Heroad, Holistic Evaluation of Road Assessment

Report on environmental components: Strategies for the effective integration of environmental parameters into asset management systems

Deliverable Nr 4.1

May 2012

VTI, Sweden

TRL, UK

BRRC, Belgium

FEHRL, Belgium

ZAG, Slovenia

AIT, Austria

This project was initiated by ERA-NET ROAD.

Project Nr. 09/16771-39

Project acronym: HEROAD

Project title:

Holistic Evaluation of Road Assessment

Deliverable 4.1 – Report on environmental components: Strategies for the effective integration of environmental parameters into asset management systems

Due date of deliverable: 31.05.2012

Actual submission date: 31.05.2012

Start date of project: 01.01.2011 End date of project: 31.12.2012

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Version: 1.00

Executive summary

This document is deliverable 4.1 of the HEROAD project and covers the environmental aspects of road asset condition monitoring which can be used in asset management to achieve the desired environmental performance of the road transport system. It focuses on the operational phase roads and on assets that can be influenced by road owners and operators and which in turn exhibit quantifiable properties which influence the target environmental performance indicators. Road assets in HEROAD are pavements, structures (e.g. bridges) and road equipment. The definition of stakeholder-oriented environmental key performance indicators (E-KPIs) in the EVITA project is taken into account. However, in some cases the connections between the parameters describing the intrinsic properties of road assets and the E-KPIs are difficult to establish. This means that in such cases the tools of condition monitoring, maintenance and asset management are limited in their capability to contribute to the desired environmental results. In other cases, where clear links can be established, substantial improvements of the situation can be achieved by correctly using and maintaining the relevant road assets.

The environmental analysis in this document considers the following impacts arising from road transport:

- Noise
- Greenhouse gas emission (CO_2)
- Air pollutants including particulate emissions
- Water and ground pollution

While environmental concerns are growing, the environment-related properties of road assets are usually not the main concern in condition monitoring and asset management. The environmental impact of road traffic is well recognized on the level of national environmental policy, but the possible contributions of road owners and operators are not always easy to recognize.

This analysis has shown that in the field of noise, low-noise pavements and noise barriers are powerful tools with relatively well-understood impact on the ambient noise levels affecting the population. European efforts like the Environmental Noise Directive have contributed substantially to a common understanding. Nevertheless a full integration of noise-related asset parameters and a full understanding of their long-term performance have yet to be achieved.

In the field of greenhouse gas emissions and air pollutants, however effective assets under the control of road owners and operators are largely missing. The growing understanding of the pavement influence on rolling resistance, or the effects traffic management systems may yield more effective tools in the future. Water and ground pollution can be influenced by drainage systems and the use of porous pavements, which need to work together to achieve their full benefits.

More sophisticated models based on already monitored proxy parameters may be used to substitute specific measurements and reduce monitoring costs. Finally further research into the links between asset parameters and E-KPIs will improve the positive environmental impact of condition monitoring and asset management.

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1 Introduction

“ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” was a Coordination Action funded by the 6th Framework Programme of the EC. The partners in ERA-NET ROAD (ENR) were United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.eranetroad.org). Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research projects are Belgium, Switzerland, Germany, Denmark, Finland, France, Ireland, Lithuania, The Netherlands, Norway, Slovenia, Sweden and United Kingdom.

To manage the road network, road managers and operators have to consider existing policies such as the requirement to keep the network in good condition, and to deliver this condition at minimum whole life cost. However, the condition should also meet the expectations of stakeholders. The management process has to optimise the total costs for society, whilst minimizing the effects of given condition levels on safety, reliability, environmental impact, economics and sustainability. This principle and its overall goals are equal for all road managers around Europe. HEROAD investigates the holistic process (the combination of individual components, levels of assessment and the inclusion of a life cycle perspective) to incorporate also new challenges in the asset management. This includes

- Looking at data collection, assessment and reporting regimes
- Especially considering new challenges (climate change, traffic configuration, new materials, LCC and the focus on road users’ expectations)
- Identify and assess the key technical components of these regimes and then determine whether they are best practice or not
- Identifying and describe indicators at different assessment levels (for road operators complicated technical parameters are okay, for decision makers and public more understandable indicators that could be built from combination of technical parameters are needed)

This document is a deliverable reporting the outcomes from the work on the environmental aspects of road assets in the HEROAD project.

2 Background

The environmental impact of the road network plays an important role in the overall environmental performance of many EU countries. For example noise and air pollutant emissions are in many EU countries heavily influenced, if not dominated by the sources arising from road transport.

For this reason road owners and operators are facing increased pressure to ensure ecological sustainability and minimized environmental effects. In order to achieve the desired results it is essential to integrate environmental parameters into asset management while taking into account that they may require special considerations different from other functional parameters. Environmental performance often depends on the combined properties of road components which are currently managed separately, like in the case of road pavements and noise barriers, which together determine the noise pollution generated by road traffic. Additionally the impending effects of climate change will in turn present additional challenges to asset management.

