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DISCUSSION PAPER

"State of infrastructure maintenance"

This discussion paper is based on a mapping exercise and provides an overview about:

1. The **state of transport infrastructure** across the EU Member States and look into the way quality monitoring and maintenance planning and execution is implemented;
2. How a **maintenance backlog** is measured/assessed in terms of methodologies and the way different MS deal with it;
3. The **differences in approach** by different governance structures - including potential differences between national and local or regional level transport networks;
4. Existing **innovations** that aim to deal with maintenance problems including contracting (e.g. Design, Build, Finance & Maintain - DBFM), methodological (e.g. Asset, Ageing and Risk Management Methodology) and IT tools innovation that aim to optimise the life cycle performance of transportation infrastructure.

The purpose of this paper is to present the findings of a mapping of these topics for road and rail infrastructure maintenance. The mapping researched the status quo at the level of the EU as well as for MS (with the focus on Germany, the Netherlands and Italy). The paper also reflects contributions from stakeholders.

For the purposes of this discussion paper, infrastructure maintenance is considered to cover spending on preservation of transport infrastructure. This means regular or planned maintenance, however since some sources often do not distinguish between regular and irregular maintenance activities, such as minor rehabilitation actions, when this is the case we have tried to take note it. For the purposes of this paper we refer to both maintenance expenditure financed by public administrations, as well as by private operators.

Introduction

Maintenance activities are an important part of the life cycle costs of infrastructure

Civil engineering works are a significant part of the EU construction activity. Within this category, transport infrastructure is a significant contributor, accounting for 1.1% of GDP in the 19 EU Member States form part of EUROCONSTRUCT[1]. With this perspective in mind, it can be deduced that the development of transport infrastructure is a significant and expensive investment even for economically advanced EU countries. Because transport infrastructure's life cycle can span multiple decades, it is essential to get the best possible return on these significant investments.

The experiences of road infrastructure show that if maintenance is neglected over a period of 3 years, it is estimated that the necessary repairs or renewals of these roads may cost 3 to 6 times more than relevant

[1] http://www.euroconstruct.org/jart/prj3/wifo/data/uploads/euroconstruct/blog/2017_01_ECblog_switzerland.pdf

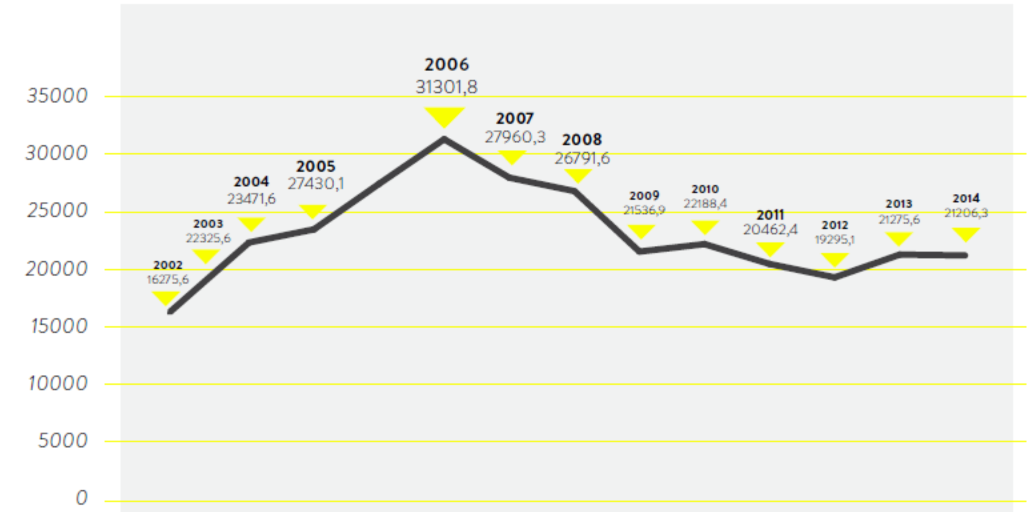
maintenance.[2] [3] Therefore, appropriate planning of maintenance, taking into account the principles of asset management, needs to be done in a cost-efficient way to optimise infrastructure life expectancy. As an EC study on infrastructure expenditures and costs[4] indicates, maintenance and operational costs for road infrastructure are important parts of the overall costs of transport infrastructure. However, the proportion of maintenance and operational costs can differ significantly depending on the country and level of transport infrastructure (12-65%).[5] [6] The same study also shows that maintenance and operational costs of regional and local level infrastructure networks form a larger part of the overall infrastructure cost structure than at higher level.

Therefore, the optimisation of these spending elements is essential and can potentially bring significant reductions to the overall cost of transport infrastructure.

Financial allocations for maintenance can be volatile, depending on the financial/political context and overall operational needs

Data comparisons between EU countries is very difficult due to the limited homogeneity of relevant data. This is because data quality differs significantly between MS, as they are not based on homogenous definitions of maintenance expenditures. The other difficulty is the fact that several bodies (national, regional or local) may be responsible for the good condition of infrastructure - further complicating coherent data collection. The most reliable international dataset in this respect is thought to be that collected by the OECD via the International Transport Forum (ITF).[7]

Figure 1: Maintenance expenditures in road infrastructure in selected EU countries (in euro mln)



Source: ERF, Road Statistics 2017 Yearbook (based on ITF data for a selection of MS with consistent datasets)

The OECD dataset on transport infrastructure investment and maintenance expenditures[8] confirms the existence of an increasing need for transport maintenance infrastructure in Europe as this infrastructure ages. While most EU MS had been steadily stepping up their transport infrastructure maintenance efforts

[2] World Bank, Why road maintenance is important and how to get it done, transport notes, 2005
[3] Ricardo et al. (2017), Support Study for the Impact Assessment Accompanying the Revision of Directive 1999/62/EC.
[4] D. Tsamboulas. Estimating and Benchmarking Transport Infrastructure costs UNECE Workshop on "Good practices and new tools for financing transport infrastructure", 8 September 2014
[5] Examples from Austria, Switzerland and Germany
[6] FIEC estimates road maintenance costs approximately €25/m² annually which corresponds to 1% of the initial investment
[7] European Parliament, EU Road Surfaces: Economic and safety impact of the lack of regular road maintenance, 2014
[8] International Transport Forum Database, https://data.oecd.org/transport/infrastructure-maintenance.htm#indicator-chart

prior to the 2008 crisis, this trend was mostly reversed in the years since. Essentially, road maintenance expenditures plunged by 38% between 2006 and 2012 from € 31 bln down to approximately € 19 bln per year.[9] This development brought road maintenance expenditure to roughly 0.5% of GDP by 2013, which is a significant reduction compared to the 0.8% attributed in 2008.[10] [11] For rail infrastructure, the OECD dataset indicates a mild reduction of expenditure from € 16.6 to € 15.7 bln. However, the preliminary Rail Market Monitoring Report (RMMR) data seem to contradict this trend indicating an increase of 30% in rail infrastructure maintenance and renewals expenditure from € 19.84 to € 25.94 bln.[12]

