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Transportation Research Procedia 00 (2022) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

Transport Research Arena (TRA) Conference

Analyses of barriers, trends and best practices for better monitoring and maintenance of European transport infrastructure

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Abstract

Europe depend on a well-functioning transport infrastructure. In the EU-project IM-SAFE we identified the political, economic, social, and technical (PEST) barriers against optimal monitoring and maintenance with a special focus on bridges and tunnels. The analysis show that the most damaging barrier for implementing monitoring is an inadequate funding. Hazards originating from increased loading of the infrastructure caused by the increased traffic volume and traffic loads as well as future climatic conditions are the most severe challenge for the longevity. The impact of aging of the objects might not have been designed for the current and future conditions of use, it is necessary to improve the current practices in monitoring and maintenance of transport infrastructure. The most important enablers of overcoming the barriers are sought in standardization and digitalization.

Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference
Keywords: maintenance; monitoring; standardization; infrastructure; PEST-analysis

1. Overview and motivation

Transport infrastructure owners have to manage and maintain large portfolios of transport infrastructure assets, such as bridges and tunnels. In particular, they have to ensure that these assets are safe and do not set its users at risk or impair with the transportation performance of the traffic network. Recently safety risks have become critical and manifested in major disasters due to structural failures partly due to maintenance deficiencies. Large difference in practice for monitoring and maintenance are found between different countries and in many cases each individual engineer has a lot of freedom to choose their own strategy.

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Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference

Recent technological developments have the clear potential to support these developments. The most promising are already taken up by local communities and they have been identified as major trends for development. It is expected that future development is triggered by the development of corresponding future orientated standards that both, take up established and proven best practices and at the same time open up for the full exploration of the existing potential of the technological developments in engineering and data technology.

The following trends applied in Europe have been identified by relevant stakeholders during local and Pan-European workshops of the established Community of Practice (CoP):

- Trend 1: Risk-based maintenance management and condition-based preventive maintenance strategies
- Trend 2: Risk-based inspection and condition survey planning
- Trend 3: SHM with novel technologies: distributed sensing, wireless and energy-efficient sensor technologies
- Trend 4: Autonomous sensing incl. drone inspections
- Trend 5: Remote sensing
- Trend 6: Implementation of IoT and data analytics

Acknowledging that successful development, roll-out and implementation of standardisation is only possible with thorough understanding of the full context, the EU-project IM-SAFE evaluated the main barriers that need to be overcome in order to enable well-functioning monitoring and maintenance of transport infrastructure, in particular road and railway bridges and tunnels and other relevant transport infrastructure assets. This paper presents the outcomes of the analysis of Political, Economic, Social and Technological (PEST) barriers and discusses the connection between these barriers and the limitations and gaps in the existing EU monitoring standards and the national implementation. The full reports (Hoff, et al., 2021) and (Navas et al, 2021) could be found at the project web page[†].

2. Methodology

A PEST-analysis consists of systematic identification of external political, economic, social, and technical factors that have impact on the functionality and safety of a system (Sammut-Bonnici & Galea, 2015). This analysis is commonly used for strategic analysis. They are often a mix of "hard facts" combined with more subjective analyses which require careful interpretation of the results. It is, for instance, not clear how different barriers should be weighed against each other to decide which one is more important. Nevertheless, in this paper an attempt to identify the most important barriers have been made. To partly overcome the concerns with subjectiveness of a PEST-analysis, inputs have been collected from a wide range of sources. Workshops with the IM-SAFE Community of Practitioners has been arranged and expert evaluations from these workshops has been integrated.

As the European countries have different political, economic, and social situations, the analyses have been performed on national level for countries representative for the European regions, and the outcomes have been aggregated to identify main barriers at European level. Although the technological development is to a large extend similar throughout Europe and technical barriers are to a larger extent alike, they were treated similarly as they may also vary due to different local (climatical, historical, educational) context. The countries analysed were: Austria, Germany, Italy, Netherlands, Norway, Poland, and Portugal. The analyses for each country were performed by a small group of experts who have lived and worked in the country for several years with good knowledge of how inspection and maintenance were performed and how this was influenced by special conditions in each country. If possible, the barriers were backed up by publications (scientific or from mor popular sources)

2.1 Ideal world without any barriers

The PEST analysis aims to show the barriers towards reaching an "ideal" situation. This situation is not a condition where unlimited resources could be spent on the infrastructure (this would not be ideal). The following is a description of an "ideal" but still realistic situation.