HEROAD focuses on asset management based on condition monitoring in the operational phase of road networks. Therefore the environmental impacts considered in HEROAD are noise, air pollutants and particulate emissions, greenhouse gas emission and energy consumption, and water and ground pollution (see also [26]).

The following environmental questions are addressed by HEROAD:

- Which environmental or environment-related parameters are currently being measured and monitored during the operational phase? Which data are available for asset management?
- Which special considerations are necessary to achieve effective management of the environmental output of a road network?
- Which role do environmental parameters play in the performance assessment of road assets? Are they integrated into decision-making processes?
- How are the environment-related properties of road assets managed? Which road assets are seen as the primary tools to addressing environmental problems? How are components with primarily environmental functions managed?
- Are there combined parameters to evaluate the overall environmental performance? Are there combined parameters for partial aspects, e.g. total energy or noise performance?
- How does environmental management perform on the local and on the network level?
- Which priorities are assigned in the process of managing environmental performance? (e.g. preferences for certain pavement types, noise barriers, etc.)
- How can asset management contribute to achieving long-term environmental sustainability?
- What are the potential benefits of a harmonised EU approach to environmental performance of road assets? (e.g. in the light of the Environmental Noise Directive)

Ideal environmental management systems would rely on appropriately measured performance, long-term monitoring, proven harmonised evaluation tools and optimised cross-asset maintenance strategies. While this ideal is currently not realized, elements from different countries can provide stepping stones towards this objective.

The results of this work will be taken forward to task 5 where the implications of environmental performance for decision making will be analysed in Deliverable D5.

3 Methodology

The results presented in this document are based on a mix of literature research, evaluation of previous projects, analysis of environmental reporting by national road administrations and expert interviews and discussions. The focus of the research was on asset condition data available on the network level which can be used to gauge the impact of assets on environmental performance.

Part of the information collection was performed using an interview guideline consisting of a set of questions for each of the three identified asset types of pavements, structures and road equipment, complemented with more general questions concerning the management of environmental performance.

One set of research questions is centred on the environmental awareness of key players in the different countries, usually comprising the transport and environmental ministries and the national road administrations. The overall framework for this is set by the national environmental policies in combination with legal requirements on national and EU level. The comparative relevance of the sectors contributing to pollution will be evaluated by the environmental ministry or an environmental protection agency. The importance attributed to road transport as a source of emissions determines the priority given to environmental issues by the national road administrations. If there is sufficient awareness of the role of road infrastructure, national road administrations will have incentives to include environmental aspects into their asset management.

At this point the question arises if the national road administrations have the tools and necessary information to influence the emissions created by road traffic. While the construction and maintenance processes can be tightly controlled by road administrations, many environmental impacts during operation are linked to the traffic volumes, percentages of heavy vehicles and the typical emissions of individual vehicles, where only limited control is possible. Therefore the investigations also focused on the question which road infrastructure assets could be used to reduce road traffic emissions. Obvious examples are noise barriers or low-noise pavements for the purpose of noise abatement. In the case of these dedicated road assets direct management of the desired performance is quite feasible and is actually performed in several EU countries.

For other road assets the link is not quite so obvious, e.g. the effect of tunnels on air pollutant emissions. However, in both cases it is important to identify properties of the relevant assets which can be monitored to ensure satisfactory environmental performance.

The question of which asset parameters to monitor and to include into asset management can be quite difficult in the case of environmental issues. While ambient levels of noise, air pollutants or particulates can be readily measured in the residential areas surrounding roads, typically only a part will be attributable to road traffic. E.g. particulates levels are also influenced by nearby industrial activity and domestic fuel use, which can create a substantial ambient background. Emission models can be used to predict the impact of roads on the overall ambient levels, but not all are sophisticated enough to take specific road asset-related parameters into account. For example ambient noise levels can be calculated by using traffic speed, composition and volume, pavement type and presence of noise barriers. However, the current maintenance state of pavements and noise barriers may cause them to deviate from their design values. This information is usually not available and not included in model calculations.

For this reason environmental condition monitoring of road assets needs to focus on parameters which quantify asset-specific emissions directly or where a model exists, which allows it to deduce the environmental performance from other non-specific parameters with satisfactory accuracy. One example for this would be the determination of rolling resistance of pavements, which is linked to CO_2 emission of road vehicles. Rolling resistance could either be measured directly with a dedicated trailer or calculated using a model based on surface texture measurements.

The following chapters will discuss and analyse these topics based on the information available at the time of writing.

4 Stakeholder expectations

The environmental impact of road assets should ideally meet both the stakeholder expectations and the legal requirements and limits. The basic stakeholder expectations in the field of environment are listed in Table 4-1. However, the conservation of the environment is in most cases regarded as a public good. As the road user himself is often unaware of the environmental impact of his use of the road infrastructure, requirements usually arise from legislation and regulations intended for environmental protection. These apply to both the road user and the road operator.

