RECOMMENDATIONS TO REMOVE THE PEST BARRIERS AND PRIORITIZATION OF RISK MANAGEMENT AREAS TAKING THE LESSONS FROM RECENT INFRASTRUCTURE FAILURES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958171.

Document Information

Name	Remark
Document Name	Recommendations to remove the PEST barriers and prioritization of risk management areas taking the lessons from recent infrastructure failures
Version No.	V1.0
Due date Annex I	15/07/2020
Report date	31/10/2021 (last updated in 30/10/2021, 0.9)
Number of pages	50 (including Annexes)
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Dissemination level	Public

Document history

Ver.	Date	Remark	Revision Author	Checked by
Rev. 0.1	20/09/2020	Creation of the document	I. Hoff	S. Cuerva Navas
Rev. 0.2	03/10/2021	Preliminary draft	I. Hoff	S. Cuerva Navas
Rev. 0.3	10/10/2021	Document for review	I. Hoff	A. Strauss J. Wessels
Rev. 0.4	24/10/2021	Updated Chapters 2.2, 2.3, 2.4	J. Żach	I. Hoff
Rev. 0.5	25/10/2021	Updated Austrian PEST analyses	A.Strauss	I. Hoff
Rev. 0.6	26/10/2021	Added Chapter on Digitalization	M. Weise	I. Hoff
Rev. 0.7	28/10/2021	Added German PEST analyses	F. Fliegel	I. Hoff
Rev. 0.8	28/10/2021	Updated Italian PEST analyses	I.Alovisi	I. Hoff
Rev. 0.9	30/10/2021	Document for review	I. Hoff	F. Cinquini
Rev. 1.0	31/10/2021	Document Uploaded	I. Hoff	A. Bigaj-van Vliet

Document approval

Ver.	Date	Approval	Project's Role	Beneficiary
Rev. 1.0	31/01/2021	A. Bigaj-van Vliet	Coordinator	TNO

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958171.

Preface

This report is part of the IM-SAFE project (2020 – 2022) and is it is part of WP1 (Trends, best practices, and barriers) and Task 1.3 (Barriers in political, economic, social and technical aspects) and is listed as delivery D1.3

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This report focuses on analyzing the political, economic, social, and technical (PEST) barriers for adequate monitoring, safe operation and optimal maintenance of bridges and other relevant transport infrastructure assets, and to establish the connection between these barriers and the limitations/gaps in the existing EU monitoring standards and the national implementation.

This task will also analyze the lessons-learned from the recent infrastructure failures and disasters in the EU and worldwide. In addition to desk research / literature review, workshops with stakeholders from the CoP and experts from the SAG was held for collection of actual and anticipated future issues and challenges, next to discussing needs, trends This information was used to evaluate for each of the three periods (past, current and future) using a thorough PEST analysis. A risk analysis of the recent failures and disasters will yield a set of recommendations for prioritization of risk management areas.

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Executive summary

This report addresses the main barriers against well-functioning monitoring and maintenance of transport infrastructure with focus on road and railway bridges and tunnels. Political, Economic, Social and Technological barriers were included in the PEST-analyses.

Several barriers were found and several of them are linked together with the result that in general not enough resources are allocated to monitoring and maintenance of the infrastructure. Transport users do not think about the infrastructure before some failure or closing interrupts their mobility.

The large number of objects makes it challenging to keep track of the maintenance need and remaining lifetime. Some asset management system exists but is not taken into use elsewhere.

A significant part of the infrastructure is getting older, and some are even older than the initial design life. This means that the need for inspection, performance prediction, risk analysis and the actual maintenance work is increasing.

On the other side increasing opportunities for efficient inspection methods and more advanced asset management system makes it possible to get a better overview of the situation and to be able to prioritize better between objects for maintenance.

Some of the barriers are not so easy to overcome e.g., there will always be budget limitations, but one of the most important action that should be taken is to prepare European standards for inspection and maintenance to give the engineer in charge a tool to improve decisions.

The last part of the report is to study recent failures that are caused by lack of monitoring or maintenance or where this is a contributing factor to see if we can learn from these failures. Luckily there are not that many real failures and the only lesson that could be extracted is that maintenance strategies of an object should be emphasized in the design/building phase and that it is important to transfer knowledge and documentation to the operation organization.

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1 Introduction

1.1 Purpose and scope

This report aims to identify the Political, Economic, Social, and Technical (PEST) barriers for adequate monitoring, safe operation and optimal maintenance of bridges and other relevant transport infrastructure assets, and to establish the connection between these barriers and the limitations/gaps in the existing EU monitoring standards and the national implementations. In addition, we propose strategies to overcome the important barriers that are within reach.

We have also analysed the lessons-learned from recent infrastructure failures and disasters in the EU and worldwide. A risk analysis of the recent failures and disasters was performed to set recommendations for the prioritisation of risk management areas.

1.2 Ideal world without any barriers

The PEST analysis aims to show the Political, Economic, Social and Technical 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.

1.2.1 Adequate monitoring

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 (VoI) 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 (Ministry of road transport, road operators, engineering companies, etc.). All relevant assumptions and methodologies that are necessary for the data analysis are scientifically sound and specified in a corresponding standard.

The standards allow the application of the methods to every management reality (different asset dimensions), both the municipality with few infrastructural assets and the road operator.

1.2.2 Safe operation

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.

1.2.3 Optimal management

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.

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1.3 Description of the methods and approach followed in this report

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 (1). This analysis is commonly used for strategic analysis, e.g., for evaluation of whether a new product should be launched in a region. The PEST-analysis may be extended with Legal and Environmental components and is then called PESTLE, and further extended with Ethical and Demographical factors resulting in a STEEPLED-analysis.

For the construction industry, PESTLE-analysis has recently been performed in the "Construction blueprint project" (2), analysing the building industry. In this project, a PEST-analysis was performed for the narrower scope of monitoring and maintenance of bridges and tunnels. In general, a PEST-analysis may include both positive and negative factors, however, in this project focus was put on the negative barriers.

The PEST(EL) analysis are often a mix of "hard facts" combined with more subjective analyses (or opinions) 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 report an attempt to identify the most important barriers have been made. In addition, to overcome the concerns with subjectiveness of a PEST-analysis, inputs have been collected from a wide range of sources. Workshops with the CoP has been arranged and expert evaluations from these workshops has been integrated into this report.

As the European countries have different political, economic and social situations, we have started on national level to perform PEST-analyses for selected individual countries and then attempted to aggregate the barriers that could be common at European level. The technical barriers are to a larger extent common, but they may also vary due to different climatic and historic conditions among the countries. The barriers are often linked together, and it could be difficult to determine the most relevant category and it could easily be argued that a barrier placed under the Political section should belong to the social factors. However, this is less important for the total analysis.

The pest analyses has been focused on the past/present in the main section for each barrier with a special focus on the future in a sub-section.

In this work we have not only tried to identify the PEST-barriers but also provided suggestions for possible ways to overcome or reduce the negative effect of these PEST-barriers.

The "lessons learned" has been collected from internet search and information gathered from partners in the project. Often failures or accident have complicated causes and it is not often clear what were the dominating factors leading to the failure. In this work we have looked for failures where lack of monitoring or wrong or missing maintenance were identified as main contributing factors.

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2 PEST analyses of barriers for harmonised standards adequate monitoring, safe operation and optimal maintenance transport infrastructure

2.1 Introduction

Even if the European Union has a harmonizing effect, there are still considerably large differences from country to country when it comes to barriers against monitoring and maintenance of transport infrastructure.

A common problem for most countries is that significant parts of the infrastructures are getting old, and that age related problems are becoming more important.

The ageing effect makes it necessary to increase maintenance budgets, but also to have more frequent monitoring to track the state of each object and to have reliable systems for asset management and prioritization of the maintenance efforts.

On the positive side, recent development of digital sensoring and inspection methods together with software systems for asset management makes it possible to do this much more efficient.

National PEST analyses are found in Chapter 8. In this chapter we have tried to show barriers on European level based on the national analyses. Obviously not all countries in Europe has been included, but a wide range covering geographic, size and economic differences has been included. The national PEST analyses has been backed with references, but these are not repeated in chapter 2.

2.2 Political factors

Construction and maintenance of transport infrastructure was, currently is, and will be in the future, a duty of governments or authorities. It results directly from the nature of the road network being public service offered to the citizens. Decisions of satisfying infrastructure needs are presented as objective and dispassionate, based only on technical and social requirements. In truth, infrastructure is repeatedly the physical manifestation of political power. 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.
The overall aim for the traffic infrastructure is usually set by the government in national transport plans and typically defined as an efficient, environmentally friendly, and safe transportation system, or similar.

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. However, there are many political barriers that may hinder these high-level strategies to be implemented and appropriately funded.

2.2.1 Political involvment

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.

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 ffor decisions at detailed

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level, i.e., at project level, the political opinions should to a higher extent be replaced by technical competence. Kemmerling and Stephan (3) concluded that political factors (swing voters and incumbency, congruence) affect regional allocation of transport infrastructure.

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 investment 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 (4). On the other hand, renovating a long-serving facility may go unnoticed. Even though the environmental awareness among voters is rising, there may be still more appealing the goal to launch new spectacular projects than to invest in the lifetime of an existing bridge or tunnel.

An example of an ideological influence is the political engagement to resist to urbanization trend. It has long been a priority for many political parties in Europe to support rural areas and small villages to avoid densification of the population to the largest cities. This has led to investment in infrastructure like bridges to islands with small populations, even if socio-economic cost-benefit analyses show that the return of investment was very low. This approach may be societally beneficial but may also be in conflict with the optimal allocation of national resources that could be re-destinated to intervene on existing structures rather than in building new ones.

2.2.1.1 Future situation

There is no indication that political involvement will change significantly in the near future. Since people and industry value mobility high the politicians will find this area interesting to influence and gather support from the public.

Trend is considered to be: ***small*** *changes*.

2.2.2 Local, regional and national organisations

Public transport infrastructure is often owned by several local, regional and national organizations 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.

2.2.2.1 Future situation

For many purposes it is useful for the public administration to be organized in at least three levels (local, regional and national). This means that all of these three levels will most likely continue to own and be responsible for maintaining infrastructure objects.