[†] im-safe-project.eu

Inspection and monitoring provide the information that is necessary to ensure sufficient reliability of the infrastructure. It is carried out with a purpose, at the right time and with appropriate methods. Inspection and monitoring are cost efficient meaning that the net Value of Information provided by inspection and monitoring is positive. The data from inspection and monitoring is stored and summarized in a standardized way making it accessible and usable over time, by different actors. All relevant assumptions and methodologies that are necessary for the data analysis are scientifically sound and specified in a corresponding standard.

A common metric of risk is defined in such a way that it effectively reflects the potentially dangerous asset conditions for infrastructure owners and society. This includes the representation of relevant events, their consequences, uncertainties, and spatial and temporal variability. Methods and tools for risk evaluation are available and standardized. Infrastructure owners have sufficient knowledge about the risks associated with the infrastructure objects and act rationally upon these risks. The level of risk is balanced with the costs for reducing the risk. The need to perform a Risk evaluation is well focused and identified in terms of conditions that trigger it.

The strategies for asset management are optimal in long term; they aim for a proactive and/or predictive rather than reactive approach The level of detail of the risk evaluation is flexible (based on resilience features of each structure) and refined enough for supporting the decisions to be made. When deciding on measures for non-satisfactory structures, other options than straightening interventions are evaluated, such as extraordinary inspections/monitoring, organizational measures or performing more detailed analyses.

3. Political factors

Transport system is very important in people's everyday life and therefore the politicians tend to use investments in infrastructure as a tool of winning support of the voters. Even if some political parties are critical to build new infrastructure due to environmental concerns, most will acknowledge that maintenance of existing infrastructure should be prioritized to take care of the publicly owned assets. A study (Kemmerling & Stephan, 2015) concluded that political factors (swing voters and incumbency, congruence) affect regional allocation of transport infrastructure.

3.1 Political involvement

Political involvement in the transport infrastructure management can be problematic due to e.g., lack of technical competence, political short-term goals, and ideological influences that potentially changes every election.

Decisions about investments in new transport infrastructure as well as rehabilitation and maintenance of existing infrastructure, are commonly a joint work of politicians and technical personnel, but the extent of political involvement may vary. It is obvious that politicians should be involved in strategic decisions to ensure democratic influence, but for decisions at detailed level, i.e., at project level, the political opinions should to a higher extent be replaced by technical competence.

The short-term nature of the political arena forces politicians to take actions that profit their voters now and not in 20 years, which may lead to sub-optimal solutions. The general concern is that investments in new projects are prioritized over maintenance. Putting into service a new bridge will certainly be noticed and appreciated by the citizens, and politicians will make sure that the merits are attributed to their party (Wozniak, 2019).

Public transport infrastructure is often owned by different "levels" in a country and may be managed and maintained by other organizations such as consultancies and contractors. It could be a challenge to coordinate implementation of the same standards of monitoring among different actors, in absence of appropriate information systems and communication between stakeholders. It is also obvious that there may be gaps and overlaps in responsibility, if not stated properly. Hired consultants do not have the societal preferences as goal but rather the fulfilment of the contracted requirements.

Another common issue, in some regions, is the unclear jurisdiction over the assets; in Italy, e.g., there are almost 1500 bridges whose control is parcelled out among provinces, municipalities or consortia. The difficulty of verifying the ownership of these infrastructures and the consequent fragmentation of the assets management are additional aspects that cause the interventions and renovation plans to advance slowly.

3.2 Transparency and corruption

Transparency in decision making is needed and those responsible are asked to be accountable. Transparency also means openness to criticism. Decision makers need to decide even with lack of information and existing uncertainties and have to make choices that might turn out to be wrong after events have realized. The public, learning the before unknown, can make politicians vulnerable to criticism. Even with good and transparent documentation of the decision process and the corresponding decision that might be justified given the limited information, decision makers will always be subject to imputation or even accusation when adverse events realize as a consequence of the decision.

