediate determination of BIM-defined objects.

More information

Supper & Supper (2 December 2020): More accuracy in projects with AI-supported object classification from point clouds, in: Geospatial World [online]
[11 December 2020] (Retrieved 11 September 2023):

https://www.geospatialworld.net/article/supper-supper-ai-supported-object-classification-from-point-clouds/

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Development of Digital Skills	UK University of Birmingham UK, High Income Country 

Problem

Digital skills are in high demand across the globe, with over a million digitally skilled people required by 2022 in the UK alone. It has been projected that 45%–60% of the European labour market would be displaced in coming decades as the result of digitalization, adding to the existing 14 million unemployed men and women in the EU as of February 2020. With digital skills being vital to a country's economy, there is a need to develop the higher education sector to prepare students for a digitized future. The requirements for digital skills and the demands associated with these new skills have posed a new challenge to education systems, particularly within the higher education. Further to the digital skills the graduates are not well equipped with soft skills, e.g., team working. The Institute of Engineering & Technology (IET) reported that 73% of the participated companies have had difficulties with recruiting graduates with the right academic knowledge who lacked the required workplace skills for engineering jobs.

Solution

A vehicle to enhance existing education curricula was demonstrated at the University of Birmingham, by exposing students to research-informed educational activities and to experience the key digital systems used in different industrial sectors. The overall aim of the project was to train students in cutting-edge digital technologies through two separate week-long boot camps, targeting undergraduate and postgraduate cohorts. To this end, an educational project primed by research-informed teaching was successfully organised at the University of Birmingham in collaboration with the industry, to directly enhance the student's personal development in the digital field. Researchers and practitioners presented practical applications of various digital technologies during the boot camps where students applied the skills gained during the boot camp to tackle a set of global challenges.

In total 33 students took part in two separate week-long boot camps. The first consisted of 14 undergraduates from cohorts representing years 1, 2 and 3 from Electrical, Mechanical and Civil Engineering programmes. The second boot camp consisted of 19 postgraduate students, from four different MSc Engineering Management programmes. Reflecting upon students' opinions and preferences, captured during a pre-engagement workshop, the following digital technologies were selected and covered within the boot camps' programme:

- Blockchain
- Artificial Intelligence (AI)
- (VR) and Augmented Reality (AR)

- 3D Printing
- Robotics and Automation
- Internet of Things (IoT)

Students were also trained on presentation and team working skills, including Design Thinking and were asked to present their solutions at the end of the boot camps to an expert panel. From this, the panel selected the three best solutions. The soft and transferable skills covered during the boot camps were including:

- Devising initial concepts
- Design Thinking
- Social Media Awareness and Self Branding
- Technological Challenge & Industry 4.0
- Pitching Ideas
- Crowdfunding Innovation
- Data Analytics and Business case

Benefits

The success of the boot camps was evaluated by assessing the students' knowledge both before and after the boot camps had taken place. This was achieved through questionnaires that measured students' awareness and eagerness to pursue training on various digital innovations.

Students highlighted that Presentation skills were one of the key achievements of attending the boot camp (Figure 1). This indicates the potential success and suitability of problem-based learning pedagogy provided through a boot camp to enhance students' transferable skills. Normally within higher education programmes delivery, there are opportunities for students to practice some of these transferable skills, such as presentation, while there are fewer opportunities for problem-based activities where students learn other skills such as independent learning and research skills. Problem-based learning enhances students' decision-making abilities and so help them develop the ability to decide which skills or knowledge would be beneficial for them to tackle a problem.

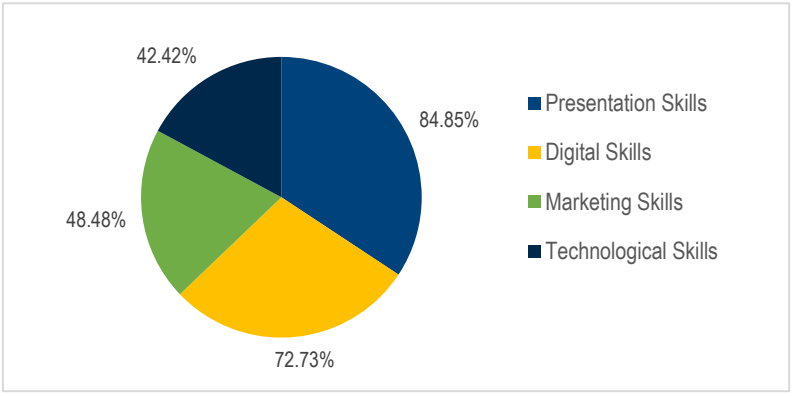
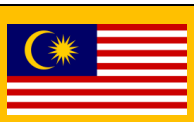


Figure 1: Skills gained from the boot camp, Question: What skills do you think the Boot Camp has prepared you for your future career in academia/industry?