Trend is considered to be: small changes

2.2.3 Unclear jurisdiction over the asset

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 parceled 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.

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2.2.3.1 Future situation
Even if new construction come with a wide variety of future maintenance contracts it is believed that the jurisdiction is more clear. As older objects gets clarification this barrier should be less problematic.

Trend is considered to be: Likely to improve

2.2.4 Political changes

Elections are held regularly in EU member states as they are democratic countries, and . Each time an election may mean a change in the structure of the ruling political forces which could lead to lack of a continuation plans. Quite often there is a political change with new political parties taking over responsibility that could change all the previous plans without giving continuity, affecting, among others, the infrastructure plans that need to be more medium and long-term plans. Also keeping the plans with lack of funding allocation from a new government may lead to cease realization of multi-annual infrastructural programmes.

This could lead to sub-optimal prioritization, but this is still a key aspect of the democratic system. The politicians that are elected by the people can change the plans that were previously decided.

2.2.4.1 Future situation
Politics seems to go in waves, if one party has been governing for a while they seem to lose some of the favor of the voters and bring in a change with the next election.

Trend is considered to be: Continue as it is

2.2.5 Transparency

Transparency in decision making is needed and those responsible are asked to be accountable. Asset management is meant to take informed decisions related to the targeted performance. IM-SAFE aims to support the development for standards that lead to qualitatively high-level informed decision making.

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 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.

2.2.5.1 Future situation
Many European countries and the European Union has long been working towards improved transparency in public organizations including transport infrastructure owners. Even if the information still could be difficult to digest for the common person improved transparency would be beneficial.

Trend is considered to be: Positive change

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2.2.6 Laws and regulations

Current technical regulations in EU members states do not impose any obligation to use monitoring systems as part of infrastructure maintenance. Moreover, even in case of voluntary use of a Structural Health Monitoring (SHM)), it is not legally possible to reduce the frequency or scope of bridge or tunnel inspections currently in practice. (5) Thus, all installed SHM-systems to some extent duplicate the tests performed during the inspection. This ensures greater efficiency in detecting possible defects, but for road agencies it means higher costs. From the legal point of view, monitoring is not appreciated or promoted in any way.

Lack of precise laws, regulations, and standards put a lot of pressure on the individual engineer that are to make decision on difficult problems that have large impact on regional economy and safety for the users of transport infrastructure.

2.2.6.1 Future situation

Several organisations at European and national levels are working to harmonize standards, laws and regulations for maintenance of transport infrastructure. Even it this is a slow process it is expected that the situation will gradually improve.

Trend is evaluated to be: Slightly positive trend.

2.3 Economic factors

2.3.1 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 labor was quite different from today's situation. This means that solutions that had low investment cost were favored 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.

2.3.1.1 Future situation

Obviously the negative economic consequences of the aging infrastructure is going to be large and it would be necessary to increase the budget for monitoring and maintenance just to keep up with the increased number of old objects in the system.

Trend is considered to be: Increase in budget is likely to be too small compared to needs

2.3.2 Limited budget creates maintanance 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 back-log in maintenance have accumulated to €100-110 billion to bring the national road infrastructure up to today's standard (6). 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,

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even after the 2008 crisis was over, the European investment in transport infrastructures has remained low, until 2020. (7)

The new 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.

In recent years there has been a growing awareness of the need for the use of continuous monitoring systems for safety management of assets. Nevertheless, the monitoring spreading is currently limited to structures that are strategic within the infrastructure network, as monitoring is still a complex and at times costly activity. This leads to a lack of information on the health state of asset of less relevance in the transport system.

Additionally, private operators in charge of the management of roads and infrastructures sometimes inherit assets from previous organizations and often are forced to face widespread structural performance issues within the limited available budget; as such, a prioritization of interventions on the structures of the same road network, that share very similar traffic and environmental conditions, has to be made in order to optimize the resources usage. Generally, private operators have higher possibilities to invest in roadway assets assistance and a faster application of maintenance plans is obtained if compared to the public sector; at regional level, road infrastructures maintenance and new construction sites are delegated to public companies, for whom is more complicated operating in short time, as tender procedures are often fragmented and time consuming.

Local municipalities strategies may favor current needs rather than investments on ordinary maintenance of infrastructures (with postponed benefits).

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 (section 8.8.2)

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.

2.3.2.1 Future situation

To keep the European infrastructure at current level and possible to fix some of the back-log will require a large effort. Even if the total life cycle cost could be reduced by increasing the condition it is not given that the budgets will be available. Public infrastructure owners see varying budget levels and even if some extra money could be made available during economic recessions it is hard to keep up with the increased need.

Trend is evaluated to be: Continued problem

2.3.3 Short perspective in contract with private companies

The duration of a contract between private road operator and infrastructure owner may influence the perspective of the private company, that size the economic investments plan according to the time it has to be guarantor of the asset's safety and service performance.

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Some Public Private Partnerships (PPP) have set up long time contracts for private companies to build, operate and maintain public owned infrastructure that permit the private company to invest in long lasting solutions; these conditions stimulate private company actions more than contracts for building with a limited warranty period.

2.3.3.1 Future situation

This struggle in perspective between private interests and public infrastructure owners will continue and we will probably see different attempts to utilize the creativity to find innovative solutions more often found in private companies without losing the long term perspective that will secure the infrastructure users a good long term solution.

Trend is evaluated to be: Different contracts forms will be developed.

2.3.4 Long term contracts

Some maintenance is contracted in long term contracts that might be difficult to renegotiate and implement new ways of monitoring or maintaining infrastructure. If a district have a wide range of contracts type this might have a negative effect on the efficiency of the asset management.

2.3.4.1 Future situation

It is likely that a wider range of contracts will be tried (se also 2.3.3)

Trend is evaluated to be: Different contracts forms will be developed – problem will remain.

2.3.5 Value and cost is 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 widely known LCC methods, but such costs do not show in public budgets in the same way like costs of monitoring and maintenance. For this reason, costs for road users are 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.

Different national CoP meetings have underlined the potentially effective influence could have the raising awareness of operators in the proportional relationship between current costs and future benefits in relation to maintenance interventions: money invested on efficient maintenance and monitoring would lead to consistent savings in the future.

2.3.5.1 Future situation

This situation is likely to continue also in the future since. Road users and road owners (even if this in principle is the same people) will have different interests and this barrier is difficult to resolve.

Trend is evaluated to be: Likely to continue as it is

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2.3.6 Spendings on monitoring itself do not improve condition of the infrastructure

Both the costs of equipping road infrastructure facilities with structural monitoring systems, as well as the subsequent annual costs of their operation, contribute to the overall increase in the costs of maintenance of this infrastructure. At the same time, they do not improve the technical conditions of this infrastructure. It results directly from the barrier mentioned above in subchapter 2.2.6, that is not recognizing monitoring by technical regulations. In case of limited resources available the first costs to cut would be those of not obligatory items e.g. monitoring systems.

By installing Structural Health Monitoring (SHM) systems, we incur additional costs, counting on being able to avoid construction disasters in the future. Such extreme events may result in fatalities and certainly mean huge costs of removing the consequences of a failure and building new facilities. Should a catastrophe occur, it would be immediately clear to everyone that the costs associated with monitoring are incomparably small and fully justified. These are situations that we try to prevent at all costs and luckily, we rarely have the opportunity to find out.

2.3.6.1 Future situation

The cost of monitoring and the possibilities to utilize the date through modern data systems will be significantly improved in the coming years. This means the cost/benefit ratio will be much better and even if it will still be true that the infrastructure does not get better just from knowing the condition, better knowledge will give better decision and more benefit for the budget.

Trend is evaluated to be: Lower price for monitoring and better use of the data.

2.3.7 Knowledge of the real situation could be hard to handle when available budget is inadequate to support interventions

If the budget prevents large rehabilitation project it might be tempting to avoid inspections that will highlight severe problems related to the transport infrastructure. However, this strategy will be problematic from a moral (and also legal) point of view.

It will always be better to get the information on current structure status, also to have a chance to influence the budget direction.

2.3.7.1 Future situation

As transparency and possibility for better monitoring increases this strategy will be more difficult to take (if it still exists). The public will to a larger degree expect infrastructure owners to assess the situation even if budget situation not always allow for quick action when negative situations are discovered.

Trend is considered to be: This strategy will be smaller and hopefully disappear

2.3.8 Economic corruption

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 mondial 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.

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In a study from 2018 Fazekas and Tóth (8) 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*.

2.3.8.1 Future situation

Even if corruption in Europe is limited and several measures are taken at several levels to avoid it, it is not likely that we could completely eliminate the problem. Increased transparence and strict enforcement of the anti-corruption laws will continue to reduce the problem.

Trend is considered to be: The problem will be less important, but not disappear.

2.4 Social factors

2.4.1 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 is 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.

2.4.1.1 Future situation

The general populations risk awareness is not likely to change very much. There will be fluctuations between alarm when a major failure happens and calm when it has been a while since something happened close by.

Trend is evaluated to be: Remains constant with local fluctuations

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2.4.2 Education of specialistes 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.

2.4.2.1 Future situation

In spite of some variation 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 we need.

Trend is considered to be: Negative for traditional civil engineering, but positive for some other helpful areas.

2.4.3 Administrative decission making could be too slow

In many regions the final decision to close infrastructure in dangerous condition is not made directly by the technical expert making the inspection. Since the decision could have large economic consequences the decision to close is taken by local, regional or national authorities. Some examples has been seen where the bad condition was known, but the failure/disaster happened before the proper authorities could reach a decision to close the infrastructure.

The main reason for the delays are likely to be that the risk could not be identified in a good way – you might know the infrastructure is damaged, but much harder to assess how serious it is.

2.4.3.1 Future situation

Better tools for asset management and clear procedures to report potential dangerous condition could improve this situation to make it simpler to come to conclusions faster. Such clear procedures would pin the responsibility to persons and make it more difficult to delay the situation.

Trend is evaluated to be: Likely to improve

2.4.4 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 conduct an investigation to pick up lessons to avoid similar mistakes in the future. The case 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. (9)

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

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2.4.4.1 Future situation

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.