The need of maintenance and monitoring interventions on infrastructures, both for the strategic importance in worldwide mobility and the direct impact of an incorrect management to the economy, is a sensitive objective for corruption strategies, that often occur in different fields of public investments. Many national and EU regulations and control systems are in place to prevent corruption and focusing on transparency.

In a study (Fazekas & Tóthb, 2018) says: *Findings indicate that corruption steers infrastructure spending towards high value as opposed to small value investment projects. It also inflates prices by 30–35% on average with largest excesses in high corruption risk regions. Contrary to perceptions, corruption risks in infrastructure are decoupled to a considerable extent from the national corruption environment.*

4. Economic factors

4.1 Limited budget creates maintenance back-log and sub-optimal use of funding

Even if Europe is spending large amounts of money on maintenance of the transport infrastructure it seems to be too little to keep up with the need. As an example, the Norwegian backlog in maintenance have accumulated to €100-110 billion to bring the national road infrastructure up to today's standard (RIF, 2021). Even if the number have a high uncertainty, it is a useful tool to communicate the consequences of the budgets used over time.

The entry into the European Economic Community for countries like Spain (1986) and Poland (2004) led to a change of direction in public policies to converge with older EU states. These new trends included increased investment in infrastructure and improved connections. The very large needs for the development of road infrastructure in the new EU Member States meant that the vast majority of funds was allocated to the construction of new roads and bridges. The repair of existing old facilities was relegated to the background. Unfortunately,
even after the 2008 crisis was over, the European investment in transport infrastructures has remained low, until 2020. (Departament infrastruktury Poland., 2015)

The 2021 budget for infrastructure has increased and includes now *Recovery and Resilience Mechanism* for many countries. Investments in the trans-European transport network are included for the final development of important sections, both in the Atlantic and the Mediterranean corridor.

4.2 Local level administrations face many different challenges

At local level, the budget available for infrastructure maintenance vary a lot between the municipalities depending on the local economy. The total amount available for each single municipality must cover different current needs, hence the resources to allocate in the area of maintenance and monitoring of infrastructures with postponed benefits compete often with different urgent fields that require support e.g., care for the elderly, better quality teaching at schools, kindergartens etc. Differences between rich and poor municipalities could be found in most countries but has especially been emphasized in the German analyses.

The importance of conscious investment in proactive maintenance programs is not completely evident since the deterioration of infrastructures often develops slowly in time, so it could seem less urgent.

4.3 Value and cost are separated in time and between different stakeholders

Infrastructure performance is perceived by the users more relating to periodically occurring closures (need for interventions, maintenance) or serious structural failures than the time in which infrastructure assets provide safe and standard usage.

The negative impact of problems related to underperforming infrastructure is felt by the infrastructure users. Associated social costs can be calculated with use of LCC methods, but such costs do not show in public budgets in the same way as costs of monitoring and maintenance. For this reason, costs for road users are sometimes ignored.

The positive effect of functional infrastructures, sometimes, is only indirectly felt by the road operator, while it may be emphasized as a reason to keep investing in the maintenance and monitoring programs.

5. Social factors

5.1 Risk awareness

The European population is in general not so willing to accept risks when it comes to transport infrastructure and a lot of effort has been into reducing traffic accidents. Several national transport authorities have adopted its national version of Vision Zero (“Zero deaths and serious injuries”) first for road traffic safety and later for all transport related activities.

However, when it comes to very rare incidents that are related to bridge failure with the corresponding large consequences the risk awareness in the general population is over-stimulated. In the absence of these events the awareness of the risk is less than the real risk, after such an event the awareness is bigger than the real risk.

Due to the recent major failures happened, in some region as Italy, people perceive the infrastructures as unsafe, and often demonstrate a feeling of mistrust in the asset management capabilities, especially when the roads and bridges are subject to frequent inspections and maintenance operations or road closures.

Tangible benefits of an efficient administration of the national road network are unfortunately delayed in time with respect to the time of the investment, and its value is not well perceived by the population, who do not have technical background, until later on in the decades.

Besides, the current corrective/preventive approach is consolidated and supported by outcomes collected during years. Asset owners (private and public) are reluctant to change the current maintenance models since current maintenance strategies have proved to be effective so far, and even if improvements can be made to current standards, the risk perception to accomplish this change is high.