These figures, however, hide the larger variations that have taken place in specific MS. For example, some MS have significantly increased maintenance expenditures (e.g. **Poland** increased road maintenance by 60% as a result of its road network expansion) while other underwent a large reduction (e.g. **France** reduced road maintenance expenditure by 35%), and Italy slashed its road maintenance budget by 45% from 2008 to 2009 alone. Asphalt consumption in **Italy** also plummeted from 48 million tonnes in 2006 to only 22 million tonnes in 2013, indicating the significant reduction in road maintenance and construction activity.[13]

The European Construction Industry Federation (FIEC) warns about the threats of aging infrastructure as a large part of the critical infrastructure in EU MS, especially bridges built in the post-war era and now facing the problems of ageing concrete structures.[14] These problems are aggravated further by cuts in public budgets that lead to reduced maintenance activities, but also to a loss of experienced personnel who are moving to the private sector. At the same time, a report by the European Court of Auditors (ECA) found that there are significant deficiencies in the performance of rail infrastructure maintenance. The insufficiency of funds for maintenance leads to a prioritisation of passenger tracks, leaving predominantly freight tracks in an alarming state where speed restrictions are implemented to avoid incidents.[15]

It is obvious from the above that the way maintenance financing is determined does not seem to be primarily need-oriented as it is rather tightly connected to MS macro-economic policies. In this context the 2011 White Paper for Transport calls for a transition to more sustainable financing for transport infrastructure applying the ‘user pays’ and ‘polluter pays’ principles with a long-term goal to introduce user charges to all vehicles on all network to reflect at least the maintenance cost of infrastructure, congestion, air and noise pollution.[16]

Questions that arise from these findings:

1. *How can the funding of maintenance activities be secured in the long-term against changing financial/political priorities?*
2. *Is there a need for infrastructure cost measurement standards, including for maintenance, as part of a sustainable infrastructure management?*

[9] The EU contributes to this amount with roughly € 1.35 bln annually during the 2014-2020 funding period.
[10] COM(2017) 275 final Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures
[11] https://ec.europa.eu/growth/sectors/construction/observatory_en
[12] Preliminary RMMS data
[13] http://www.erf.be/index.php/communication/press-releases/439-road-maintenance-the-italian-situation-is-worrying
[14] FIEC estimates that 60% of the post-war structures pose problems related to the corrosion of steal
[15] ECA, Rail freight transport in the EU: still not on the right track, 2016
[16] COM(2011) 144 final: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system

State of play of transport infrastructure

***Roads* – A fragmented responsibility**

Multiple levels of governance are involved in road infrastructure quality monitoring

When it comes to road infrastructure, road authorities usually set in place procedures to monitor road infrastructure conditions based on the outcomes of which, maintenance activities are planned and specific road sections or structures are prioritised. However, the often encountered fragmentation of responsibility for infrastructure between the different levels of government (usually split between at least 3 levels of governance i.e. national, regional and local, while even 4 levels may be involved in the larger MS such as **Italy** and **Germany**)[17] allows for different approaches even within the same MS. For instance, explicit procedures do not necessarily exist for local and regional levels of infrastructure networks even though national authorities inspect and approve them.[18]

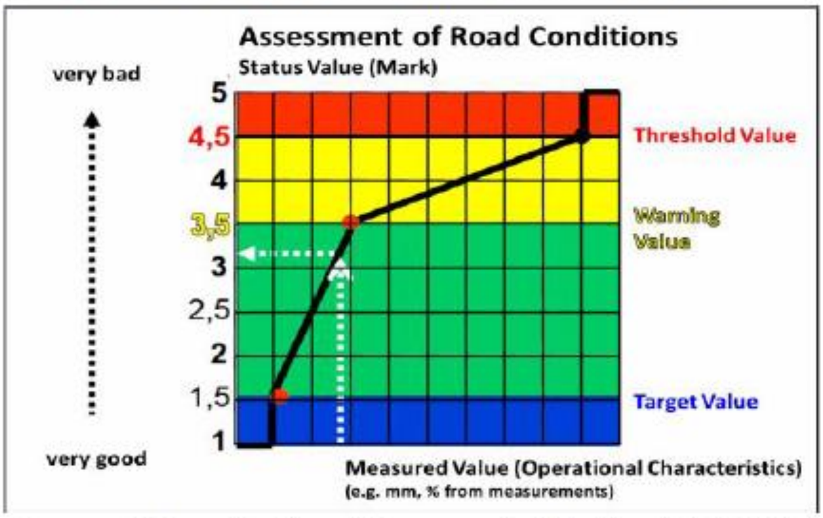
Usual practice is that a specialised mobile monitoring vehicle is used to measure critical parameters for road quality while moving in traffic. However, the frequency of such checks can vary significantly per country. In **Germany**, this monitoring takes place at regular intervals (4-5 years) for federal, state and district infrastructure. For local level infrastructure, local authorities are responsible for developing their own approach to maintenance. Finally, the degree of road usability and the pace of its deterioration are assessed and infrastructure segments are ranked accordingly. **Poland and the UK** apply such road surveys twice a year. In **Ireland,** the National Road Authority surveys the national network on an annual basis. Regional roads are surveyed in larger intervals, while local roads may, in some cases, even never be surveyed.[19]

Usability levels are defined based on a set of operational characteristics of the road surface depending on the road type and norms exist to correlate the state of infrastructure to a dimensionless indicator, as seen in the figure below presenting an example from Germany. Such indicators can differ significantly per MS, although usually based on the technical guidelines used in each country. Frequently measured operational characteristics show data for longitudinal profile, transverse profile, skid resistance, road pavement condition, cracks and defects. It needs to be emphasised at this point that 'optimal' road conditions do not mean 'as new' but rather a condition that avoids costly interventions at a later date since road surfaces that remain untreated can deteriorate at a faster rate, with the cost of repairs rising disproportionately. [20]

[17] Cases from Germany, the Netherlands and Italy
[18] European Parliament, EU Road Surfaces: Economic and safety impact of the lack of regular road maintenance, 2014
[19] FIEC indicates that in France 80% of the local authorities inspect their transport infrastructure
[20] European Parliament, EU Road Surfaces: Economic and safety impact of the lack of regular road maintenance, 2014

Figure 2: German system of linking road condition measurements to a dimensionless indicator

Presentation of a normalisation function to convert operational characteristics into dimensionless status values



Source: SDG modification of Government of Rheinland-Pfalz (2013).