It is possibly to increase learnings from failures/mistakes and maybe the best way is to have independent commissions not involved in the legal side of the situation.

Trend is evaluated to be: Unclear

2.4.5 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. Some areas that need more attention are:

- Monitoring using advanced sensors/technologies
- Supervised and unsupervised data processing (machine learning, AI)
- Methods for performance prediction
- Correlation between data anomalies and structural damages

2.4.5.1 Future situation

With increased problems and increased budgets it would be likely to assume that also the research investments should increase. However, there is no direct link between how important a topic is and how much funding is available. It is necessary for infrastructure owners to influence on the budgets for research to be able to increase the effort.

Trend is considered to be: This probably will continue with too small funding.

2.4.6 Infrastructure project associated with economic decline

Could be representative of some national moods, the example of the Spanish economy, that was greatly affected by the 2007-2008 worldwide economic crisis, as the imbalances Spain had accumulated in the previous boom and growth phase made it particularly vulnerable to changes in macroeconomic and financial conditions or in the expectations of the continuation of this expansionary cycle. Therefore, infrastructure spending has a negative connotation in society, as it is associated to the construction crisis (2007-2011) and corruption. Taxpayer belief is that infrastructure spending is negative, and it can drive the country again to a crisis. Spanish taxpayer also thinks that all services related to infrastructure construction and maintenance are over dimensioned and there is no need to invest more money on them.

2.4.6.1 Future situation

It is likely that investment in infrastructure will be used in future economic crises since it is working quite well. It creates employment for people and the ripple effect has positive effects for the economy the society also gain the benefit from improved infrastructure. The negative association that infrastructure is just to keep people busy is a long-term barrier that could reduce recruitment and willingness for investment in normal situations.

Trend is evaluated to be: Investment in infrastructure in economic crises' will continue

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2.4.7 Conservative organisations

People and organizations are in general not very willing to change the way they perform their work and the infrastructure organisations are maybe more conservative than other industries (at least this is the general assumption). Even if it was not true that we are worse than other the resistance to abandon methods that have been working well for many years to something that has potential for improvement, but that are unfamiliar is a significant barrier.

2.4.7.1 Future situation

As the digitalisation of the society increases in all fields the resistance against these changes in the infrastructure industry are likely to be reduced. Successful implementation in some part of the industry or some region will make it less scary to make changes in own organization.

Trend is evaluated to be: Industry will become less conservative

2.5 Technological factors

2.5.1 Variable and harsh climatic conditions

Europe has several regions with relatively harsh climatic conditions that often require extra maintenance for infrastructures; for example frequent freeze-thaw cycles during the winter leads to damages, and bridges (or other concrete structures) in coastal areas are exposed to salt water and this factor could lead to chloride intrusion and corrosion of reinforcement, with high consequences in terms of structural performance.

The observed and predicted climatic changes are likely to cause new challenges to the infrastructure especially caused by increased intensity of rainfall. We have already seen cases of severe floodings in several places in Europe and this is likely to increase in the future as the goals to limit emission of greenhouse gasses seems more and more unachievable.

When floodings 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.

2.5.1.1 Future situation

The observed and predicted climatic changes are likely to cause new challenges to the infrastructure especially caused by increased intensity of rainfall. We have already seen cases of severe floodings in several places in Europe and this is likely to increase in the future as the goals to limit emission of greenhouse gasses seems more and more unachievable.

When floodings 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.

Trend is evaluated to be: Significant worsening of the climatic loads on the infrastructure from climate change

2.5.2 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.

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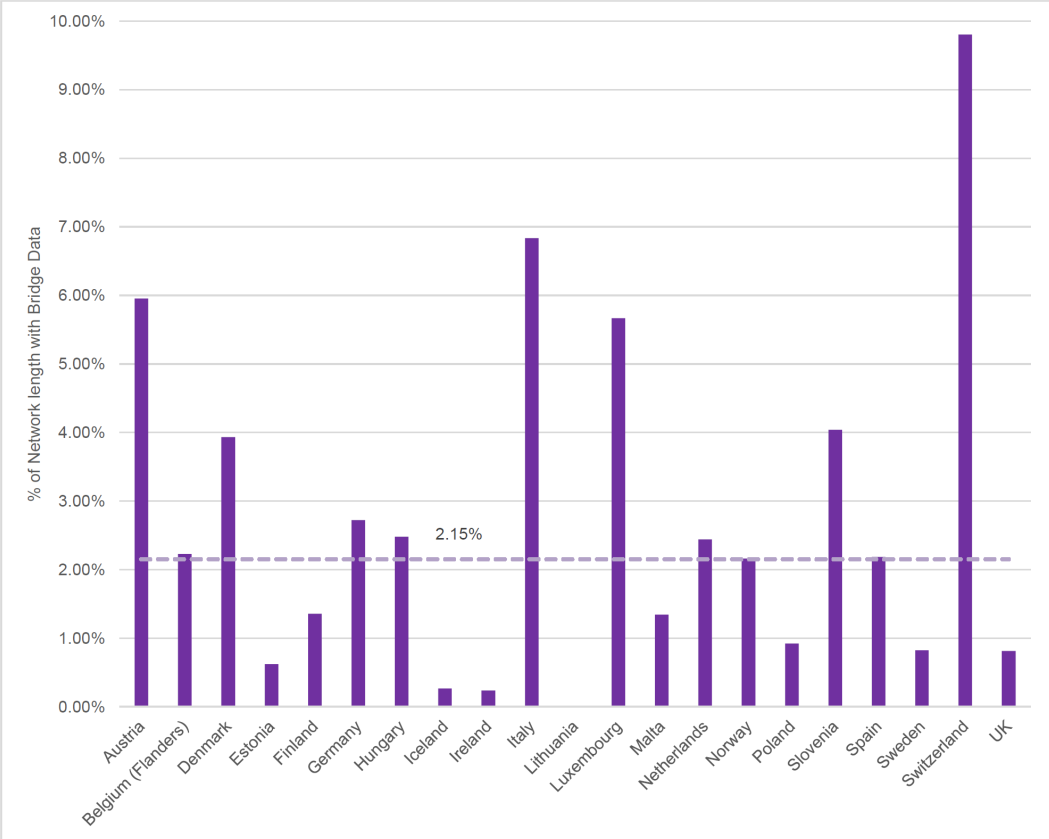

Figure 1 share of bridges as part of the total length of the road network (10)

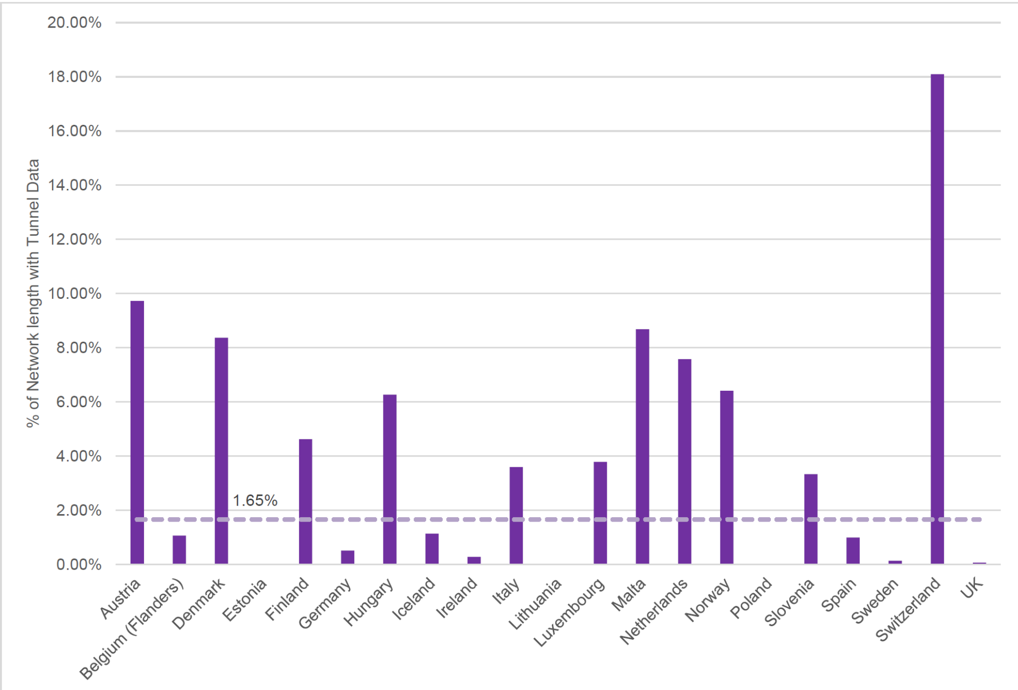

Figure 2 share of tunnels as part of the total length of the road network (10)

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A country like Switzerland have more than a quarter of the road network in tunnel or on a bridge. For Norway there are approx. 16,700 bridges on national and county roads and almost 6,000 bridges on municipal roads. There are well over 1100 road tunnels in Norway, with a total length of over 800 km. 73 of these road tunnels are over 3000 meters long and 33 Norwegian tunnels on the list of subsea.

Thus, the number of tunnels and bridges are quite high and 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.

Regions in Europe have to handle the consistent lack of information about existing infrastructures; one example is Italy, a country within mountains and hills, for which the bridges are essential features of the road infrastructure. There are about 16,000 bridges in the country, most of them over 50 years old. 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.

The big quantity of assets to manage, implies also the need to extend widespread monitoring system over to several assets on roadways; this could be achieved moving towards more and more optimized monitoring systems that combine economical limits, timing effectiveness and valuable outcomes.

2.5.2.1 Future situation

The number of infrastructure is likely to increase as new structures are build and fewer are taken out of use. However, modern digital system for asset management improves the possibility to keep track of objects and condition.