Both the boot camps acted as a pilot to test the success and impact of training students on innovation and digital skills. The results of the pre-and post-boot camps surveys showed that the boot camps were very successful in achieving their aims. Adopting digital innovation training in education curricula will position higher education institutes as a futuristic vehicle that equips future generations with up-to-date skills and therefore encourage new generations of students through higher education to enhance their future career potential. The study has helped the University of Birmingham to further incorporate digital skills into their pedagogy including MSc programme in Road Management and Engineering, which hosts students from around the world.

More information – https://ieeexplore.ieee.org/abstract/document/9783447

Rejuvenation of Aging CMP Culverts	Malaysia 

Problem

The construction of Corrugated Metal Pipe (CMP) culvert was widely adopted as an integral part of the road network system in the mid-1970s to 1980s. This is due to the fact that they were easy to handle and transported at the time, when accessibility and mode of transport were incredibly challenging. These culverts have performed their function effectively for the past 40 years despite an increase in traffic load, aging and inadequate maintenance funds.

Due to a few incidents of culvert collapse occurring in 2013, the Public Works Department (PWD) undertook a major exercise to inspect, evaluate and identify suitable treatment to these aging and deteriorated CMP culverts. An allocation of RM50 million was then granted in 2014 until 2016, over a period of 3 years to rejuvenate and extend the remaining service life of these affected culverts where the hydraulic designed capacity had not been exceeded or to replace where the hydraulic capacity needed to be increased and upgraded.

It is notably understood that the cost to replace these aging culvert structures demands much higher funding than to rejuvenate. This has resulted in a need for an alternative method to further the service life of the culverts and such interests are more focused in the field of innovative solutions involving new material and technology which can provide cost effective solutions but sufficiently robust and at the same time extending the service life of these aging culvert structures.

Solution

Total replacement or conventional way of rehabilitation normally incurred relatively high cost and is considered to be the only option in prolonging the service life of aging structures. However, in recent times a new innovative approach has entered the market.

Tunnel lining method using metal type lining plate was one of the earliest rejuvenation methods adopted to rejuvenate triple CMP culverts at Federal Route 14 in 2013. The technology then evolved from using metal type lining plates to the usage of High-Density Polyethylene (HDPE) reversed reinforcement pipes as per implemented at Federal Route 29. In comparison, rejuvenation using HDPE imposed a cost reduction of approximately 50% to 60%. HDPE pipe liners still have certain restrictions, though. The size or diameter of the material was the determining element in this situation. Unlike tunnel liner plate, which may be custom produced

on site to the desired size and form, HDPE material is only available in diameter sizes up to 3 meters. The segmented corrugated steel plate system costs more than HDPE pipe liners as it must be erected before it can be used. Consequently, it is still acceptable to take into account the usage of tunnel liner plates where much bigger diameter is applicable.

While the conventional method covers the full range of rehabilitation and total replacement the tunnel lining method provides a quick and reliable solution to address short term and medium term needs for the extension of service life and make efficient use of funds.

Benefits

Both method of tunnel lining approach available in the rejuvenating of aging culvert structures enabling reliable solution and providing the following benefits:

1. Less disruption to the daily traffic

2. Highly economical and provide cost saving up to 60% compared to conventional rehabilitation method

3. Faster project completion due to ease of installation

4. Provide cost effective solutions to the authority with high inventory of aging culvert structures.

Large scale renovation of Metropolitan Expressway	Metropolitan Expressway Company Limited Japan