Stakeholder expectations with regard to the environment were investigated in the EVITA project [1]. The results showed that the stakeholders most concerned with environmental issues of road infrastructure are the neighbouring residents, the general public and the road administrations. Communication of these expectations to the road administrations takes the form of specific policy, legislation and regulations, general media coverage, and in some cases protests.

Main drivers in formulating the desired environmental performance are the national and EU environmental programmes and legislation. The most important EU directive with respect to noise emissions is certainly the Environmental Noise Directive (END, 2002/49/EC) [4]. This document requires every EU member state to provide strategic noise maps and associated action plans for road, rail and air transport noise every 5 years. While not stipulating common limit values, the activities surrounding the noise mapping and the action plans have certainly increased the environmental awareness of road administrations across Europe. Several countries have commissioned additional investigations in parallel or based on the results of strategic noise mapping. One of the main obstacles still to be overcome is the current lack of common noise calculation models. While the first two instances of noise mapping have been carried out using existing national methods or the default method proposed by the EU, the next noise maps are planned to be based on a common calculation scheme. This will be based on the outcome of the CNOSSOS-EU project performed by the Directorate General Joint Research Centre (JRC).

Another EU directive with major impact is the directive on ambient air quality and cleaner air for Europe (2008/50/EC) [5]. It calls for the assessment of air quality in the EU member states on the basis of common methods and criteria and requires the creation of air quality plans and fixed measurement stations in areas where the target or limit values are exceeded. The regulated pollutants comprise NO_x, SO_2, PM_{10} and $PM_{2,5}$, lead, benzene, ozone and carbon monoxide.

Stakeholder	User (commercial and private)	Owner/Operator	Public/Neighbours
Environmental Impact - what the stakeholder expects	The main expectations of road users are centred around travel time, availability, safety and accessibility. Environmentally aware users may expect their emissions (noise, CO_2, air pollutants, particulates) to be low. However this is usually also dependent on vehicle technology and usage patterns and not only on road infrastructure assets.	Owners are faced with the task of meeting legal requirements and demonstrating efforts to reduce the environmental impact of the road transport system. They expect information and guidelines on the environmental impact of road assets they can control and the impact of their actions on the affected environment and population. This helps them to shape their condition monitoring and asset management practice to meet the desired goals.	Neighbours and the public expect noise, air pollutants, particulate emissions, and water run-off to be at a minimum in order to safeguard their health and conserve the natural environment. These expectations are often expressed in laws and regulations.
Environmental Impact - Ideal measurement practice	Awareness building measures can help to engage users in reducing their environmental impact. This concerns their choice of vehicle and tyre, driving patterns, choice of speed, and choice of transportation mode. Users are ideally presented with combined information showing their environmental footprint.	Owners need specific condition monitoring methods that show how road asset properties are linked to the impact on the environment. The results of condition monitoring can then be used as input for asset management systems.	The environmental impact as seen from the point of view of the public and neighbours can be determined by the pollution levels that are present at nearby residents' homes. Examples are façade noise levels, air pollutant and particulates concentrations in residential areas and contaminant levels in ground water. These impacts are often not exclusively attributable to road transport and it may also be difficult to discern the effect of individual road assets on these pollution levels.

Table 4-1: Stakeholder expectations concerning environmental performance

5 Environmentally relevant assets

5.1 Noise

In the case of noise, there are road assets which are used specifically to combat noise emission. Road infrastructure assets mainly influence tyre/road noise, noise propagation and to some extent traffic speed. Traffic volumes and composition, which are major determinants, can usually not be influenced by road assets.

a) **Noise barriers:** The most widely used noise abatement measures are noise shields in the form of noise barriers, enclosures, earth berms or even tunnels. They act by preventing noise from propagation in a direct line from the noise sources on the road to the receivers in the adjacent residential areas. Classical noise barriers have three important properties: High sound insulation, high sound absorption and low sound diffraction over the barrier top (see Figure 1).