<u>Trend is evaluated to be: growth in number of objects but much better possibilities for systematic follow-up.</u>

2.5.3 Digitalisation

An increasingly important technical factor is the efficient use of digitalisation. It is seen as an enabling technology for new ways of monitoring and data processing to get more detailed insights about the structural health of bridges for better and more cost-efficient maintenance. There are several challenges related to digitalisation, also due to its novelty and short innovation cycles. Missing long-term experiences is a natural consequence, which not only leaves questions related to its correct and efficient application but also to its durability and maintenance effort in future. New approaches such as Digital Twins and Smart Buildings being developed based on digitalization and other enabling technologies are mainly implemented in pilot projects and not yet state-of the art even in new projects. For further, urgently needed standardization efforts a main challenge will be to find the right balance between fixed and agreed procedures and methodologies and the use of new solutions proposed by research and industry. Four main areas have been identified for dealing with digitalisation:

- Data acquisition
- Data processing
- Data management
- Data sharing

More information related to these areas are given in the following sections.
Data acquisition

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There are numerous techniques and devices for collecting monitoring data. Different types of sensors, 3D laser scanning and photogrammetry combined with drones and new communication protocols, power supplies and data storage devices shall be mentioned as examples. There are also questions related to data security, fault detection (or overall quality assurance) and privacy that must be considered when using these technologies. Main goal is to ensure that data acquisition is working as expected within the predicted lifespan of the monitoring equipment. Important questions are for instance how to select and install the right equipment, when and how to maintain it, and how to identify end of life stage or wrong measurements.

Data processing
New sensing technology can easily produce a massive amount of raw data that needs to be processed and translated into meaningful information to engineers and decision makers. This can be a highly complex process using different kinds of data analytics including big data solutions, artificial intelligence, and machine learning. A key competence will be to master these steps and to draw correct conclusions, which essentially means to combine plausible measurements with correct predictive models. Accordingly, proper representation of engineering models of all kinds is another prerequisite for efficient use of digitalisation. Solutions like BIM, Digital Twins and Smart Buildings are more and more adopted in practice but are typical limited to new buildings. Thus, a digital representation of the existing building stock will remain as another big challenge for broad use of new sensing technologies.

Data management
Persistent storage of measurement data is another challenge related to digitalisation. Not all data must be stored so that it is necessary to make a well-informed decision about relevant and irrelevant data. Not all data must be available to other users so that such data may not be published to others and can remain in proprietary data formats and storage devices. All other data needs to be managed in a transparent and secure way using a standardized user interface and/or API. Nowadays, such data must be web-enabled or cloud-based in order to be usable in a distributed environment. This adds additional complexity not only related to secure data access but also related to performance, availability, access-rights management, and data backup. Functionality of so-called Common Data Environments (CDE) are currently being standardized for typical project usage which however may not support all features for long-term storage as needed in asset management applications.

Data sharing
Seamless data exchange and sharing is one of the most urgent demands when working in a collaborative way. There have been noteworthy standardization efforts in various application areas providing open and standardized data formats for the industry. IFC, CityGML, INSPIRE and SAREF are examples for such efforts, which are accepted standards that cover a specific domain but, in many cases, need to be combined in order to cover all required data. It is not expected that a single standard will support all use cases so that co-existence and proper linking of existing standards will be a crucial functionality for overall success of Digital Twin concepts. Semantic linking and the use of rule sets for automatic linking are still topics for research and further standardization, while other decisions are currently done on a per project basis and in most cases depend on the used toolset. Main decisions include for instance: proprietary vs. open data formats, (file-based) data exchange vs. data sharing approaches, set-up of CDE and other databases providing a hybrid data storage that for instance differentiates between semantic BIM data, geometry, and time-series-based sensor data. Technical solutions need to be complemented by proper data delivery agreements, ideally being encoded not only in a human readably document but also in a checkable specification. Accordingly, data exchange and sharing are very much related to data management and

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project specific requirements. Today, proper configuration requires a lot of experiences, which not only depend on technical solutions but also the knowledge and skills of involved humans.

2.5.3.1 Future situation

The potential for utilizing new sensor technology is identified as one important trend in IM-SAFE deliverable D1.1 (11). Even if introduction of new Digital tools could be seen as a barrier (challenges by introducing new technology) it is also the most promising tool to improve monitoring and asset management.

Trend is evaluated to be: Will be much more important and will transform the way we monitor and manage the infrastructure.

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3 Stragegies to overcome or reduce negative impacts of identified PEST-barriers

3.1 Background

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 this project. This means we will focus more on what could be achieved with realistic efforts.

3.2 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 responsible for the conditions. Engineers faced with difficult choices could use the standards as tools to argue for better monitoring, sufficient budgets 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 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 results in better services and reduced cost for infrastructure owners.

3.3 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 people to climb the bridge towers.

Cheaper and more accurate information about the different object combined with standardization (section 3.2) 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 potential dangerous development in time to prevent catastrophic failures and save large amounts of money and users lives.

3.4 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.

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A good asset management system combined with standardization could be a good tool to avoid confusion caused by multiple infrastructure owners in a region (see section 2.2.2).

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4 Recent infrastructure failures and disasters in the EU and worldwide

4.1 Background

Infrastructure could "fail" in many ways, but in this context, we have looked at rapid failures of "falling down" type. The failures could also have a wide range of causes that leads to failure and quite often a combination of causes is found when the failures are analysed.

We have tried to limit the analyses to failures where lack of or improper maintenance or inspection is considered contributing factor to failure as it is possible to prevent this type of failures by using SHM systems.

This means that the following common failure-type is not included:
- Design errors
- Damages of support to water erosion, flooding or landslides
- Failures caused by fires, impact from vehicles or ships etc.
- Severe overloading

4.2 Summary of main failures in connection to maintenance, inspection, and structural failure (originated from lack of maintenance)

4.2.1 Bridges

4.2.1.1 Tordera River Bridge

In January 2020, the collapse of one of the piers of the bridge over the Tordera River caused by the sudden increase in the flow of the river due to the heavy rainfall accumulated in a few days, with amounts close to 200 liters / m2, was the main impact on the infrastructure railway in Catalonia due to the storm Gloria.

The rainfall associated with the storm Gloria caused a significant increase in the flow of the Tordera River, which reached values higher than 400 m3 / s, which caused the collapse of one of the fourteen piers of the bridge, 202 meters long and located two miles from the river mouth. This pile was carried away by the current along with the two openings that rested on it.

Once the damage has been analyzed and the best technical option has been evaluated, the solution adopted by Adif (the Spanish state-owned railway infrastructure manager) consisted of the construction of a new structure of 221.3 meters in length, divided into five spans with spans between 33.15 and 51 and 7.3 meters deck.

The lesson learnt is that because of not being prepared for such levels of water, a new bridge has been built. Among the details of the project that help to improve the security of the infrastructure is the alignment of the pillars with the other bridge that also fell because of the Gloria storm. The number of pillars has also been increased.

4.2.1.2 Reichs bridge

On August 1, 1976 the Reich bridge in Vienna fell almost on the full length into the river Danube. Due to water penetration into foundations of the pillars the north-eastern pylon first collapsed when the pier sheared off just below the bridge support. The second pylon was then swept away. The facility was regularly inspected but the collapse could not have been foreseen because the pillars were surrounded by massive granite blocks and no defects was visible. One car driver died. This failure made it necessary to build a new bridge.

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4.2.1.3 Inn bridge Kufstein.

The structure of the bridge consists of three separate parallel box girders. Two of the motorway are constructed as continuous beams over six supports i.e. five spans formed by continuous beams. The failure happened when erosion of the river bed caused sinking of a pier which supported the three girders. Each of the girders experienced deformations and support cross-section was rotated.
Later the girders ware lifted up and all other damage was repaired allowing bringing the bridge back to service.

4.2.1.4 Eastern Macedonia and Thrace district, Greece

One of three simple supported spans of precast prestressed concrete girders bridge, on the national highway, fallen down on 10 September 2017. The pillars made of reinforced concrete on shallow foundations in riverbed. Circumstances of the event are not fully investigated, there was no major storms before to flood the river and possibly explain inclination of one pillar. No injuries have been reported. Probable cause is the time evolving scour and poor inspection. There were no casualties or injuries.

4.2.1.5 Troja footbridge PragueCzech Republic

At 2 December 2017 a simple suspension concrete pedestrian bridge failed. Probably cause was corrosion or damage of the suspension cables, impossibility of their effective inspection, impact of 2002 flood supposed. 4 injured (2 heavily). Total collapse.
Diagnostic research in 2007–2009 and in 2016 assessed the condition as wrong but not emergency. The last expert opinion was finished three weeks before the collapse. Since 2014, the bridge motion was continuously monitored every 2 minutes. The monitored data from 1:16 pm indicated nothing extraordinary, at 1:18 pm, the bridge was collapsed already. A footbridge from an important Prague Park to the Prague Zoo over an arm of the Vltava river collapsed.[112][113]

4.2.1.6 Polcevera bridge, Italy

The viaduct had an overall length of 1102 m and consisted of 11 spans varying from 65 to 208 m between the piers.
It was a reinforced and prestressed concrete cable-stayed structure, with balanced trestles and pre-stressed concrete coated stays, with the main purpose of protecting them from atmospheric agents and to improve the behavior during service life.
The investigation campaigns carried out on the structure showed some deterioration of the structural elements and the engineering analysis confirmed the lacking in resilience due to the particular structural scheme.

After this event, the awareness of the need to protect the national infrastructure heritage with up-to-date inspection and monitoring techniques has grown.

4.2.1.7 Bridge between Castelo de Paiva and Penafiel, Portugal

This old steel truss bridge was opened to traffic in September 1888, and later undergone many rehabilitations e.g. widening the carriageway in the year 1959. On March 4, 2001, the bridge partially collapsed, causing a passenger bus to fall into the river. Total 70 fatalities were reported. The collapse of the bridge involved a pillar, and the two spans of the deck that rested on it. Due tu deterioration of the structure as well as washing of the foundations one of the pillars fell according to a rotation movement around the foundation base.

4.2.1.8 Arnvikbrua, Norway

The bridge over Arnvik river in Åfjord Norway collapsed due to a local flood situation in December 2016 with one person killed in the accident. Even if the direct cause of the accident

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is the flooding the bridge was identified to have been weakened by cracks and corrosion and was put on a list for extra inspection. It is likely that the condition have contributed to the failure. (12)

4.2.2 Tunnels

4.2.2.1 Obaga Negra tunnel

In August 2012 the repairing works began with a total budget of 3.9 million euros. The works consisted of reinforcing the lining of the tunnel, 792 meters long and 12 meters wide. The repairing works have made it possible to solve the pathologies that had been detected in recent years and thus improve the resistance of the tunnel and promote road safety.