Problem

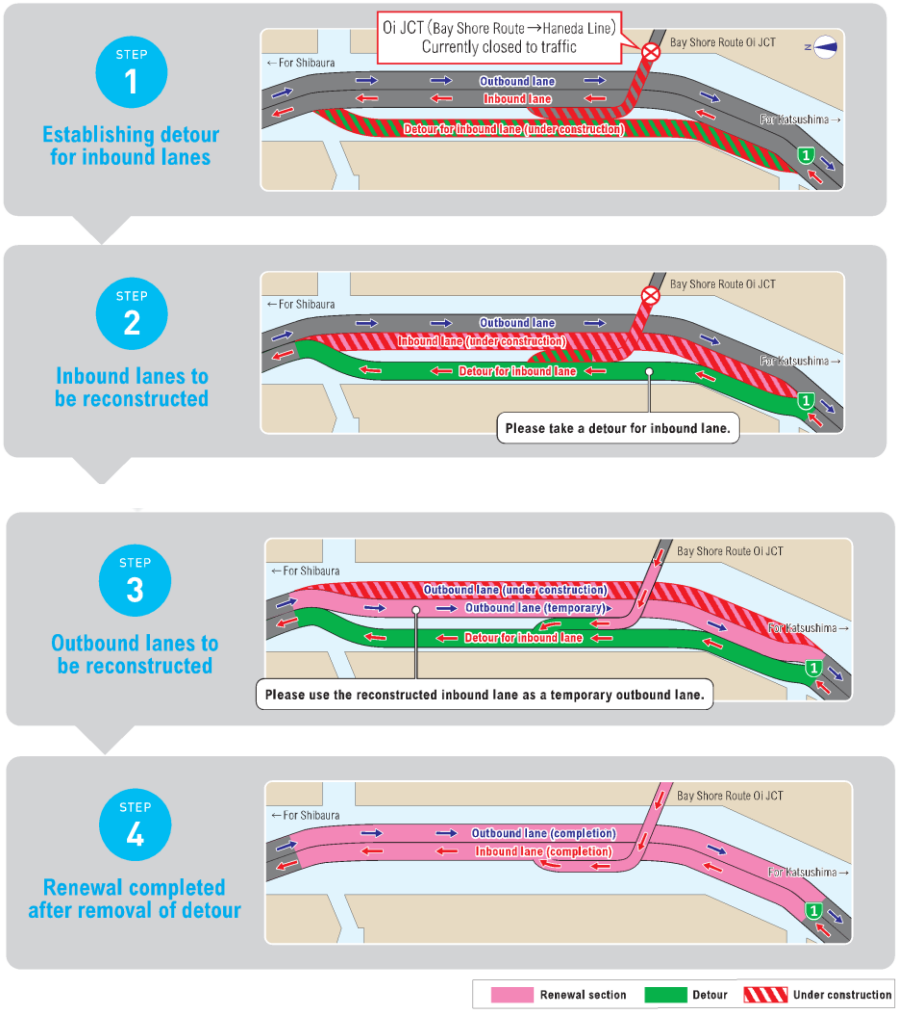
Tokyo Metropolitan Expressway Route No. 1 Haneda Line is a route connecting Haneda Airport to the city centre, and it has been around 60 years since it opened in 1963. The Pier section is constructed over the canal, there have been many instances of concrete separation and rebar corrosion because the space between the bridge girder and the sea surface is extremely narrow and can be easily damaged. The Reclamation area has a structure similar to that of a temporary construction, and serious damage such as collapse of the road surface has occurred. In addition, traffic flow couldn't be stopped.

Solution

This section had been regularly inspected and maintained during this time to provide safe and reliable road traffic; its renewal commenced in 2016 to ensure long-term safety as the first large-scale renewal project on a Japanese highway. Renewal structure is designed with consideration for maintainability and sustainability. Various strict constraints were imposed on the construction. For example, the renewal section has a lot of traffic, so this plan requires construction without obstructing existing traffic. A detour route is implemented to re-routing traffic according to various stages of the renewal project. The construction steps of this renewal project are shown in the following figure.

Large scale renovation of Metropolitan Expressway	**Metropolitan Expressway Company Limited** **Japan**

Step 1 is establishing detour for inbound lane. The construction of the detour needed to be particularly urgent for the Olympic Games. Therefore, it plans to complete a detour of about 1.9km in a year and a half by making most of the part's precast products. In step 2, build a new inbound lane (Phase I) with space of moved traffic on step1. Once the construction of the new inbound lane is complete, provisionally outbound lane traffic was moved to new inbound lane. And in Step3, new outbound lane (Phase II) is reconstructed. Phase II construction should be carried out in a very narrow environment between Phase I and the Tokyo Monorail. In the last step4, the temporary traffic is moved to the renewal road. In this way, this renewal construction is proceeding while ensuring the traffic flow.



Benefits

Benefits of this approach included:

- Reduction in maintenance work and cost
- Reduction in the risk of structural failure
- Provision of safety service for driving users

Large scale renovation of Metropolitan Expressway	**Metropolitan Expressway Company Limited** **Japan** 
Despite various constraints, this work was one of the first large-scale renewal project in Japan, and through ingenious design and construction, we were able to make a significant contribution to maintaining and improving the functionality of the Metropolitan Expressway, thereby improving local communities, economies, and lifestyles. We sincerely hope that this report will be useful in all future construction projects, as renewal projects due to aging will be necessary not only for expressways but also, in all other situations in the future.	

World Road Association (PIARC)

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