5.2 Education of specialists and skilled workers

The education of engineers and skilled workers is not in balance with the current needs, but local variations exist. To be able to take advantage of new methods for monitoring and asset management it will be necessary to increase education capacity for new engineers and skilled workers and also to focus on continuous education programs to increase knowledge among current employees.

In general, traditional Civil engineering seems to lose some popularity for BSc/MSc studies. This might be a problem for some of the traditional competence in structural, pavement, traffic engineering. On the other hand, more students move towards topics like cybernetics and computer science that might benefit other parts of what is needed.

5.3 Difficult to learn from failures due to legal issues

Large failures with fatalities will most of the time be investigated, but the scope of the investigation will often be on the legal side to identify organisations or persons that could be blamed for the accident and to less extent is the focus on learning what happened and what could be changed to prevent future failures.

For the "smaller" failures or mistakes made it is less public interest and everybody involved could have less motivation to investigate to pick up lessons to avoid similar mistakes in the future. The cases are often settled outside of the court system, and it is not uncommon that both parties agree to a non-disclosure clause as part of the agreement. (Refvem, 2020)

This lack of openness about mistakes will prevent learning and unnecessary funding is spent repeating mistakes.

The conflict between contractors and infrastructure owners are likely to remain since infrastructure projects are often large involving significant amount of money. And construction and maintenance of the infrastructure is quite difficult involving natural soils and materials with a lot of variation that often are unknown at the contracting stage.

5.4 Willingness to invest in research

Research funding for projects on maintenance of transport infrastructure has been relatively low compared to the big value of the infrastructure. Some increased focus has been seen recently, but still several important research questions remain unanswered. Increased effort in research is necessary to overcome some of the barriers identified in this work.

6. Technological factors

6.1 Aging infrastructure

A lot of Europe's infrastructure facilities was designed and built following guidelines that were developed when the economy and cost for maintenance labour was quite different from today's situation. This means that solutions that had low investment cost were favoured over solutions with increased service life. In today's situation this results in high maintenance costs. A lot of the infrastructure has now already reached its design-life but are still in daily use and are still a valuable part of the infrastructure.

6.2 Variable and harsh climatic conditions

Europe has several regions with relatively harsh climatic conditions that often require extra maintenance for infrastructure, e.g., frequent freeze-thaw cycles during the winter leads to damages, and bridges in coastal areas are exposed to salt water and this factor could lead to chloride intrusion and corrosion, with high consequences in terms of structural performance. The same could also happen in more inland location if salt is used for winter maintenance.

The observed and predicted climatic changes are likely to cause new, and more severe challenges to the infrastructure, especially caused by increased intensity of rainfall. We have already seen cases of severe flooding, and this is likely to increase in the future. When flooding and water induced landslides far outside of the design parameters hits infrastructure disastrous results must be expected. The challenge lies in prediction what infrastructure is more exposed to climate related extreme loadings.

6.3 Number of assets makes it hard to keep them well tracked

The amount of infrastructure objects like tunnels and bridges in Europe is very high. Just the city of Hamburg by itself has almost 2500 bridges of varying size. A country like Switzerland have more than a quarter of the road network in a tunnel or on a bridge.

The high number of tunnels and bridges make it difficult to keep a good control about the condition and to optimize the maintenance effort. To be able to monitor and maintain them it is necessary to have a good asset management system to keep track of the condition.

Nowadays, the census of the roadway assets is still to be completed to exhaustively represent the actual total number and status of local minor bridges. This lack on information often causes a dispersion on management plan and delays in the maintenance program.

7. Strategies to overcome or reduce negative impacts of identified PEST-barriers

Some of the identified barriers are not so easy to overcome without dramatically changing the political, economic, and social situation in Europe which is outside of the scope of the IM-SAFE project.

7.1 Standardization

A standardized system for monitoring and inspection in Europe would make it harder to hide behind the “we did not know about the problem” and make infrastructure owners and politicians responsible for the conditions. Engineers faced with difficult choices could use standards as tools to argue for better monitoring, sufficient budget, and better solutions.

A more uniform system for quantification of the condition would also make it easier for politicians and the public to assess the development and state of the infrastructure and by this opening up for adequate budgets for maintenance and upgrading.