There is no standard methodology determining the maintenance need in Member States

The traditional approach to planning maintenance activities is based on infrastructure age with maintenance usually planned a number of years after construction has finished or from the last maintenance round (as seen in the previous section). When such a point is reached, an assessment of road quality is made using a mobile monitoring vehicle. The ranking of infrastructure regarding their condition defines the maintenance priority ranking. Such an approach is common in countries like **Germany, Lithuania** and **Poland.**

In other countries (like **the Netherlands** and **Scotland**), transport asset owners (governments) develop a Service Level Agreement with the asset managing authorities (road or rail infrastructure management companies). These agreements stipulate the quality of the infrastructure based on technical characteristics and the condition of the surface. Depending on this quality agreement and the available budget, as well as on the agreement on priority/strategic infrastructure, a (annual) maintenance working plan is developed. This means that maintenance is partially susceptible to budget availability and infrastructure might not necessarily be maintained as a priority. In the Netherlands, postponement of maintenance is usually well reasoned such as for infrastructure of sufficient quality or postponing works to combine activities.[21]

In most MS, maintenance planning depends on the outcomes of the monitoring assessments. However, the criteria used to prioritise maintenance can differ. For example, in **Poland** maintenance is prioritised for the stretches in worst condition and roads classified as unsatisfactory (Class C – Surface with damage in need of routine maintenance) or in a bad condition (Class D – surface with damage in need of immediate repair).. In **the UK**, on the other hand**,** the stretches upon which conditions are deteriorating faster are maintained first.[22] Also more complex approaches exist, such as that in place by the Road Association of **Spain** who has defined an index to assess road conditions based on surface scanning. This ranking of road sections indicates which sections are in need of maintenance. Similarly, in **France**, two sophisticated indexes, which draw input from operational characteristics of the infrastructure, are used to assess the need for maintenance (the IQOA – Quality of Civil Engineering Structures[23] and the IQRN – Quality of National

[21] Ecorys, Indicatoren Doelmatigheid, 2015 (research performed for Rijkswaterstaat in Dutch)
[22] European Parliament, EU Road Surfaces: Economic and safety impact of the lack of regular road maintenance, 2014
[23] IQOA classifications: http://lagora.setra.developpement-durable.gouv.fr/Fichiers/IQOA-Classification%20des%20ouvrages_Mai1996.pdf

Roads[24]). Nowadays, also **Germany** is in the process of transitioning towards a monitoring-based approach, in an attempt to implement a more efficient infrastructure management for its highways (Autobahnen) independent from financial/political priorities. The Infrastrukturgesellschaft für Autobahnen (IGA) has been established as a state-owned corporation to ensure the necessary maintenance activities based on a so-called five year "financial and execution framework" (mehrjähriger Finanzierungs-und Realisierungsplan). This plan will be based on a biennial infrastructure status report (Infrastrukturzustandsbericht) in which cost measurement needs to be taken into account as well as scoring systems to evaluate infrastructure condition.

These differences in infrastructure monitoring and maintenance management approaches have led to limited opportunities to transfer good practices between European countries.

Infrastructure ownership differences impact the stability of maintenance funding

Different mechanisms exist to fund and deliver road infrastructure maintenance amongst EU MS. While in some countries the funding is provided directly by government spending, in other countries it is provided by other sources (e.g. toll roads). Governance structures which connect maintenance funding to government budget availability have proven to be more vulnerable to spending cuts in some cases. This has been the case especially in some of the MS most harshly hit by the crisis such as **Spain**, where the road maintenance programme[25] has been curtailed from € 1,257 mln in 2009 to just € 820 mln in 2014 (35% reduction). Similarly, in **Italy**, the road maintenance budget was reduced by € 500 mln between 2008 and 2012 due to a decrease of (amongst others) routine maintenance for national-level roads by 16%. The maintenance budget for roads under the responsibility of local authorities was reduced by 43%.[26] Overall, the potential availability of funding for infrastructure maintenance is dependent on decision-makers' political choices. In **Germany**, for instance, the increase in infrastructure maintenance spending has been part of two government "stimulus packages" during the early years of the crisis commencing in 2008.

Maintenance expenditure is considered to be more resilient to governmental budget changes when linked to alternative sources of funding. Nevertheless, these are also affected by the general economic environment, which can impact national revenues. For instance, in **Austria** the ASFINAG[27], which is responsible for transport infrastructure maintenance, is independent of government funding as it draws funds from tolls and other sources. As such, following the reduction in traffic flows in the first years of the 2008 crisis, also the maintenance budget had to be curtailed. Similar is the case in **Lithuania** where the Road Maintenance and Development Programme (RMPD), which is supported by excise duties on fuel, gas and road taxes, was forced to cut its maintenance funding by 32% since the beginning of the crisis.

Local governance faces the largest challenge

In general, local and regional level roads have been harder hit by spending cuts during the crisis. In the case of **the UK,** for example, local authorities pay roughly 70% of the cost for all road maintenance activities and it is expected that they will see their budgets devoted to maintenance cut by 30%. The Local Government Association assesses that this funding reduction will result in a multi-billion euro funding gap by 2020.

There is no condensed reporting of the condition of local roads in **Italy**, but it seems that insufficient budgets are available to local authorities. The deteriorating quality of local roads is often picked up by local media[28] [29] since local authorities are frequently sued for damages due to the condition of the roads.[30] On average, regional or local infrastructure is maintained at a poorer level than that of national level infrastructure.[31]

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[24] IQRN classifications: http://dtrf.setra.fr/pdf/pj/Dtrf/0002/Dtrf-0002369/DT2369.pdf
[25] Programme 453C
[26] European Parliament, EU Road Surfaces: Economic and safety impact of the lack of regular road maintenance, 2014
[27] http://www.asfinag.at
[28] http://www.lacittadisalerno.it/cronaca/strade-dissestate-e-lavori-in-ritardo-1.1085825?utm_medium=migrazione
[29] http://www.ilgiornaledivicenza.it/territori/montecchio/strade-dissestate-in-cantiere-lavori-per-oltre-un-milione-1.6259914?refresh_ce#scroll=770

An innovative approach to monitoring the state of local infrastructure has been developed in **London** to faster identify deteriorating road infrastructure. This is based on user-fed information where drivers can report highway defects directly to road managers via a web-based system.[32]

Questions arise from these findings:

3. *Are there generic characteristics of transport infrastructure which could be identified to suggest a standardisation of key indicators of performance (level of urgency, operational degree, expected service life, maintenance standards, etc.)?*
4. *Are the different inspection frequencies in Member States justified?*
5. *Across the EU, maintenance is defined in different ways, depending on the MS-specific approaches and traditions. To which extent should such differentiation be considered problematic?*
6. *Do the current differences in methodologies and indexes used to assess the maintenance need hinder the transfer of good practices?*
7. *How could local authorities be better supported in keeping local infrastructure in good condition?*

Railways **– A more centralised approach**

(Usually) a centralised responsibility

Regarding rail infrastructure, the identified approach is fairly consistent with most MS, having a single authority responsible for infrastructure quality. For example, in **the Netherlands**, the infrastructure management authority is responsible for the infrastructure's quality. However, ProRail procures rail maintenance from private enterprises through competitive procurement procedures. Similar is the case for **Italy** where the Rate Ferroviaria Italiana (RFI) assumes the role of infrastructure manager. In **Germany** however**,** railway infrastructure is managed by a consortium of railway infrastructure companies called Eisenbahninfrastrukturunternehmen (EIU). There are about 150 EIUs in Germany, which receive funding from a combination of the federal budget and receipts from users of the infrastructure.