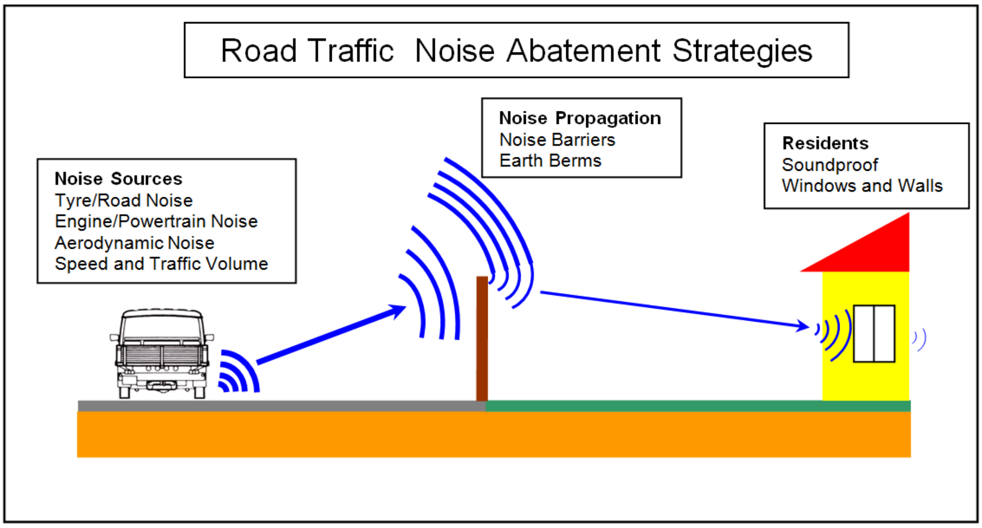

Figure 1: Road traffic noise abatement with noise barriers

Sound insulation describes the ability of the noise barrier to prevent sound from passing through it, whereas sound absorption reduces the sound reflected back from the barrier. Both are important intrinsic characteristics of noise barriers and can be tested in the laboratory according to EN 1793-1 [6] and EN 1793-2 [7] or in-situ according to CEN/TS 1793-5 [8] or prEN 1793-6 [9]. If both are at a sufficient level, the noise barrier can be modelled as a non-reflecting impenetrable barrier and only the sound diffraction at the barrier top needs to be considered. While there are attempts to also quantify this phenomenon as an intrinsic property of the barrier (see [10]), the noise levels at the receiver position are still strongly dependent on the barrier height, the local topography and the relative positions of sound source and receiver. The resulting insertion loss due to the presence of the barrier can typically range from 0 dB up to 20 dB depending on these circumstances.

This means that ensuring a sufficiently low noise level in the residential area is a task for noise abatement planning, while condition monitoring of noise barriers will typically focus on physical integrity and maintaining high sound insulation and absorption.

b) **Low-noise pavements:** Pavements interact with the tyres of road vehicles by generating tyre/road noise or rolling noise. Rolling noise of vehicles is typically broadband noise with a single peak at 800 or 1000 Hz. The low-frequency portion of the noise below 1000 Hz is due to the tyre vibrations which are induced by the interaction of tyre tread and road surface texture. The high-frequency portion is caused by air pumping, i.e. air compression and decompression in the cavities between tyre tread and road surface. The choice of the road surface gives rise to a variation of tyre/road noise of up to 15 dB if extremes like Belgian Block and porous asphalt are included [11]. The noise reduction potential of conventional dense road surfaces like stone mastic asphalt (SMA), asphalt concrete (AC) or exposed aggregate cement concrete (EACC) is mainly due to texture optimisation. Thin layer asphalt with small maximum chipping sizes is one of the most silent dense road pavements. However, with the introduction of single- and double-layer porous asphalt substantial noise absorption at the source can be added, which substantially increases the noise reduction potential.

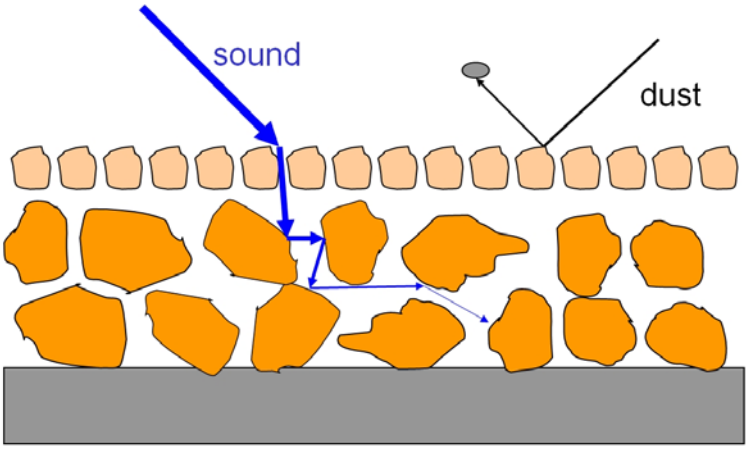

Figure 2: Principle of low-noise double-layer porous asphalt pavements

The noise reduction of low-noise pavements compared to conventional pavements rests on their texture and pore structure properties. If these properties are compromised, e.g. by ravelling, polishing or clogging of the pores, the low-noise surfaces can rather quickly revert to higher noise emission. Noise emission from pavements can be measured directly by using the Statistical Pass-By method (SPB, ISO 11891-1 [12]) or the Close-Proximity method (CPX, ISO/CD 11819-2 [13]). In principle it is also possible to derive the noise emission from texture measurements and sound absorption data using models like SPERoN [14].

c) **Noise reduction by control of traffic flow, composition and speed:** Road equipment like variable message signs (VMS) or variable road signs can be used in traffic management to control traffic flows. An impact on noise is possible if lower speed limits or access restrictions for heavy vehicles can be enforced in this way. However the role of the road assets themselves in this case is restricted to performing their functions as conveyors of information.