Standardization will allow for more specialized companies that could be available to be contracted to perform inspections or install automatic monitoring systems. This means that the cost of information will be reduced and open up for more knowledge about the objects. In the next line this will allow for better modelling and asset management.

For international contractors and service providers standardization makes it simpler to compete over borders and this will ultimately result in better services and reduced cost for infrastructure owners.

7.2 Develop automated monitoring systems

Better and cheaper communication and sensor systems are being developed making it possible to instrument larger objects and also open for faster and easier inspection of infrastructure. E.g., using drones for inspection of tall bridges where you before needed especially trained and brave people to climb the bridge towers.

Cheaper and more accurate information about the different objects combined with standardization will make it possible to get a better overview of current and estimated future conditions of the infrastructure and by this make it easier to select the right objects for maintenance and to choose the best method for rehabilitation.

It will be possible to lower the Life cycle costs of the infrastructure and also possible to detect potentially dangerous development in time to prevent catastrophic failures and save large amounts of money and users lives.

7.3 Asset management systems

To be able to handle the large number of objects in the network for roads and railways it is necessary to have a computer-based asset management system to keep track of the condition of all the objects. A good asset management system will make it easier to identify which objects should be prioritized for maintenance to keep the risk for failure low and optimize the life cycle costs for the infrastructure.

A good asset management system combined with standardization could be a good tool to avoid confusion caused by multiple infrastructure owners in a region.

8. Conclusion and future works

Several PEST barriers have been identified that could make it more difficult to enable optimal maintenance supported by timely and accurate information obtain from structurally implemented monitoring of transport infrastructure in Europe. Of the political, economic, and societal barriers the most damaging is inadequate funding in several countries. Hazards originating from the increased traffic volume and traffic loads as well as increased loading of the infrastructure caused by future climatic conditions, in form of more precipitation causing floods, landslides etc are the most severe challenge for the infrastructure longevity. Considering the impact of aging of the objects that might have not been designed for the current and future conditions of use, it is necessary to significantly improve the current practices in monitoring and maintenance of transport infrastructure. With regard to the technical barriers the huge volume of the assets is a major challenge, followed by the risk issues retaliated to dealing with the technical innovations (Navas et al, 2021).

Standardized methods for surveying, monitoring, and analysing the condition and performance of infrastructure assets would make it easier for engineers to prioritize maintenance budgets to get optimal asset management and safe and reliable infrastructure for the public. Hence, standardisation may become a key enabler for the envisaged transition towards cost-efficient and effective asset management schemes for authorities and infrastructure operators. As such, this shall enable increase of safety in road intervention actions for road users and personnel, more efficient road intervention processes and reduction of traffic disruptions, increase of road network capacity and, last but not least, overall reduction of maintenance costs. The latter is of crucial importance as with the increased demand on mobility, the society will also face an economical challenge to increase the budgets for maintenance of transport infrastructure. This demand may therefore require a change in priorities and stronger focus on maintenance of existing infrastructure.

For maximal safety, availability and cost-effectiveness of transport infrastructure, a paradigm shift from corrective maintenance towards risk-based maintenance management and condition-based and predictive maintenance strategies through data-informed decision-making is necessary. This should be enabled by new set of harmonised European standards for maintenance, safety assessment and monitoring. The new standards should be supported and implemented coherently by the public authorities and the industrial stakeholders across Europe.

Recent technological developments have the clear potential to support these developments. The IM-Safe project provides the insights inti the most relevant developments in the domain of the methodologies and instruments for diagnostics of transport infrastructure (Longo, et al., 2022), data-informed risk and safety evaluation (Vliet, et al., 2022), and decision-making regarding maintenance strategies (Darò, et al., 2022), as well as the use of digital solutions as supporting technology (Giurgiu, Rigotti, & Sanecka, 2022). The most promising are already taken up by local communities and they have been identified as major trends for development. It is expected that future development is triggered by the development of corresponding future orientated standards that both, take up established and proven best practices and at the same time open up for the full exploration of the existing potential of the technological developments in engineering and data technology.

Acknowledgement

The authors acknowledge that IM-SAFE project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 958171. The sole responsibility for the content of this publication lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the Innovation and Networks Executive Agency (INEA) nor the European Commission are responsible for any use that may be made of the in-formation contained therein.

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