Two different approaches: budgeted vs performance-based

In **Germany,** when it comes to rail infrastructure maintenance, there is standard state funding of about € 2.5 bln annually agreed between the federal government and the Deutsche Bahn.[33] This amount is provided to the Railway Infrastructure Companies (EIU), which are tasked with keeping the network at a guaranteed quality. In the 2015-2019 period this funding has been increased to € 4 bln annually. While this seems to be quite a steady commitment to expanding the availability of infrastructure funds, this can be misleading, since the final amounts of public funds to be invested in infrastructure are adopted annually in the federal budget by the Parliament. This short-term financing does not always correspond with the mid-term planning laid down in the Federal Transport Infrastructure Plan.

Contrary to the road case, the rail infrastructure reality in **the Netherlands** is quite different. The infrastructure network operator (ProRail), via competitive tendering, contracts the network infrastructure maintenance of various network segments. This creates performance-based multi-year contracts which focus on functional requirements for the network, defined as RAMSHE (reliability, availability, maintainability, safety, health and environment), measuring performance instead of setting technical requirements for maintenance activities. Contractors are called upon to design and plan maintenance activities themselves, based on defined criteria.

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[30] http://palermo.repubblica.it/cronaca/2010/10/30/news/strade_dissestate_e_abbandonate_ogni_anno_500_cause_al_comune-8573786/?refresh_ce

[31] Ricardo et al. (2017), Support Study for the Impact Assessment Accompanying the Revision of Directive 1999/62/EC

[32] European Parliament, EU Road Surfaces: Economic and safety impact of the lack of regular road maintenance, 2014

[33] Leistungs- und Finanzierungsvereinbarung; LuFV

This performance is measured by indicators related to:

i) the percentage of train trips delayed by more than 3 minutes (reliability),
ii) the percentage of train trips performed compared to the ones planned (availability),
iii) the number of resources – time and costs - devoted to maintenance (maintainability),
iv) accidents involving passengers and workers, as well as risks to residents (safety),
v) system accessibility, noise, wellbeing at work, air quality (health)
vi) environmental impacts such as waste produced, ecological damage, landscape design, energy use, water use, etc. (environment)

Sweden and Finland have also moved towards competitive procurement procedures for maintenance activities. This approach has created a competitive market, although in each country only a handful of maintenance companies have the capacity to compete.[34]

The Platform of Rail Infrastructure Managers[35] has developed a Key Performance Indicator (KPI) and Benchmarking scheme to monitor and compare the state of rail infrastructure across the EU. Amongst others, the 13 Infrastructure Managers cooperating on this initiative measure the operating expenses per kilometre of track. The expenses of rail infrastructure managers on infrastructure maintenance proves to vary greatly, with ProRail (the Netherlands) spending as much as €70,000 per track-kilometre, while the average spending is approximately half of that at about €38,000 with great variations between operators. However, it needs to be noted that although these figures provide useful insight into the performance of the different networks, these can by no means be compared directly before considering the specificities of each network (e.g. density, utilisation, complexity etc.). To prove this constraint in any direct comparison of such data, the Dutch network also appears to be suffering by far the most frequent structure (bridges and tunnels) failures in relation to its network size (probably also related to the density of the Dutch network).[36]

Questions that arise from these findings:

8. *Under what conditions can the introduction of market elements and performance agreements lead to more effective and cost-efficient infrastructure maintenance activities?*
9. *What could be an appropriate balance between public funding and users' payments for funding infrastructure maintenance?*

Analysing the maintenance backlog

Mismatches between needs and available budgets can lead to gaps in the funding of the maintenance activities. The accumulated funding gaps are referred to as the maintenance backlog.

The 2008 crisis affected the way MS approach maintenance funding in different ways

During the early years of the financial crisis (2008-2011), the maintenance expenditure levels showed different trends across EU MS. Maintenance activities declined significantly in a number of the EU MS most severely affected by the crisis (i.e. Italy, Ireland, Slovenia and Spain). A strong decline was observed also in a number of other MS.[37] At the same time, some MS increased their maintenance expenditures over the same period, in some cases due to government attempts to balance the circular fluctuations in economic activity.[38] These variations are also believed to depend on parameters such as the source of maintenance funding and political choices made by policy makers, rather than from changes in the actual maintenance needs.[39]

[34] VTI, Mapping railways maintenance contracts – the case of Netherlands, Finland and UK, 2014
[35] https://webgate.ec.europa.eu/multisite/primeinfrastructure/prime-news_en
[36] PRIME 2016 Benchmarking Report, Good practice benchmarking of the rail infrastructure managers
[37] Slovakia, Finland, Czech Republic, the UK, Portugal and Hungary
[38] Austria, Germany, France, Croatia, Lithuania, Luxemburg and Poland.
[39] European Parliament, EU Road Surfaces: Economic and safety impact of the lack of regular road maintenance, 2014

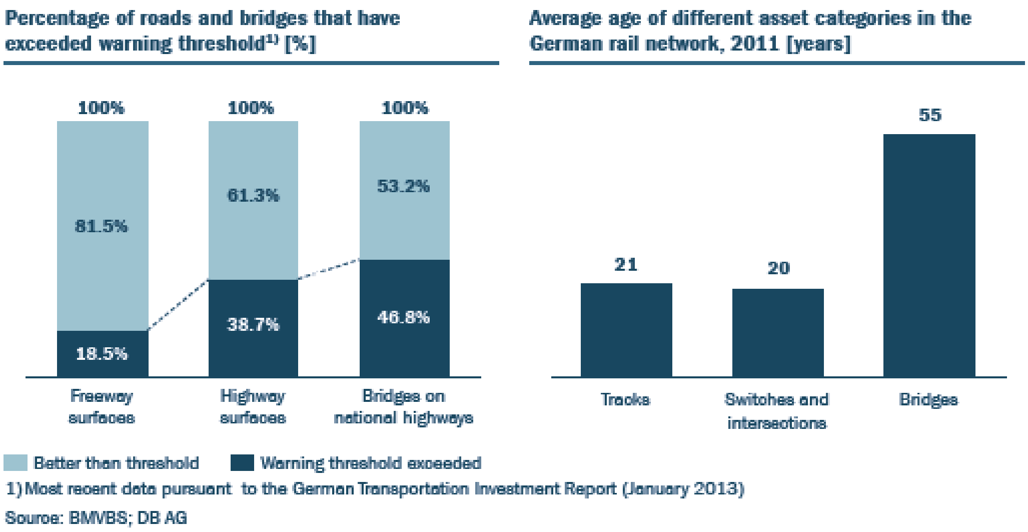
In conclusion, the differences in maintenance spending are mostly driven by funding availability rather the actual maintenance needs. This means that most probably, in countries where spending cuts where observed, and since no major changes in maintenance needs is presumed to have occurred within this limited timeframe, a maintenance backlog will probably develop.[40]