As a consequence of the type and disposition of the ground strata and the heavy rains that have taken place in the recent years, the Obaga Negra tunnel on the C-14 presented various pathologies in its lining. After monitoring this situation and carrying out specific repair works, the works done have made it possible to globally resolve the problems detected, improving the resistance of the infrastructure.

4.2.2.2 Hanekleiva tunnel – Norway

In the evening 25 December 2006 parts of the roof of the 10-year-old Hanekleiva tunnel caved inn. Due to the time, it was minimal traffic and no injured persons. However, the tunnel was closed for a long time to repair. The cause of the failure was a weakness zone that was known during construction but underestimated. The following investigation pointed at several problems for this particular tunnel, but some of the weaknesses were common for most tunnels built at the time:

Drawings and as-build documentation were not properly taken care of, and important knowledge was not transferred to the organization responsible for operation and maintenance.

Procedures for inspection and follow-up was not made.

The tunnel was built with very limited access to facilitate inspection. Frost/moisture protection linings without openings so you could inspect the rock surface behind.

After the accident it was put much more focus on these problems and the design guidelines and requirements to documentation and knowledge transfer was increased.

The failure was investigated by an expert commission (13)

4.2.2.3 Fire in Kaprun railway:

Fire disaster on the Kaprun 2 glacier railway 155 people died on November 11, 2000 in a fire in a train on the Kaprun 2 glacier railway in the tunnel. It was the biggest catastrophe that occurred in Austria since the Second World War.

According to the investigations of the public prosecutor's office, the accident was triggered by a subsequently installed fan heater, which set fire to a leaky brake line installed immediately next to it. The court countered that there was a design and material defect because the so-called heater star came loose and the rear wall of the device caught fire - the housing was therefore not "intrinsically safe", as the experts put it. The court followed the appraisers' assessment that the fire would have spread even without the adjacent brake line.

After the accident it was put much more focus on these problems and the design guidelines and requirements to documentation and knowledge transfer was increased.

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5 Set of recommendations for prioritization of risk management areas

Since so few maintenance related failures were found it is not possible to make recommendations with great confidence based on these analyses. It might have been possible to gather more precise knowledge from analyses of cases where severe damages were discovered before failure or in situation without failure but excessive expensive maintenance.

However, the following more general recommendations could be made for areas to look closer at:

- Undetected negative material development (e.g., corrosion is a significant risk factor.
- Climatic change causing the climatic load to be higher than design values.
- Identified problems could be underestimated and not closely monitored.
- Loss of continuity in maintenance administration

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6 Conclusions

6.1 Summary of the PEST analyses across Europe

Several barriers have been identified that could make it more difficult to obtain a good level of monitoring and maintenance of transport infrastructure in Europe. Of the political, economic, and societal barriers the most damaging is inadequate funding in several countries.

Increased loading for the infrastructure future climatic conditions in form of more precipitation causing floods, landslides etc and the increased traffic volume and loading is the most severe challenge for the infrastructure. Combined with aging objects that might not be designed for the current situation it is necessary to increase quality of monitoring and maintenance significantly

For the technical barriers the volume of objects is a major challenge. Standardized methods for surveying, monitoring and analysing would make it easier for engineers to prioritize maintenance budgets to get optimal asset management and safe and reliable infrastructure for the public.

With the increased demand the society will also face an economical challenge to increase the budgets for maintenance. This will require a change in priorities that goes in a little different direction that has been political prioritisation with somewhat stronger focus on new projects/structures.

6.2 Lessons learned

Fortunately, disastrous failures of transport infrastructure are rather rare and often have multiple causes. A few failures have been identified where lack of inspection or maintenance has been identified as a major contributing factor. A barrier against learning is that the focus of the investigations are on the legal issues and less about what could be learned to avoid future problems (se also barrier description in section 2.4.4)

This makes it difficult to identify "lessons" that can be generalize from the few cases. However, a few cases were found were lack maintenance focus in the planning and construction phase led to problems later on.

In some cases lack of knowledge transfer from the construction organisation to the maintenance organisation have led to failures. This was the case for the Hanakleiva tunnel (section 4.2.2.2) where the weak rock zone was known during construction, but not followed up in the maintenance phase leading to failure ca 10 years after opening.

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Appendix A - PEST analyses from individual countries

A.1 Draft PEST analysis and lessons learned from recent failures. *Norway*

A.1.1 Political barriers

The overall aim for the traffic infrastructure is set by the government (as part of the national transport plan (14)) as an efficient, environmentally friendly, and safe transportation system. In that plan, it is acknowledged that maintenance should be prioritized to take care of the publicly owned assets. However, there are many political barriers that may hinder this high-level strategy to be implemented.

In Norway the politicians are involved at quite detailed level for economical investment in new infrastructure construction, but also for rehabilitation interventions on existing ones. This involvement has the aim to ensure democratic influence on important strategic decisions at the national level. However, political short-term goals and political trades could also have the opposite outcomes and to lead to sub-optimal solutions (15) (e.g., prioritization of home regions for influential politicians).

It is also a risk that investment in new projects could be prioritized over maintenance on existing assets. Often the overall perceived trend is that the political campaigns seem to be more appealing for electors by sponsoring new spectacular projects than ensuring more years of lifetime to an existing bridge or tunnel (16).

One example, that has generated during past years several discussions on it, is the construction of the new railway line connecting the town Tromsø and the northern part of Norway to the existing rail network at Fauske. This project has been re-proposed at every election year for decades, but it is a too onerous national effort to proceed and the population is too small to effectively invest on it.

It has long been a priority for most political parties in Norway to support small villages and population centers to avoid densification of the population only to the largest cities. This has led to investment in infrastructure like bridges to islands with small populations, even if socio-economic cost-benefit analyses show that the return of investment is very low. The cost for maintenance is to less degree included in this prioritization.

Public transport infrastructure is owned by several organizations in Norway. This condition could make difficult to coordinate different institutions to be able to monitor and manage maintenance with a common approach. Moreover, recently a large part of the infrastructure assets was moved from the national level to the county level, and it will take some time for the new owners to get up to speed with effective inspection and maintenance plans.

A.1.2 Economical

A lot of Norway's infrastructures was designed and built following guidelines that were developed when the national economy and cost for maintenance labor was quite different from today's situation. This means that solutions that had low investment cost were favored over solutions with increased service life. In today's situation this gives high maintenance costs.

Even if the economic situation in Norway today is very good, there are large regions with relatively small population with small budget for maintenance available. Over several years the back-lag in maintenance have accumulated to €100-110 billion to bring the national road infrastructure up to today's standard, according to the report State of the nation – Norges

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tilstand 2021 ((6) RIF, 2021). Even if the number has a high uncertainty, it is a useful tool to communicate the consequences of the budgets used over time.

At local level, the budget available for infrastructure maintenance varies a lot between the municipalities depending on the local economy. This area is in direct competition for the same money that could go to care for the elderly, better quality teaching at schools and kindergartens. Since deterioration of infrastructure often develop slowly it is often tempting to push these expenses and focus on more pressing needs.

Related to existing infrastructures interventions field, the mention to the procurement chain is needed because it is most of the time preferred the low price rather than the quality of components; recently it has become relevant and integrated in the selection criteria also the low emission of CO2.

A.1.3 Social barriers

The Norwegian 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 including accepting lower speed limits than in many other European countries. Norway adopted its version of Vision Zero (“Zero deaths and serious injuries”) first for road traffic safety and later for all transport related activities in 1999 (17).

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.

The education of engineers and skilled workers is not in balance with the current need, several of public organizations struggle to find qualified people (18).

A.1.4 Technical barriers

Norway has relatively harsh climatic conditions that often require extra maintenance. Especially the frequent freeze-thaw cycles during the winter leads to damages. Bridges and other concrete structures in coastal areas are exposed to salt water could lead to chloride intrusion and corrosion of reinforcement. (19)

In total, there are approx. 16,700 bridges on national and county roads and almost 6,000 bridges on municipal roads. With some exceptions, most of the longest bridges in the country have been built since 1970. There are well over 1100 road tunnels in Norway (March 2018), with a total length of over 800 km. 73 of these road tunnels are over 3000 meters long and 33 Norwegian tunnels on the list of subsea. Thus, the number of tunnels and bridges are quite high and make it difficult to keep a good control about the condition and to optimize the maintenance effort.

Another Technical limit is the lack of reliable predictive models to be able to act in advance when an asset reaches a critical state.

Finally, separate sectors of the same organization are responsible for the construction and maintenance of infrastructures. This separation is reflected in the fact that often the maintenance will not be in focus during design and construction phases and examples of non-optimized choices are very common (20).

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A.2 PEST analysis and lessons learned from recent failures. *Spain*

Infrastructure in Spain is aging. By 2030, more than half of the assets will be over 20 years old and, without appropriate maintenance strategies, there will be a loss of around 60% of the capacity to generate service. The sustainability of transport services is threatened by 2030, if investment in transport infrastructure remains at 2020 levels. If the situation continues, the percentage of assets with at least ten years old will exceed 80% in 2030 and, more than half (56.7%), will be 20 or more years old.

A.2.1 Political barriers

The entry of Spain into the European Economic Community in 1986 led to a change of direction in public policies to converge with Europe. These new trends included increased investment in infrastructure and improved connections. Unfortunately, once the 2008 crisis was over, investment in transport infrastructure has remained low until 2020.

Although 2021 Budget has a social focus against COVID-19, the new 2021 budget for infrastructure has increased and includes now a Recovery and Resilience Mechanism. Investments in the trans-European transport network are included for the final development of important sections, both in the Atlantic and the Mediterranean corridor. In the plan, the following is included:

"*Digitization: It is necessary to have adequate systems for existing technological advances that allow improving the management of road assets, detecting the needs for its conservation and improvement, preferably with a preventive versus corrective nature, and optimizing the resources available at all times.* "

However, it is not specified if maintenance and monitoring activities will increase and with what budget and whether the construction of new roads and railway lines will be prioritized.