5.2 Greenhouse gas emission (CO_2)

Greenhouse gas emissions are typically expressed as CO_2 equivalents (CO_2e), as CO_2 is the main component. Greenhouse gas emissions have a global impact by contributing to climate change and global warming, in contrast with air pollutants or noise, which have a much more localized effect. For this reason only the total CO_2 emission is relevant, independent of the type or location of the source. The most important sources are power plants, industrial activities, transport activities, fuel use for heating purposes and agriculture. CO_2 emissions from road transport constitute the largest portion of transport-related CO_2 emissions by far, and they are constantly increasing (see Figure 1). While major efforts are underway in the car industry to develop low-emission or zero-emission vehicles, there is also a potential of a contribution by the road infrastructure.

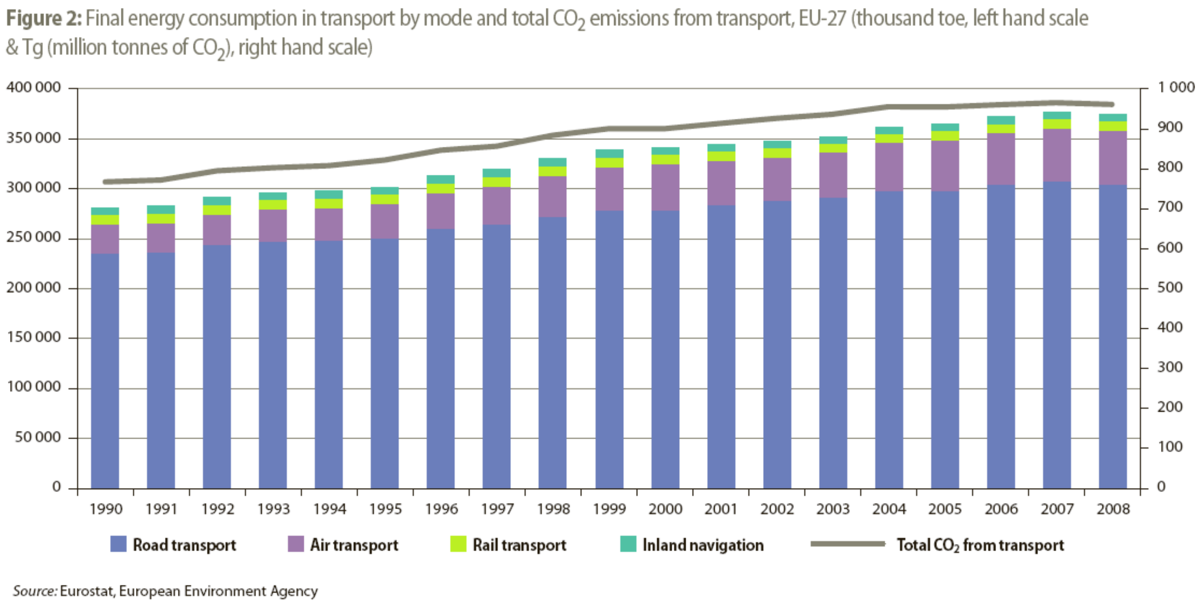

Figure 3: Energy consumption and CO_2 emissions from different transport modes [20]

CO_2 emission in the operational phase of roads is mainly due to the emissions from the fuel consumption of road vehicles traveling on the road infrastructure. In order to convert traffic volumes into CO_2 emissions, tables of emission factors and associated models can be used [16] [19]. The following groups of factors influence fuel consumption and greenhouse gas emission:

1) Traffic volume, composition and speed profiles
2) Fuel composition
3) Vehicle technology (engine, transmission, suspension, tyres)
4) Air resistance
5) Road layout (gradients, curves, intersections)
6) Road surface (evenness, texture, rolling resistance)

Only a small portion of these factors can be influenced by road assets. Apart from traffic management, only road layout and road surface are fully under the control of road owners. However, road layout is typically fixed in the planning and construction phases, so that the pavement remains as the major road asset that can be influenced and monitored by national road administrations.

The main characteristic of pavements that influences fuel consumption of road vehicles is the rolling resistance [23] [24]. Rolling resistance is a measure for the force opposing propulsion that arises from tyre-road interaction. Current models assume that the pavement-dependent portion of rolling resistance mainly depends on macrotexture (MPD) and unevenness (IRI), apart from a speed dependence. In [21] and [22] the effect of optimizing road surfaces on the Danish road network for low rolling resistance is analysed, which resulted in an estimated fuel saving potential of 3.3%.