MS struggling to keep up with the "maintenance backlog": some more than others

A study supporting the impact assessment of the Eurovignette Directive found that according to national reports there are concerns over the deteriorating state of the road network in seven MS[41] while another five were struggling to meet the needs for investment[42] indicating that the difficulties in maintaining road infrastructure can be common across different MS. [43]

In **Germany** maintenance activities are based on infrastructure age and are usually planned a determined number of years after construction has finished (or from the last maintenance round). Nevertheless, 18.5% of the country's motorways have exceeded the warning threshold for maintaining their surfaces regarding their classification for usability. When it comes to bridges, for nearly half of them (46.8%) maintenance activities are already overdue as can be seen in the Figure underneath. This backlog accounts for approximately € 7.2 bln annually,[44] out of which € 4.7 bln are needed for roads and € 2 bln for rail. The municipal backlog is said to have increased to €136 billion by 2015. In response, public investment increased 2.2% in 2016, showing some willingness to counter this trend although considerably more is needed.[45] Overall, it seems that the maintenance backlog exists, nearly without exception, at local level.

Figure 1: Indicators of the condition of the road and rail network



The **Netherlands Court of Audit** studied the infrastructure maintenance backlog of the country in 2014. This has to be seen in the context of a sharp decrease in the funds allocated to maintenance, which in the case of roads fell from approx. € 1.2 bln in 2010 to only € 0.3 bln in 2011.[46] Subsequently, the Minister for Infrastructure reported a shortage of € 2.9 bln in the road maintenance budget. The Court concluded that postponing the maintenance had brought risks for the quality of the road network and the efficiency of the maintenance, as postponing the work also increases the costs. Some of the main recommendations were to:

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[40] Alternatively, it could be assumed that a considerable rationalisation of maintenance activities occurred, but this is totally unsupported by the retrieved facts.
[41] Including Bulgaria, Belgium, Estonia, Latvia, Lithuania, Romania and Spain
[42] Denmark, Italy,, Austria, Poland and Hungary
[43] Ricardo et al. (2017), Support Study for the Impact Assessment Accompanying the Revision of Directive 1999/62/EC
[44] Roland Berger, Planning and financing transportation infrastructure in the EU – A best practice study, 2013
[45] European Construction Sector Observatory, Country Profile Germany, March 2017.
[46] ERF, Road Statistics, 2017 Yearbook, http://www.erf.be/images/2017/Statistics/Road_statistics_2017.pdf

- Prioritise maintenance before construction of new roads within the existing budget;
- Regularly measure and report the extent of the maintenance backlog to the Parliament;
- Change to a system accounting for the “life cycle thinking” costs of infrastructure and investigate the possibility to introduce an integral maintenance regime for the main road network instead of separate budgeting regimes, based on performance agreements;
- Improve the information management in such a way that (a) there is an up-to-date view of the road maintenance situation (b) the quality of the main road network can be related to the available financial resources and maintenance performed, (c) there are several maintenance scenarios that can be developed.[47]

In spite of the ageing of infrastructure in **Italy** (with the majority built in the 1960s and 1970s), during the period 2007-2013 the road infrastructure manager (ANAS) only spent an annual average of € 180 mln for exceptional maintenance (securing and improving infrastructure).

In the last 5 years (since 2013), 9 bridges have collapsed in Italy[48]. One of those was located on highway A14: it collapsed on the 9th of March 2017, killing 2 people and injuring another 3. Following the accident, an investigation proved that it was caused by bad maintenance: 41 people are under investigation, including managers of Autostrade per l’Italia[49].
The discussion on the safety of Italian railways started again very recently, following a major accident that took place in Milan on the 25th January 2018. Managers from RFI, along with workers of the maintenance sector, are now being investigated.[50]

According to the Italian Association of traffic engineers,[51] exceptional maintenance of the national roadways should be at the level of € 2.5 bln annually. However, ANAS plan for 2016-2020 provides for an annual average of € 1.04 bln. [52] In fact, real expenditure was only € 450 mln in 2016.[53] The investment plan presented by ANAS was delayed by the government's late approval of the ‘Contratto di Programma’ (Government Programme Contract) which was signed in October 2016, but did not come into effect until August 2017.[54]

Transport **Scotland** applies a rigorous monitoring approach to the road infrastructure network to find out the backlog of maintenance expenditures, whose elimination is required to bring the road network to an optimal level. This is defined as a degree of quality where close monitoring is not required anymore. This is based on the 3 grades for classifying trunk roads (where 'Good condition' refers to no need for repair, 'Fair condition' refers to the need for frequent monitoring and 'Poor condition' refers to the need for structural maintenance). This monitoring activity revealed that between 2010 and 2014 the maintenance backlog for road infrastructure rose from € 0.8 bln to € 1.35 bln. With the annual expenditure budgeted for maintenance falling short by € 0.3 bln, it is understandable that catching up with this backlog can only be seen as challenging.[55]

The allocation of sufficient funding to hinder a maintenance backlog is critical to maintaining the infrastructure's condition. In **Poland**, the increased maintenance spending led to a decrease of the roads

[47] https://www.rekenkamer.nl/publicaties/rapporten/2014/10/15/instandhouding-hoofdwegennet
[48] http://www.corriere.it/cronache/cards/i-ponti-crollati-italia/autostrada-a14_principale.shtml
[49] http://www.lastampa.it/2017/05/18/italia/cronache/ponte-crollato-sulla-indagati-coinvolti-anche-dirigenti-della-societ-autostrade-KQun9heQ7QMfMorxMZ3vIM/pagina.html
[50] https://webgate.ec.europa.eu/multisite/primeinfrastructure/prime-news_en
[51] Associazione italiani ingegneri del traffico
[52] http://www.ilsole24ore.com/art/notizie/2017-10-04/piano-investimenti-anas-295-miliardi-operativo-entro-l-anno--151944.shtml?uuid=AE28AeeC
[53] http://www.ilsole24ore.com/art/impresa-e-territori/2017-04-19/per-manutenzione-strade-servono-25-miliardi-l-anno-124542.shtml?uuid=AEUZEk7
[54] http://www.stradeanas.it/it/contratto-di-programma
[55] European Commission, The Performing Rail Infrastructure manager, 2013 https://ec.europa.eu/transport/sites/transport/files/media/publications/doc/2013-the-performing-rail-infrastructure-manager-lo-res.pdf

classified as being in a bad condition, from 25% in 2005 to 13% in 2012. On the other hand, **Spain**'s Road Association assesses that maintenance spending needs to double to bring infrastructure levels back to being acceptable. In **France,** despite a drop of 8% in the road sections classified as "very good", roads remain in a predominantly good state.