In addition, in Spain a political instability has been taking place in this century that means that there are no continuation plans. Every 4 years there is a political change that changes all the previous plans without giving continuity, affecting, among others, the infrastructure plans that need to be more medium and long-term plans. The government prepares plans, which have a time horizon of more than 4 years, but after those 4 years when the government partners and the parties that are in government change, instead of continuing those plans or making small modifications to them, they stop them or completely change them. In this way, there is no continuity and medium-long-term strategies are not effective.

A.2.2 Economic barriers

Gross investment in infrastructure has been below 50% of 2000-2009 levels for the last decade. It is a rhythm that does not guarantee the maintenance of the existing stock, causing its reduction and aging in the different means of transport.

Spain, being the country with the largest high-speed rail network after China, is the country with the least intensive use of it. The demand has been lower than expected and the necessary budget to maintain it, higher. The cost benefit analysis of the network indicates that the socioeconomic returns are very low, if any. Therefore, taxes are being used to cover maintenance and operation budgets. If there is a change in the maintenance strategy (from a corrective and preventive maintenance strategy, towards a predictive maintenance), it would require a higher investment in the short-term but a lower one during operation as the maintenance activities would be optimized to the required ones to keep the asset in the best possible shape. This investment will take place along with the current plan to expand the

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network towards a more radial model, which would mean reaching approximately 50% more kilometers of track than what currently is built.

A.2.3 Social barriers

The Spanish economy was greatly affected by the 2007-2008 worldwide economic crisis, as the imbalances Spain had accumulated in the previous boom and growth phase made it particularly vulnerable to changes in macroeconomic and financial conditions or in the expectations of the continuation of this expansionary cycle. Therefore, infrastructure spending has a negative connotation in Spanish society, as it is associated to the construction crisis (2007-2011) and corruption. Spanish taxpayer belief is that infrastructure spending is negative, and it can drive the country again to a crisis. Spanish taxpayer also thinks that all services related to infrastructure construction and maintenance are over dimensioned and there is no need to invest more money on them.

Besides, the current corrective/preventive approach is well known to adequate dimension maintenance contracts. 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.

A.2.4 Technical barriers

Of all fears, one of the most basic is the fear of not having control of things, or the fear of losing it. The best way to achieve this desired control is by understanding the principles of operation. The industry sector is changing, it is immersed in the fourth industrial revolution, better known as Industry 4.0. In this stage, companies have to adapt quickly to the many changes required by the market, technology and regulations that apply.

However, the construction sector, although willing to change, is doing it very slowly. Infrastructure owners are reluctant to apply methodologies and concepts that have not been previously validated and demonstrated in real scenarios. The paradox is that there is a lack of real-life scenarios devoted to testing of new concepts in Spain. And if no real-life testing is possible, if there is a lack of places for testing and deployment of new maintenance concepts, it makes it very difficult to implement new methodologies, concepts or technologies. Besides, the use of new technologies and methodologies implies a high initial investment that there is reluctancy to be assumed.

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A.3 PEST analysis and lessons learned from recent failures. *The Netherlands*

A.3.1 Politics

The aims of an aware and effective involvement of political System should consider the following:

- Transparency in decision making is needed.
- The politicians responsible are asked to be accountable.
- Asset management is meant to take informed decisions related to the targeted performance. -

Some of the main gaps in this direction could be:
Transparency also means being open to criticism. (21)

Decision makers need to decide even with lack of information and existing uncertainties and have to make (sometimes less popular) choices.

The public, knowing the unknown, can make politicians vulnerable to criticism.
It would be very difficult to get all information structured and transparent (and even then, decisions will be disputable).

Maintenance, especially Renovation and Replacement applied on existing infrastructures, is a long-term investment. In politics system a long term and increasing budget reservation is necessary to let the System able to maintain the network / single constructions on a performant service life.

The constructions are old, and the load is increasing in time and this condition causes a growing need to replace structures; this need is not always clear for politicians nor for the civilians; so that clear and undoubtful information is needed to keep the budget in line with the needs. (22)

One snag in the plan could be that the benefits of keeping the road network with an excellent performance are not directly linked to governmental bodies: no income can be expected. Also most of the indirect costs of network problems (e.g. queues) will not be carried by the governmental bodies responsible for the infrastructure; they will be felt as a problem for road users.

In railway infrastructure a more direct cost benefit relation has been established, and this seems to be working better. (23)

Asset managers are often part of small(er) governmental bodies (municipalities) and the number of structures managed by these organizations is a large part of the national asset portfolio. Interest in and importance of the structures in these organizations is very dependent on the local political circumstances. (24)

A.3.2 Economical

The cost to engage a technical specialist to make a Safety Assessment of a structure is generally high and it has no immediate outcomes on improving the structural behavior itself.
To spend money without an urge can hardly be explained. Investments in assessment of constructions are urgent mostly when it is too late for the structure: when a construction is already in a bad shape. The costs, that can be saved by keeping the knowledge about the state of the assets up to date, can only theoretically been shown.

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Until now most of the constructions have been healthy without paying much attention. Due to the changing conditions, aging constructions plus higher loads, much more attention and much more money are needed to keep them healthy.

The governmental economical system is not designed as it is in industry: value of the assets and / or depreciation is not an issue in governmental accountancy. As a consequence repair, renovation and renewal is seen as spending money on an existing asset, without any expression of increased value in the accountancy. Also knowledge about the state of the assets cannot be accounted and inspections and monitoring cannot be demonstrated as a useful investment in infrastructure. (23)

A.3.3 Social

Changing the good practice of several decades is hard to achieve. Employees are not necessarily happy with such a change and not necessarily capable of this change.

New young employees do not yet have the seniority to be trusted in a new way of working.

Lack of well-educated and well-trained technical personnel is apparent. This affects the quality of information and the quality of the network; also this impacts the implementation of new ways of working, often make worse because of work pressure. (25)

Asset managers are often part of small(er) governmental bodies (municipalities). Finding suitable personnel is difficult for these organizations. Suitable personnel often prefer to work in organizations with more challenging work in order to develop themselves. Successful employees are offered jobs in engineering companies and / or larger governmental bodies with another (better) job perspective.

The expectations on the infrastructure performance is commonly high and their availability and functioning are taken as granted. Social costs of down-time (partly unavailable infrastructure), are high. Time to inspect and monitor structures is hard to find and down-time not appreciated by public. Although, on the long run, optimal inspection, monitoring and maintenance strategies can save down-time and money. (26)

A.3.4 Technical

Current processes, rules and regulations are not designed for long term optimal maintenance decision making.

Use (analysis) of monitoring and inspection data is still difficult because of a lack of uniformity. Past data is hardly useful for trend analysis, etc.

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A.4 Draft PEST analysis and lessons learned from recent failures. *Austria*

A.4.1 Political barriers

As outlined in the PEST analysis of Norway, the government defines the overall goal for the transport infrastructure to be an efficient, environmentally friendly and safe transport system. Maintenance has a very high priority in this plan in order to preserve public resources. As in the other countries, there are many possible political obstacles to the implementation of these objectives.

In Austria, as in other countries, both Austrian politics and environmental organisations (see Lobautunnel in Vienna) are involved at a very deep level when it comes to investments in new infrastructures, but also to a certain extent in renovation. On the one hand, this ensures democratic influence on important decisions, but on the other hand, it very often delays important eco-social decisions. As in other economies, short-term political goals and political trade prevail, leading to suboptimal solutions, e.g. prioritizing home regions for politicians with influence.

The dynamics of decision-making in engineering practice is more complex than usually addressed in research. In practice, decisions involve multiple factors and are highly dominated by non-technical components. For example, decisions regarding maintenance depend on legal requirements, budget availability, or logistics of interventions, among others. They are also conditioned by the incentives of decision-makers, or the interest of stakeholders, which are difficult to quantify. Frequently decisions respond to the project circumstances at a particular point in time. More work is required to get research closer to the actual need in engineering practice.

A.4.2 Economical

There is a wide range of decisions in infrastructure management, which depend on the level at which they are made within the organization. Technicians, engineers, and upper management officials make decisions with different aims, restrictions, and levels of responsibility. Therefore, they need different types and amounts of information, as evidence to support their decisions. Still most engineering research falls short in identifying these needs and developing models that provide the suitable evidence. (27) (28)

Infrastructure development has a significant impact on the environment and the socioeconomic development. (29) There are many research initiatives directed towards dealing with the consequences of the built environment on climate change and sustainability. They focus mostly on reducing the impact on CO2 emissions (and their effect on global warming) and the rational use of natural resources. However, there is still a large gap between research and practice that does not facilitate the industry to move quicker to a sustainable business model. Small profit margins, insufficient incentives for innovation and slow technological changes go against the implementation of creative engineering solutions in practice.

A.4.3 Social barriers

In Austria, great efforts are also being made to reduce the number of road accidents. In urban areas there is already a high level of acceptance for lower speed limits in motorway and open country areas this acceptance is even less pronounced.

As generally happens, risk awareness in the population is only strongly sharpened by the perception of very rare events, as is the case with the collapse of bridges and its consequences. Naturally, risk awareness decreases with the longevity of such events. A

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variety of investment predictive models that cannot be validated due to political periods, but also a variety of generic degradation predictive models that require very extensive on-site information and that have not yet been validated or have only been partially validated over the entire life cycle of a structure.

The acceptance of automated monitoring systems is very limited from a maintenance perspective and also in terms of accountability in a decision-making process.

Since the construction and maintenance of infrastructure assets are generally separated from each other, maintenance during the construction phase is not the focus, as it should be. This gap causes unnecessarily high maintenance costs in many cases.

In Austria, great efforts are also being made to reduce the number of road accidents. In urban areas there is already a high level of acceptance for lower speed limits in motorway and open country areas this acceptance is even less pronounced.

As generally happens, risk awareness in the population is only strongly sharpened by the perception of very rare events, as is the case with the collapse of bridges and its consequences. Naturally, risk awareness decreases with the longevity of such events.

A.4.4 Technical barriers

Austria has relatively harsh climatic conditions that often require extra maintenance. Especially the frequent chloride during the winter leads to damages. Bridges and other concrete structures in Alps are exposed to salt lead to chloride intrusion and corrosion of reinforcement.