5.3 Air pollutants (NO_x), particulate emissions

Air pollutants are substances and aerosols residing in the air with detrimental effects on human health and the environment. The most important air pollutants are Nitrogen oxides (NO_2 and NO_x), sulphur oxides (SO_2), ammonia (NH_3), particulate emissions (PM_{10} and $PM_{2.5}$), ozone (O_3), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), hydrocarbons (HC), lead and mercury. A high correlation with road traffic can be found for NO_x (including NO_2), PM_{10} and $PM_{2.5}$, and to some extent for NMVOC. However, air pollutants are not exclusively emitted by road traffic. There are in all cases substantial background concentrations from industrial activity, heating, energy production or agriculture. Moreover, air pollution is a strongly location-dependent phenomenon, which is also heavily influenced by meteorological conditions. A clear connection to road traffic as the source of air pollution can mainly be determined in the immediate vicinity of roads.

NO_x and PM emissions due to road vehicle emissions can be calculated using the same tools as described in 5.2 (e.g. [16]). The main basis of calculations is again the traffic volume, composition and speed profile. Emissions are derived using emission factors which convert fuel consumption into emitted amounts of NO_x and PM.

Apart from the vehicle-based emissions abrasion of material from road surfaces and winter maintenance is an additional source of particulate matter.

For this reason, as in 5.2, the most important road asset for road traffic emission of air pollutants is the pavement. Road equipment which is part of traffic management systems like traffic lights, or variable message signs (VMS) can also contribute to the reduction of air pollution if it helps to avoid stop-and-go traffic or congestion. There are also trials using pollutant-absorbing noise barriers or catalytic surfaces, but they are still in the experimental stages.

5.4 Water and ground pollutants

Water and ground pollution in the operational phase of roads can be assessed by measuring the levels of heavy metals like lead and zinc, hydrocarbons including polycyclic aromatic hydrocarbons (PAH) and de-icing salts (Sodium and Calcium Chloride) in those media. Pollutants are typically part of the run-off mainly from pavements, but also from other road structures (see [17] and [18]). Run-off contains deposits from fuel combustion, tyre and pavement abrasion, leakage from the pavement and structures, and leakage and wear products of road vehicles. Precipitation or dust fall can also introduce originally airborne pollutants. The presence of de-icing salts is due to winter maintenance.

Relevant road assets are the pavement and especially the drainage systems. Collection of the pollutants in the drainage systems allows the application of treatments like gravity settling, filtering or biological and chemical neutralisation.

Porous road surfaces used also for reducing noise pollution have a mixed effect on water pollutants [18]. On the one hand the drainage through the porous structure reduces pollutant deposition through splash and spray considerably and allows more of the pollutants to be collected in the drainage system, where they can be treated accordingly. This of course requires the prevention of clogging. On the other hand much more de-icing agent is necessary for porous surfaces compared to dense surfaces. The overall effect may be seen as beneficial, as the removed pollutants like PAH are more detrimental to the environment than de-icing salts.

6 Measurement and management of environment-related asset parameters

The EVITA project has evaluated so-called environmental key performance indicators (E-KPIs) related to stakeholder needs which are currently in use [26]. The relevant key performance indicators discussed in [26] will be linked to the asset parameters accessible to condition monitoring by national road administrations in the following sections. The focus of HEROAD is on the relevant asset-specific parameters that are known to influence the E-KPIs and which are accessible to asset condition monitoring. The chain of influences is shown in Figure 4.

Figure 4: Chain of influences from assets to E-KPIs

6.1 Noise emission

The following noise E-KPIs for noise were analysed in [26]: Equivalent continuous sound level L_{eq} or $L_{Aeq,T}$, Day-Evening-Night equivalent level L_{den}, Night time level L_{night}, and the sound absorption coefficient. The first three E-KPIs are derived from calculation or measurement of the ambient noise levels at the resident's location. L_{den} and L_{night} are defined by the Environmental Noise Directive [4] and have to be reported in strategic noise maps. This information is combined with information on the location and number of the affected residents to give an indication of the amount of noise exposure of the population.

The ambient noise levels at the resident's location are influenced by the following main factors on high-level road networks:

1) traffic volume, composition and speed
2) local topography and relative positions of source and receiver
3) ground and air absorption along the sound propagation path
4) presence of noise barriers or other natural or artificial sound propagation obstacles
5) pavement type and maintenance condition

All factors 1-5 have to be taken into account in the initial road and noise abatement planning and construction phase. However, once in operation, the ambient noise levels are in most cases not measured directly but calculated using models based on the changes in traffic. Ambient noise measurement networks are typically operated in urban or residential areas, which make it difficult to attribute changes directly to the performance of road assets. The road assets which are accessible to condition monitoring in the operational phase are pavements and noise barriers.