Even when deterioration of infrastructure does not lead to major construction failures, but results in the need for exceptional maintenance, the prolonged closing down of infrastructure to perform such activities can go hand in hand with considerable social costs. An example is the assessment of such costs conducted in **Germany** for the case of the Leverkusen bridge which was closed to traffic for 4 months. This resulted in additional user costs of € 80 mln due to time lost and additional fuel consumption.[56]

The maintenance needs are expected to increase even further in the short term, as the phenomenon of steel corrosion within reinforced and pre-stressed concrete structures appears to reduce the life cycle of critical infrastructure earlier than what was initially expected.

The conclusion that can be derived from the above is that MS are not always diverting the required amount of funding to maintenance activities to assure a good quality of transport infrastructure. However, important differences can be seen in their capacity to do so.

Questions that arise from these findings:

10. *How can safe road conditions be safeguarded in an environment of reduced maintenance budgets?*
11. *In order to plan and implement maintenance activities in time, how could the use of information management be improved?*
12. *How could life cycle thinking be introduced to assist MS in keeping infrastructure at a good level?*
13. *Which operational recommendations could be made to MS to help them make decisions and solve the financial and technical dilemmas of road maintenance and public finance constraints?*

Possible levers of action/improvement

Contracts incorporating life cycle and performance-based maintenance as a tool for high quality infrastructure

The Confederation of European Directors of Roads (CEDR)[57] prepared a study exploring funding formulas for roads in which the pros and cons of different funding instruments are presented as well as their capacity to address the needs of newer and ageing transport networks and deal with economic volatility. While there seems to be no single recipe for success, various funding instruments can be mobilised. What arises as a priority is to guarantee the funding necessary either by earmarking specific tax revenues, mobilising grants, implementing road pricing schemes or exploring Public Private Partnerships (PPP) options and adapt project contracting to include maintenance activities.[58]

In Design, Build, Finance & Maintain project contracts, a life cycle approach is taken as a whole for the construction as well as the use phase of the infrastructure, to optimize the use of resources over the entire life cycle of the property (= project duration). The important life phases of a property are: planning, building, use / operation and, if necessary, renovation or demolition. Unlike the self-implementation by the public sector, it is not the individual partial services that are tendered, but all services as a whole.

[56] ERF, Keep Europe Moving, Christophe Nicodeme, 2015
[57] http://www.cedr.eu/
[58] CEDR, Funding formulas for roads: Inventory and assessment (2017)

In **the Netherlands**, new contracts for road construction also transfer the responsibility for maintenance to construction companies providing them with an incentive for more sustainable choices in the design and build of the roads. An example of a project under such a contract is the construction of the second Coentunnel near Amsterdam. For this project, a consortium comprising of BESIX, CFE, TBI, VINCI, DURA VERMEER and DEME was responsible for both the construction of the road as well as the maintenance for 25 years. In this case, the construction company benefits from the road's reduced maintenance needs. Another advantage is that the high quality of the asphalt increases the residual value of the road.

Furthermore, Dura Vermeer is now working on an approach, which includes not only the road infrastructure, but also the direct environment around the road. Innovations include the creation of a soil stabilization method, which reduces the required thickness of asphalt from 21 cm to 6 cm. In addition, service-based LED lighting is used, combined with reflective bitumen, reducing the amount of lighting that is needed to ensure a well-lit, safe road. Along the roadside, genetically modified plants can be used to filter more CO_2 from the air. The plants can later be converted into bio-fuel.[59]

Regarding rail infrastructure, in 2016 the Dutch company ProRail started a **Performance-Oriented Maintenance program** (in Dutch: PGO[60]), aiming to move from maintenance contracts which describe the maintenance work exactly towards the expected railway performance. The contractors then decide themselves which maintenance actions are required to meet ProRails' standards. This way ProRail aims to have more preventive maintenance, increasing the availability and quality of the railways.[61] In comparison to the more traditional Output Process Contracts (OPC), the areas where ProRail has introduced the new PGO contracts are performing better in terms of their degree of train nuisance and the duration of the malfunctions. Moreover, the PGO areas have a more favourable price-performance ratio due to market forces that have arisen as a result of the tendering and optimisations that are being performed.[62]

Efficient methodologies to asset management

Traditionally, maintenance used to be planned based on empirical experience. However, the long-term impacts of maintenance planning on infrastructure conditions shows a need for decisions being taken based on the full life cycle, for example taking into account the savings of preventive maintenance[63] on the overall maintenance costs. To perform such analyses, infrastructure managers need maintenance analysis and planning tools that enable them to systematically analyse and optimise budget needs to minimise the total costs for the required Reliability, Availability, Safety and Maintainability (RAMS) level, and guarantee the quality of the railway assets in the long run. Already in 2013, **the Netherlands**, **Austria, France** and **Germany** introduced computer models to estimate the life cycle costs for track maintenance decisions.[64]

Specifically in the **Netherlands,** ProRail is using an **asset management database** called *SpoorData,* which creates a form of infrastructure passport, ensuring that the asset chain has reliable information about objects. For example, the location of switches, overhead lines and signals, their types, and when they are at the end of their life cycle. It covers both configuration and control data of the infrastructure. Configuration data consists of the (static) object data about 'what is it', 'what can it do' and 'where is it'. Control data (dynamic) includes the maintenance data, failure data and condition data of an object. In 2017, information supply specifications were developed together with the maintenance contractors for the nine most important types of objects (including signal, switch and track). These are prioritized on the basis of criteria such as 'performance killers', 'cost drivers' and 'feasibility' and are used to improve the data quality. In 2018, the SpoorData programme will make the data available for everyone in the railway sector to facilitate the exchange of information and data.

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[59] https://www.circulairondernemen.nl/challenges/dura-vermeer-de-circulaire-weg
[60] *Prestatie Gericht Onderhoud*
[61] https://www.prorail.nl/reizigers/aanbesteden-en-inkoop/spooronderhoud-pgo
[62] ProRail Beheerplan 2018
[63] Also the contribution of innovative materials that can alter the maintenance cycle should be accounted in a life-cycle approach e.g. use of rapid concrete or other material that can shorten or postpone maintenance activities.
[64] European Commission, The Performing Rail Infrastructure manager, 2013

ProRail expects to achieve potential annual savings of 20% through the use of this asset management tool thanks to a reduction in the number of inspections needed.[65] Obviously, the existence of comprehensive information can help create an infrastructure 'passport' (Carnet d'entretien); a useful innovation currently used in **the Netherlands** and **Spain** and which could be extended to EU level as well.

Transport **Scotland** (TS) has also been working on a structured approach to asset management since 2005. According to the Asset Management Improvement Plan of Transport Scotland, the introduction of asset management must result in more efficient and effective execution of activities through:

- Introduction of a performance framework;
- Improvement of information systems;
- Improvement of value management;
- Introduction of life cycle planning.

Although Transport Scotland has outsourced the performance of road operation activities, a considerable amount of know-how is required for the authority to keep track of the performance of contracted companies and devise a concise set of indicators that can be used to monitor their performance.[66]

Technological developments

Using drones to monitor infrastructure

In 2017, PwC delivered a report on the use of drones to optimise transport infrastructure management.[67] Amongst others, they identified the use of drones to inspect infrastructure. Drones equipped with high-resolution cameras and scanners can replace humans in conducting precise inspections as is already being done in the case of energy networks. This can significantly reduce the cost and improve precision of infrastructure inspection and allow for more targeted maintenance activities. Drones are already used to scan and monitor infrastructure condition for bridge inspections in Italy. These do not, however, entirely replace the need for a human expert to assess the collected data.