In total, there are approx. 5,500 bridges on national and county roads and almost 3,000 bridges on municipal roads. There are well over 500 road tunnels in Austria (March 2018), with a total length of over 700 km. (30) Thus, the number of tunnels and bridges are quite high and make it difficult to keep a good control about the condition and to optimize the maintenance effort. (31)

With the advancement of data acquisition methods, nowadays the industry is capable of gathering large amounts of data at a low price. However, the capacity of the industry to process such data is quite limited. In particular the adaptation of data analytics methods and tools (software) is occurring at a slow pace. Furthermore, there are limitations in training of personnel in regards with data acquisition, data processing and data analysis. Although many research groups are working on modern methods and strategies to make the most out of data in infrastructure, there is still a way to go before these methods can permeate the industry.

Infrastructure maintenance and operation is a dynamic process that changes continuously through time. Recognizing the changing nature of infrastructure has led in the past to over costs and poor decisions. It is necessary to work closely with the industry in understanding these dynamics and develop models and tools that facilitate the decision process.

A variety of investment predictive models that cannot be validated due to political periods, but also a variety of generic degradation predictive models that require very extensive on-site information and that have not yet been validated or have only been partially validated over the entire life cycle of a structure.

The acceptance of atomized monitoring systems is very limited from a maintenance perspective and also in terms of accountability in a decision-making process.

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A.5 PEST analysis and lessons learned from recent failures. *Italy*

A.5.1 Political barriers

Currently there is a significant difference in monitoring capabilities between small local authorities and public/private big road operators in terms of available fundings to be allocated to the infrastructure maintenance.
Consequently, especially for local entities, the lack of sufficient fundings leads to a difference in terms of level of detail/effort in the monitoring and asset management procedures between different operators/owners.

Data collected by Tagliacarne Institute concur to confirm this trend: the infrastructure resources of Italian provinces in 2001 and 2015 respectively are represented in Figure 2 on the basis of ratio of supply indicator to demand indicator.

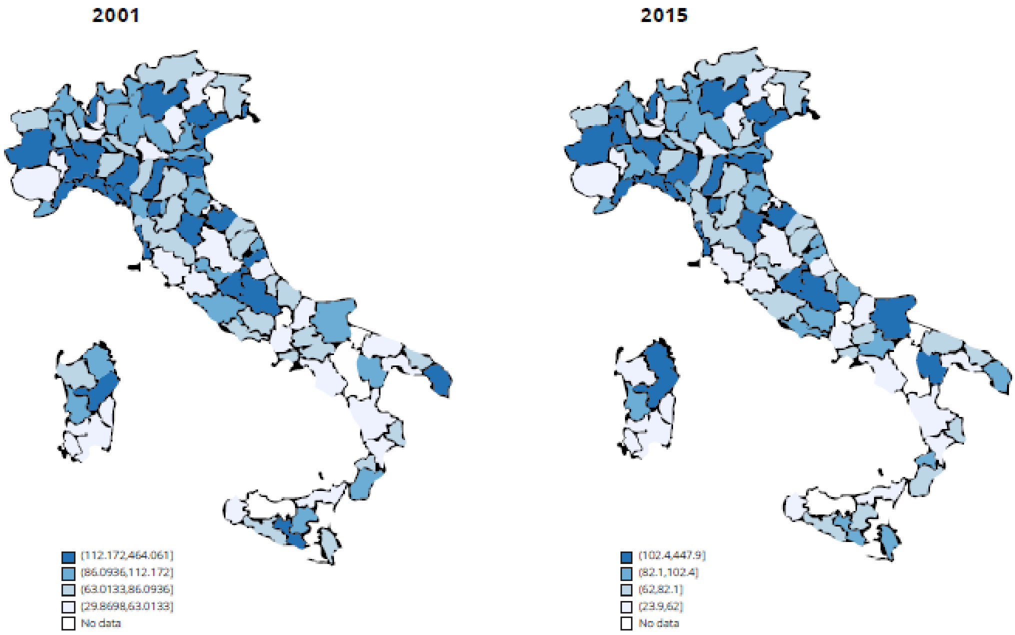

Figure 1: Infrastructure resources of Italian provinces in 2001 and 2015 (32)

The darker colored provinces are those with a higher value of the indicator: it can be noted that the condition is highly heterogeneous both in 2001 and 2015.
The different infrastructure resources within the territory of Italy is strongly correlated with the different degree of economic development of the territory development: there is significant heterogeneity between macro-areas of the country (North, Centre and South), which remains substantially unchanged nowadays.

Figure 3 shows a diagram of Italian regions measured along these two dimensions: the degree of economic development on the one hand and the Tagliacarne Institute's index of infrastructure on the other.

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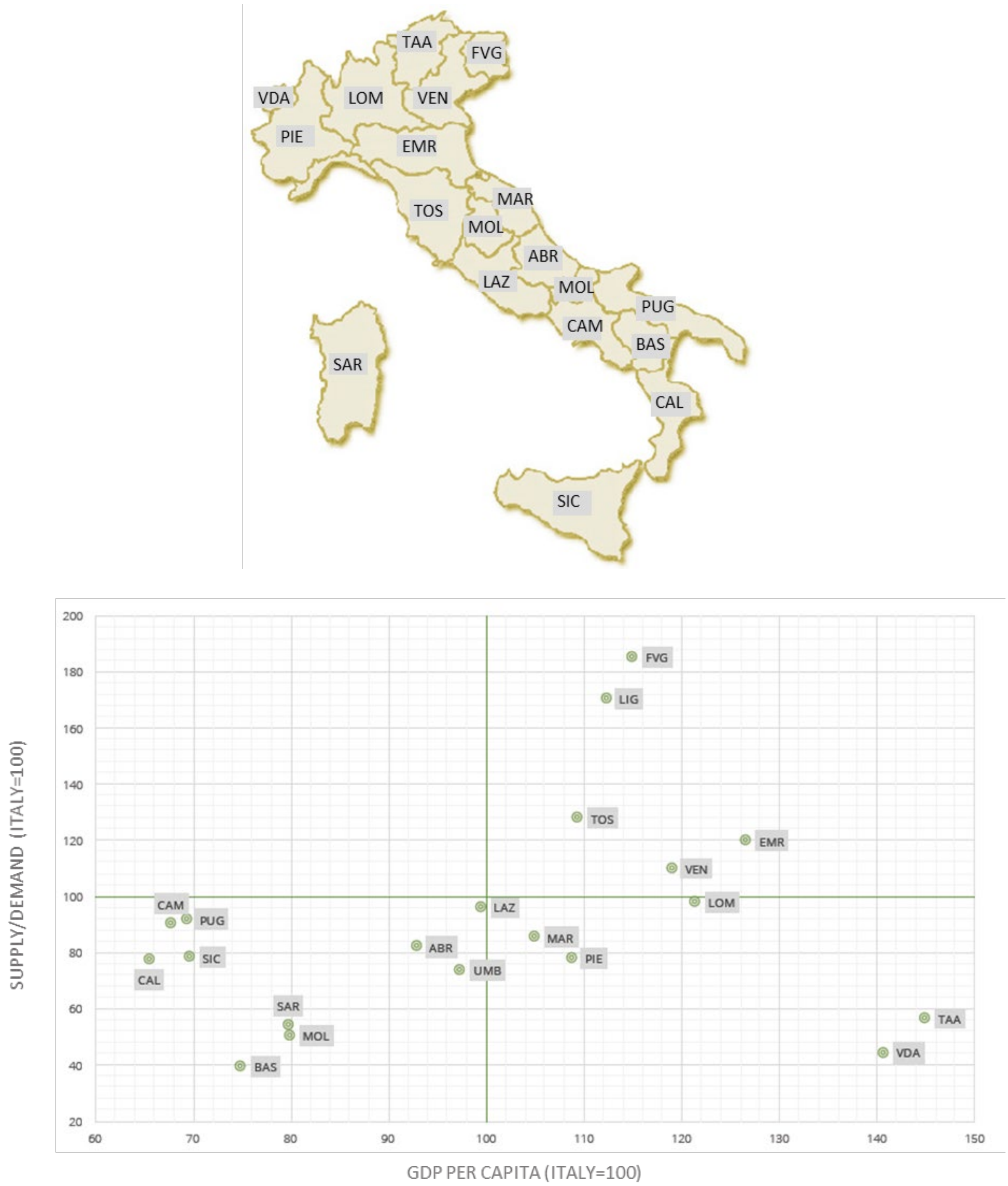

Figure 2: Degree of economic development and total infrastructure capacity (32)

The long-term perspectives needed for an effective interventions programs often have been in contrast with the uncertainties in decision policy that has affected Italy in past decades; the alternance of address in transport/infrastructure management has affected the effectiveness of the interventions plans.

A.5.2 Economical barriers

Italy is a country within mountains and hills, for which the bridges are essential features of the road infrastructure. There are about 200,000 bridges in the country, most of them over 50 years old. 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

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often causes a dispersion on management plan and delays in the maintenance program. Another issue is the unclear jurisdiction over the assets. In fact, in Italy there are almost 1500 bridges whose control is parceled 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.

Over the years, the entire process of planning and realization of strategic infrastructures, and in particular, the evaluation phase regarding the allocation of public economical resources, has shown limits (33). The main factors increasing the implementation times of infrastructure policies concern:
lack of planning: projects of insufficient quality and too expensive
funding uncertainty: uncertainty about availability of funds, need to find additional resources due to the increase in the costs of works and disputes during the awarding and execution of works;

Currently, in Italy each year between €3-4 billion are spent on upgrades and extraordinary maintenance and another €3-4 billion on ordinary maintenance (34). However, these investments are not enough to upgrade the existing road network, both in terms of safety and capacity, to better serve the population. In recent years there has been a growing awareness of the need for the use of continuous monitoring systems for safety management of assets. Nevertheless, the monitoring spreading is currently limited to structures that are strategic within the infrastructure network, as monitoring is still a complex and at times costly activity. This leads to a lack of information on the health state of asset of less relevance in the transport system.