The following condition monitoring techniques are available:

a) **Noise barriers:** As pointed out in 5.1 the key technical parameters of noise barriers are sound insulation and sound absorption. While on-site condition monitoring techniques based on acoustic measurements are available (see [8] and [9]), they are still not used for standard inspections. Typical condition monitoring includes a visual inspection to detect damage, ensure the structural integrity and prevent safety hazards. The monitoring intervals for noise barriers e.g. in Austria include a survey every year, an inspection every 4 years, and a major assessment every 12 years. The inspector looks for e.g. corrosion of metal parts, cracks, deformation of elements or dislocation of posts.
Some of these damages do actually have an impact on acoustic properties. Sound insulation is typically compromised when gaps between elements or between element and post are allowed to develop. Sound absorption is affected by loss of sound absorbing material. However, some acoustic changes are difficult to detect by visual inspection alone, like compaction of absorption material due to humidity, clogging of porous structures or failure of seals between post and elements. For this reason it may be advisable to use condition monitoring techniques based on acoustic measurements ([8], [9]) in addition to visual checking.

   Maintenance activities for noise barriers will typically consist in the replacement of damaged elements or even the rebuilding of sections of the barrier.

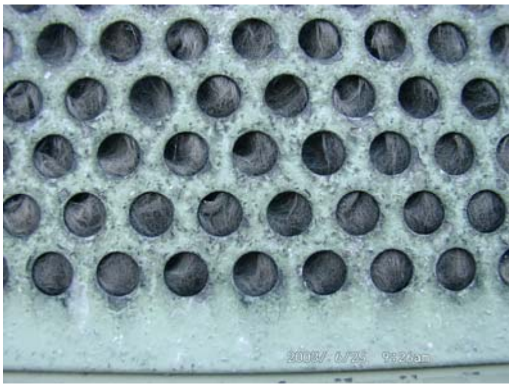

Figure 5: Loss of absorptive material from a noise barrier element

Figure 6: Gap below a noise barrier

b) **Low-noise pavements:** The noise emission of road pavements can be directly monitored using the SPB [12] and/or CPX [13] measurement method. The SPB method is based on the measurement of a statistically significant number of individual vehicle pass-by events at the road side. It can characterize pavement influence on overall vehicle noise emission, separately for passenger cars and heavy vehicles. While it can be related to ambient noise measurements at resident's homes, it is only valid for a relatively short road section (100 m), is time-consuming and assumes that the vehicle collective does not change substantially between different measurements. SPB also requires acoustic free-field conditions without obstacles like noise barriers or buildings, which severely limits the selection of measurement sites. Moreover the speed range depends on the speeds actually occurring in the vehicle collective, which may limit the validity of results for other speeds. The SPB method is most suited for initial characterization of pavement noise emission, less for continuous monitoring. The Controlled Pass-By (CPB) method is a variant of SPB with a small, controlled number of measurement vehicles covering a wider speed range.

The CPX method uses a dedicated trailer or vehicle and measures the noise emission very close to the tyre/road contact of a small set of selected representative measurement tyres. The measurement can be performed at traffic speeds over long distances, and is therefore more suitable for network monitoring. Ideally SPB and CPX are combined, with SPB used for initial characterization of pavement types and CPX used for approval testing and long-distance monitoring. However, the correlation between SPB and CPX is not always satisfactory, so that additional initial CPX measurements may be needed.

The sound absorption coefficient of pavements is mainly of interest for porous pavements. In-situ measurements [15] are available and can be used to document loss of performance due to clogging of the pores.

Acoustic condition monitoring of low-noise pavement currently mainly uses variants of the CPX method or repeated SPB measurements. The use of ambient measurements for continuous monitoring is also possible, but requires the installation of a fixed noise monitoring network.

Some information concerning the acoustic performance of pavements can also be derived from non-acoustic condition monitoring. The observation of ravelling, loss of material, polishing, reduction of texture depth and clogging of porous surfaces can indicate a degradation of the noise reduction performance. However, in order to quantify this degradation, specific measurements are still required.

Maintenance activities for low-noise pavements may include surface treatments, replacement of the top layer, or declogging of porous pavements.

6.2 Greenhouse gas emission (CO_2)

As pointed out in 5.2, total CO_2 equivalent emissions from road transport are the most important stakeholder-oriented environmental key performance indicators (E-KPIs) in this field, which is also recognized in [26]. Rolling resistance of pavements is the most important asset property accessible to management by national road administrations which can influence this E-KPI. Measurement of the pavement contribution to rolling resistance is carried out in one of the following ways [25]:

1) Measurement with dedicated rolling resistance trailer at traffic speeds
2) Coast-down measurements with standard road vehicles
3) Drum measurements using a steel drum (ISO 28580 [29])

4) Drum measurements using selected tyres and a drum coated with a pavement surface

A round-robin test of trailers and drums using methods 1 and 4 has been carried out in the framework of the MIRIAM project [25] [27]. However, repeatability and correlations between the results have so far been unsatisfactory. Method 2 has been investigated in the ECRPD project [23]. The resulting model incorporates the relevant mechanisms, however the uncertainties of the experimentally determined parameters are still deemed too high. Method 3 is the one currently used for type approval of tyres, however as only a steel drum is used, no pavement effect can be derived. All methods suffer from the fact that measuring the pavement influence on rolling resistance means measuring very small effects in the presence of much larger ones, like the effect of road gradients. Therefore all other causes of driving resistance must be carefully eliminated before pavement-related rolling resistance can be deduced. For this reason the current measurement methods and models have to be further developed.