Research projects aiming to improve infrastructure maintenance

Amongst a great number of research projects aiming to increase the physical durability of infrastructure components, some projects aim to improve transport infrastructure life cycle management from a systems perspective and reduce the need for maintenance. Technological advancements such as advanced sensor systems, modelling of infrastructure conditions based on traffic volumes, weather conditions and other external factors plus the use of big data, could all assist in achieving a shift from preventive to predictive maintenance practices, which would be expected to come with significant cost savings. A selection of such projects is presented in the Annex, List A.

In European R&I funded projects, the rail sector today uses a centralised and cooperative approach through the 2014-2024 PPP programme initiative Shift2Rail managed by a dedicated EU Body, the Joint Undertaking Shift2Rail. Part of the programme (Innovation Programme 3[68]) focuses on support for the reduction of maintenance costs through improved procedures and automation, and on solutions that could be rapidly and efficiently deployed. Shift2Rail plans to manage infrastructures in a more holistic and intelligent way using lean operational practices and smart technologies that can ultimately contribute to improving the reliability and responsiveness of customer service, as well as the capacity and the whole economics of rail transportation based on principles of EU interoperability and standardisation.

Work on S2R and its future implementation will also help to avoid infrastructure failures, as the Joint Undertaking is developing solutions that aim to shift from current widely used reactive and/or preventive

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[65] European Commission, The Performing Rail Infrastructure manager, 2013
[66] Transport Scotland, Road Asset Management Plan for Scottish Trunk Roads, January 2016
[67] http://eu-smartcities.eu/sites/default/files/2017-09/SUM_the-futures-of-mobility-how-cities-can-benefit%20%282%29.pdf
[68] https://shift2rail.org/research-development/ip3/

maintenance to condition based and/or predictive maintenance, based on intelligent monitoring/analysis of the assets. Through its EU funded projects, Shift2Rail is developing the decision tools and the culture (challenging past processes/procedures) for this to happen. A number of infrastructure monitoring/improving/disruptive related collaborative projects is presented in the Annex, List B.

The EU also funded, with its Framework Programmes (Horizon 2020, FP7, FP6 and FP4) several research projects in areas relevant to bridge/infrastructure maintenance (e.g. monitoring, safety, testing and repair methods).The examples (in the Annex, List C) show the relevance of the research effort.

Questions that arise from these findings:

14. *To what extent can the mainstreaming of contractual, organisational or technological innovations be used to improve the delivery of infrastructure maintenance?*
15. *What is the potential for artificial intelligence (AI) in infrastructure networks management and maintenance?*

Possible role for the EU

The findings of this research note raise questions regarding the potential role the EU could have in improving the delivery of infrastructure maintenance for MS. Such questions could link to the following issues:

A. Would a standardisation of maintenance assessment methodologies be useful for keeping up the standard infrastructure quality for the TEN-T corridors (Trans-European Network – Transport)? Would common guidelines be useful for lower levels of infrastructure networks as well?
B. Is there a need for a knowledge exchange mechanism between MS to share good practices for performance-based contracts for infrastructure maintenance?
C. Does the current research agenda of the EU address the current needs of the sector?
D. What is the potential for EU support for the development of digitalisation and artificial intelligence in the management and maintenance of transport infrastructure?

ANNEX

Research projects aiming to improve infrastructure maintenance

List A

- The **Pilot4Safety** project **(ended)** compiled a collection of best practices used to standardise road infrastructure maintenance across Europe.[69]
- The **BENEFIT** project **(ended)** explores the performance of transport infrastructure business models and their project rating by which further value propositions may be included to lead to funding schemes with enhanced creditworthiness enabling viable financing.[70]
- **SENSKIN** aims to develop a skin-like sensing solution for the structural monitoring of the transport infrastructure, to be used for targeting maintenance activities. The project will develop hardware and software for the communication interface and perform field tests in real bridges.[71]
- **SAFELIFE-X (ended)** focused on the improvement of the ageing management for energy and transport infrastructures (including bridges), towards an improved availability and a cost effective management. It also provided input on standardisation procedures.[72]
- **INNOTRACK (ended)** was a project that brought together rail infrastructure managers, industry suppliers and research bodies in providing innovative solutions to cut LCC (Life Cycle Cost) and improve RAMS (Reliability, Availability, Maintainability & Safety) of track structures.[73]
- **ACEM-Rail (ended)** was a project dealing with automation and optimisation of railway infrastructure maintenance. It aims to develop automated and cost effective inspection of rail tracks and estimate potential defects through predictive algorithms, which will be used to plan maintenance tasks optimally.[74]
- **CAPACITY4RAIL (ended)** was a project looking at new concepts for low maintenance infrastructure, using standardized and "plug-and-play" concepts. Non-intrusive innovative monitoring techniques or self-monitoring infrastructure were investigated, allowing low or no impact on train operations.[75]
- **DESTinationRAIL** (**ended**) was a project aiming to create a holistic management tool which would, for example, use advanced probabilistic models fed by performance statistics to allow a move towards risk assessment, moving from the current subjective (qualitative) basis to become fundamentally based on quantifiable data and proposing maintenance strategies according to a whole life cycle model which includes financial and environmental costs and the impact of works on traffic flow.[76]

List B

- **IN2RAIL (ended)** is the first Shift2Rail project on infrastructure setting the foundations for a resilient, consistent, cost-efficient, high capacity European network by delivering important building blocks to unlock the transformational potential of innovative technologies integrating information management, traffic management, monitoring & maintenance techniques, energy, and engineering.[77]
- **IN2SMART (running)** contributes to the overall concept for Intelligent Asset Management based on measuring and monitoring systems, data management, decision making tools and maintenance strategies. It is complementing the work of the IN2RAIL lighthouse project to reach a homogeneous TRL4/5 demonstrator.[78]

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[69] Pilot4Safety, Deliverable D7: Evaluation report, 2010
[70] http://www.benefit4transport.eu
[71] http://www.senskin.eu/
[72] http://www.safelife.eu-vri.eu/
[73] https://cordis.europa.eu/project/rcn/81513_en.html
[74] http://www.acem-rail.eu
[75] http://www.capacity4rail.eu
[76] http://www.destinationrail.eu
[77] http://www.in2rail.eu
[78] https://shift2rail.org/project/in2smart