Additionally, private operators in charge of the management of roads and infrastructures sometimes inherit assets from previous organizations and often are forced to face widespread structural performance issues within the limited available budget; as such, a prioritization of interventions on the structures of the same road network, that share very similar traffic and environmental conditions, has to be made in order to optimize the resources usage. Generally, private operators have higher possibilities to invest in roadway assets assistance and a faster application of maintenance plans is obtained if compared to the public sector; at regional level, road infrastructures maintenance and new construction sites are delegated to public companies, for whom is more complicated operating in short time, as tender procedures are often fragmented and time consuming.

A.5.3 Social barriers

Safety assessment has the aim to correctly identify the structural behavior and its status, and as such requires a detailed knowledge on the construction process and the successive structural modifications over time, as well as testing and monitoring information along the structure design life.

In most cases, though, there is lack of information regarding the structural health status and the necessity to guarantee the required structural reliability triggers the necessity to activate monitoring processes.

Due to the recent major failures happened along the national road network, Italian 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. (35)
The sequence of collapses of Italian road infrastructures has taken on a worrying trend for some years: in July 2014 a span of the Petrulla viaduct collapsed, on the state road 626 between Ravanusa and Licata (Agrigento, Sicilia), due to the crisis of the prestressing system;

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in October 2016, an overpass in Annone (Lecco, Lombardia) collapsed due to an exceptional load on structure, which, however, was very aged compared to its original capacity; in March 2017 an overpass of the Adriatic motorway collapsed, due to an accidental event during maintenance works; in April 2017 a span of the Fossano ring road (Cuneo, Piemonte) collapsed, in the absence of vehicles and in a manner very similar to those of the Petrulla viaduct.

The element in common to the events described is the (average) age: most of the Italian road infrastructures (road bridges) are over 50 years old, which corresponds to the working life associated with the reinforced concrete structures built with the technologies available after World War II (1950s and 1960s). (36)
Moreover tangible benefits of an efficient administration of the national roadway network is 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 technicians background, until later on in the decades.

A.5.4 Technical barriers

Structural Health Monitoring allows planning and implementation of structural safety management activities.

At the same time, management of monitoring systems requires the analysis of a large amount of data: the flow of data from installed SHM and investigation campaigns must be properly processed and interpreted. Currently, there is lack of technical competence to manage data by the asset owner/operator (37). Most of the operators that have started a large-scale monitoring program of their infrastructures have been collected big amount of data without being ready (with specializes teams) to interpretate it; the final outcome, often, is the impossibility to use this information to feed the structural assessment and a proactive maintenance plan (38).

The limited (and very recent) monitoring experience in Italy, sometime, leads the Road Operators/public expectations beyond the current technological limits and often this complicates the development of knowledge in this field; moreover, the need to extend activities (as maintenance) to prevent bad performance on a great number of assets implies to move towards more and more optimized monitoring systems that combine economical limits, timing effectiveness and valuable outcomes.

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A.6 PEST analysis. *Portugal*

There is a large territorial dispersion regarding bridges, tunnels and culverts, with different construction periods to refer, in Portugal. Hence, there is a wide variety of construction materials and even, the construction techniques used to build these infrastructures. The inventory, in terms of bridges and tunnels, shows the number of infrastructures to maintain and inspect:

- 5328 bridges and tunnels in highways
- 1820 bridges in rails.
- 79 tunnels in the roadways.

A.6.1 Political barriers

In terms of politics, politicians have a strong focus on new structures disregarding maintenance of existing structures. It directly affects the choice of the resources to carry out these tasks.
On the legal side, the lack of national or European standards that establish the need/protocol for inspection, diagnosis and maintenance is a barrier highly considered.

A.6.2 Economic barriers

The experiences of past crises reflect on the capacity to invest and maintain/hire human resources for the maintenance of structures. Usually, there are budget cuts, and not always proportionally in the maintenance area.

A.6.3 Social barriers

People usually increase requirements to the infrastructure (e.g. less closures or no traffic jams), and demand for risk-free strategies, but also have a lack of awareness of the need and costs of maintenance. Society usually tends to prioritize the need for new structures rather than for the maintenance needs.
Regarding the environment, although society is currently more concerned about climate change, there is no awareness that it also affects structures requiring new factors to take into account to increase the resilience.

A.6.4 Technical barriers

There is an increasing and rapid technological development in the maintenance area with the inclusion of new technologies such as: drones, satellites, BIM, etc. that requires a policy of continuous investment and for that investment in technology, it is necessary the awareness of the top management that can manage the resources to boost these initiatives.

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A.7 PEST analysis. *Poland*

A.7.1 Political barriers

Funds for infrastructure are allocated mainly to new investments and, to a lesser extent, to the maintenance of the already existing infrastructure. Such trend results from the fact that building and commissioning new infrastructure allows politicians to gain satisfaction among voters. As consequence not all infrastructure facilities are properly maintained.

A.7.2 Economic barriers

Insufficient funds for investments perceived as important but not urgent. Renovation of a road facility object that is not in danger of failure, is often postponed for the following (budget) year. While the construction of health monitoring installations of infrastructure facilities has to compete for funds with other more urgent social needs. Statistics show that in Poland existing facilities are rarely equipped with structural monitoring systems.

A.7.3 Social barriers

One important social barrier in dissemination of monitoring systems is balanced educational level. There are practically no Structural Health Monitoring (SHM) specialists on the Polish labor market. The challenge is to create curricula (personal development programmes) to educate in the field of SHM at high schools and at training courses.

A.7.4 Technical barriers

The measuring apparatus is too complicated and expensive, very often suitable for use in laboratory conditions. The cost of sensors and collecting and sending devices is high. So there is a need of a methodology for the design SHM- systems involving only essential elements. The challenge is to develop and introduce simpler and cheaper SHM components.

The variety of facilities' construction types requires individual design of Structural Health Monitoring (SHM) systems. There is no inventory of existing road facility objects based on the state of wear. It is needed to create digital models of old structures. Hence, equipping the facility with the Structural Health Monitoring (SHM) system is associated with higher cost and is more time consuming.

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A.8 PEST analysis. *Germany*

The majority of existing engineering structures such as bridges and tunnels were built between 1960 and 1980. Due to the high age, this results in an increased need for rehabilitation and maintenance. This situation is aggravated by the fact that the structures planned at that time were not designed for today's traffic loads. In particular, the increase in heavy goods traffic leads to faster wear and tear and thus to an increased need for rehabilitation of existing engineering structures.

Another problem is that due to the unplanned increase in heavy goods traffic, the current traffic infrastructure is undersized and needs to be expanded. Despite increased funding, these problems do not lead to an improvement of the current condition of the engineering structures. Thus, more than 75% of the bridges are declared with the condition grade "Satisfactory or Sufficient".

A.8.1 Political barriers

In Germany, there are several political barriers that have a direct influence on the monitoring, inspection, and safety of transport infrastructure. One major problem is the financing required for engineering structures, which is mainly due to the lack of reforms in the federal-state fiscal equalization system. The imbalance between financially weak and financially strong municipalities should be mentioned here. Political reform is difficult, as this always means that the financially better-off municipalities support the financially worse-off municipalities. (39)

The financial imbalance of the municipalities is reinforced by bad investments that were made in the past. Thus, investments that increase the social attractiveness of the location (leisure pools, cinemas, etc.) were promoted, while investments for infrastructure were reduced.

The financial situation continues to be worsened by politically motivated prestige projects. Thus, projects are approved that have a high political relevance and whose success has a positive influence on elections. Economic efficiency criteria play a subordinate role here. Infrastructure projects with a high benefit-cost ratio, on the other hand, are not approved or are approved later. Overall, the approval process for infrastructure projects in Germany has become more complicated. This, in combination with a reduction in personnel in the construction offices, leads to an increased time requirement. The duration from planning to completion is thus becoming longer, increasing the refurbishment and investment backlog.

A.8.2 Economic barriers

In Germany, investment in infrastructure projects has continued to increase in recent years. For example, the funds available for 2021 for the entire transport infrastructure amount to €18.57 billion. However, net investments in the public sector are negative. This means that the financial requirement is growing from year to year and is not covered by the funds available each year.

A major problem is the aging infrastructure. The main focus here is on the maintenance and upkeep of existing structures. Due to the insufficient funds available, the focus of rehabilitation measures is on important and relevant engineering structures that have a condition rating of "Sufficient" and "Insufficient". Upcoming rehabilitation measures of structures with a better condition grade are postponed. The result is that the basic condition of the transport infrastructure is getting worse and worse on average.
In addition, many municipalities are heavily over-indebted and have high social expenditures and few revenues. Important investments cannot be made here and lead to a further deterioration in the condition of the transport infrastructure. Problems and weak points can be

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identified quickly and effectively during regular maintenance intervals. However, due to a lack of financial resources, necessary rehabilitation measures are only approved once damage has occurred.

The costs for the countermeasures then incurred are then much higher than if a remediation measure had been carried out immediately. A further expansion of the transport network is also prevented by the lack of financial resources. In combination with an increase in heavy goods traffic, this leads to faster wear and tear of the existing infrastructure and thus to increased rehabilitation and maintenance costs. (40)

A.8.3 Social barriers

The ever-faster pace of digitization in the construction industry poses a major challenge. Here, Germany is below average in a national comparison. Essentially, there is a lack of specific expertise and skills in the various construction companies carrying out the work. The added value and the potential for improvement of work processes are not yet recognized by the masses. Employees are also slow to accept new methods.

A.8.4 Technical barriers

In particular, the increase in heavy goods traffic in combination with the progressive aging of engineering structures is leading to more frequent and more cost-intensive damage. Often, these are only detected at a very late stage and thus increase the rehabilitation measures that need to be carried out. (41)

Monitoring systems that control the structure and register even small changes such as cracks, corrosion damage, structural changes, etc., provide a remedy. Installing these monitoring systems on important engineering structures is very time-consuming and cost-intensive and is not yet the norm in Germany (42). Another challenge is the digitization of existing data. For example, many existing bridges are not yet designed in a 3D model. (43) The data required for maintenance and repair is also usually only available in paper form and in various documents. Access to all the necessary data is therefore difficult and there is a risk of information being lost. The future use of BIM should support these processes and ensure simple and fast access to the necessary data. Currently, however, this is not the case for existing buildings. (44)

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