- **IN2TRACK (running)** works on enhancing and optimising the switch, crossings and track systems in order to ensure optimal line usage and capacity, and investigates novel ways of extending the life of bridges and tunnel assets through new approaches to maintain, repair and upgrade these structures.[79]
- **IN2STEMPO (running)** addresses the topic of "Smart system energy management solution and future station solutions" looking at a smart railway power grid, in an interconnected and communicated system, achieving a fine mapping of energy flows within the entire railway system. This would form the basis of a later energy management strategy and improve the customer experience at Railway Stations.[80]
- **MOMIT (running) works with IN2SMART** to bring, at cutting edge level, the remote sensing technology applied to railway infrastructure monitoring for both RPAS and Satellite based solutions. It will also help in developing new platform independent tools supporting data analysis and the decision making process. Ultimately it will be also defining operational criteria for an effective and efficient use of unmanned (drone) technology to highlight benefits, complementarities and limitations in term standard monitoring technologies.[81]
- **S-CODE (running) works with IN2TRACK** and is investigating radically new concepts for switches and crossings that have the potential to lead to increases in capacity, reliability and safety while reducing investment and operating costs.[82]
- **In2Dreams (running) works with IN2SMART and IN2STEMPO** to deliver a non-intrusive Smart Metering sensor network, an open system and interface for data collection, aggregation and analysis in an open source Operational Data Management Platform and a set of User Applications design and specifications to exploit the energy analysis process, as well as other possible improvements such as preventive maintenance.[83]

List C

- **SENSKIN (running)** - developing of a skin-like sensing solution for the structural monitoring of the transport infrastructure with spatial sensing of reversible (repeated) strains and securing that strain measurements acquired through the 'sensing skin' will reach the base station even under extreme environmental conditions and natural disaster events such as high winds or an earthquake. Leading to development of a Decision-Support-System for proactive condition-based structural intervention under operating loads and intervention after extreme events.[84]
- **SAFE-10-T (running)** - moving from considering critical infrastructure such as bridges, tunnels and earthworks as inert objects to being intelligent (self-learning objects). The project will provide means of virtually eradicating sudden failures. The Safety framework will incorporate remote monitoring data stored in a BIM model that feeds into a decision support framework that will enable decisions to be made automatically with maintenance prioritised for elements exhibiting stress.[85]
- **COBRI (ended)** - based on a novel smart design for ultrasonic image data capture from solid materials like concrete, the project aimed to develop and implement a fully functional model of a hand held NDT/E (Non-Destructive Testing /Evaluation) instrument. This user-friendly NDE tomograph (3D-scanner) is able to scan 10 times faster than the current state of the art instrument, with better resolution in a human readable format. This innovative solution simplifies and improves current bridge inspection methods and consequently improves safety, enhances capital investments and road infrastructure capacity.[86]
- **LoStPReCon (ended)** – monitoring of long-term structural performance of pre-stressed concrete bridges: A risk-based monitoring informed framework for life-cycle asset management. Problems are solved by integrating physical and probabilistic models and benefiting from the increasing use of monitoring data.[87]

[79] https://shift2rail.org/project/in2track
[80] https://shift2rail.org/project/in2stempo
[81] http://www.momit-project.eu
[82] http://www.s-code.info
[83] http://www.in2dreams.eu
[84] http://www.senskin.eu
[85] https://cordis.europa.eu/project/rcn/209711_en.html
[86] https://cordis.europa.eu/result/rcn/227700_en.html
[87] http://www.lostprecon.eu

- **FASTSCALE (ended)** - modular repair and newbuilding system for concrete bridges, with clear, demonstrated benefits against the traditional methods: e.g. over 50% reduction in work effort, over 50% reduction in net work duration and up to 90% reduction of non-recyclable waste materials.[88]
- **SERON (ended)** - development of a methodology helping owners and operators to analyse critical road transport networks or parts thereof with regard to possible terrorist attacks. It evaluated planned protection measures for critical road transport infrastructures concerning their impact on security and cost-effectiveness, giving adequate recommendations concerning possible current and future threat situations and the related most effective security measures.[89]
- **WI-HEALTH (ended)** - development of a wireless system for bridges to enable authorities to monitor their structural health more efficiently and pre-empt disaster by combining long-range ultrasonic and acoustic emission monitoring in autonomously powered nodes to detect bridge defects such as in welded plate structures. The project also developed software to drive the structural health monitoring system to identify defects using advanced trend analysis and data processing.[90]
- **BRIDGEMON (ended)** - developed tools, which can be used to allow more detailed information to be collected on the loading being experienced by a bridge in service along with its ability to resist that loading. Bridge Weigh-in-Motion (B-WIM) refers to the technology, which uses measurements taken from a bridge as a truck drives over it, at full speed, to calculate the weight of that truck. Also to apply the B-WIM approach to railway bridges, allowing the weights of trains to be easily calculated. In addition, BridgeMon developed a 'virtual monitoring' approach which could be used to estimate the remaining fatigue life of steel bridges and hence provide accurate information on the resistance of the bridge to fatigue loading.[91]
- **LONG LIFE BRIDGES (ended)** - facilitated the identification of old bridges that are safe to remain in service and those that need maintenance plans, incorporating structural control and health monitoring, to optimise their remaining life. Coupled with reduced spending on infrastructure, ensuring the maximum return possible from the existing bridge infrastructure as opposed to undertaking expensive and carbon-intensive new projects. The project lead to more road and rail bridges being proven to be in a safe state, higher speeds on our (non-high-speed) railway lines, less demand for non-renewable and carbon intensive resources for less cost.[92]
- **SUSTAINABLE BRIDGES (ended)** – focused on upgrading of bridges so they could accommodate up to 33 tonnes in freight traffic and higher speeds up to 350 km/hour for passenger trains to increase remaining life of bridges by 25 %, resulting in significant savings in infrastructure and for the transport sector. Measurement techniques were developed to assess the bridges, and wireless sensors based on fibre-optic technology were proposed to monitor and assess viability. Load and resistance assessment were studied as well as repair and strengthening methods using fibre-reinforced polymers (CFRPs).[93]
- **ARCHES (ended)** – developed a guidance for assessing bridges, dealing with monitoring, load testing of different types, dynamic impact on bridges and bridge management system development. A key aspect of the project was to monitor and prevent corrosion of existing bridge reinforcement and to develop new highly resistant materials to achieve this. The researchers looked into the costs of cathodic protection of reinforcing steel and found that this well-developed technique can be instrumental in saving considerable amounts of money over periods of up to 25 years.[94]
- **BRIME (ended)** – developed a framework for the management of bridges on the European road network and identified the inputs required to implement such a system and the most appropriate action for a sub-standard or deteriorated structure i.e. whether it should be repaired, strengthened or replaced including mechanisms for prioritising bridges in terms of their need for repair, rehabilitation or improvement.[95]

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[88] http://www.fast-beam.com
[89] http://www.seron-project.eu
[90] https://cordis.europa.eu/result/rcn/141121_en.html
[91] http://bridgemon.zag.si
[92] https://cordis.europa.eu/result/rcn/194580_en.html
[93] https://cordis.europa.eu/result/rcn/46916_en.html
[94] https://cordis.europa.eu/project/rcn/91822_en.html
[95] https://cordis.europa.eu/project/rcn/44707_en.html