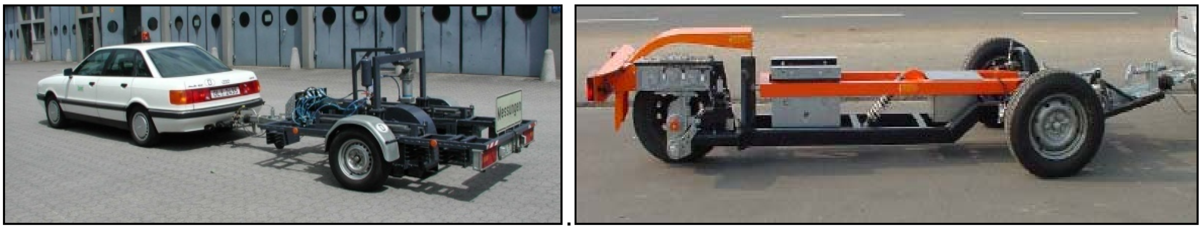

Figure 7: Different rolling resistance trailers for passenger car tyres [28]

6.3 Air pollutants (NOx), particulate emissions

The measurement of air pollutants and particulate emissions is typically performed using fixed or mobile monitoring networks in urban or residential areas as required by EU Directive 2008/50/EC [5]. These measurement devices operate according to standardized measurement methods (e.g. [31][32][33]) and determine the ambient air pollutant concentrations. However, as these concentrations are also influenced by other sources, there is often no direct link to the performance of road assets. The relevant E-KPIs from EVITA [26] are the ambient levels of pollutant concentrations.

The influencing factors which can be controlled by national road administrations in the operational phase via road assets are rolling resistance of pavements and winter maintenance. For a detailed discussion of measurement and modelling of rolling resistance, see 6.2. Optimization of winter maintenance may be able to reduce the PM levels; however, there is a strong dependence on weather conditions and safety requirements, which usually go before environmental considerations. Air pollution in tunnels is a special case, which can be solved by the installation and maintenance of ventilation systems. Road equipment used to influence traffic flow (traffic lights, traffic management systems, VMS) can also help to reduce air pollution. Condition monitoring of road assets in this case, however, will be focused on keeping the system components functional and in good order.

6.4 Water and ground pollutants

Water and ground pollution measurements are usually not conducted in association with road condition monitoring. In the case of road accidents with suspected contamination, specific investigations may be launched. The potential release of dangerous substances must be addressed in the planning and construction phase of road assets. The relevant E-KPIs from EVITA [26] are the levels of pollutant concentrations found in water and soil. The main road asset connected with the avoidance of water and ground pollution is the drainage system, which is subject to regular condition monitoring concerning its functionality. The presence of de-icing salts in the runoff water can be addressed via optimization of winter maintenance. Moreover, reduced fuel consumption due to low-rolling resistance pavements will also contribute to a reduction of water and ground pollution. For a discussion of rolling resistance, see 6.2. In order to reap the benefits of porous road surfaces, clogging of the road surface must be prevented or repaired.

7 Use of environment-related data in asset management

7.1 Environmental policy

Due to its numerous environmental impacts, road transport and its effects figure prominently in the environmental policies of European countries. These policies are generally defined at the level of the environmental ministry or it national equivalent. Consequently national road administrations are required to provide environmental action plans or sustainability reports which describe their contribution to achieving the national environmental targets. Examples are the sustainable development plan [37] and the environment strategy [38] of the UK Highways Agency or the annual Sustainability Report [39] of the Austrian ASFINAG.

7.2 Noise

Noise-related performance of road assets is currently only investigated for road assets specifically dedicated to noise reduction, which comprises low-noise pavements, noise barriers, berms and semi-enclosures, and absorptive claddings inside tunnels. While those assets form part of the noise abatement planning required when constructing new roads or rehabilitating existing ones, their noise-reducing performance is often assumed to be fixed and continuous monitoring over time does not include acoustic parameters. This of course results in a lack of noise-specific data in asset management systems. While degradation of acoustic performance can be inferred from condition monitoring activities like physical inspections of noise barriers or pavement surfaces, the exact impact cannot be quantified.

According to the 2010 report of the CEDR noise group [41] 65% of the surveyed countries do include noise emission as a parameter in the selection of new road surfaces, however only 10% have it included in their national pavement management systems.

In the Netherlands (see [43]) the use of low-noise pavements is very widespread and even fixed in the legal framework. In 2007 approximately 70% of the high-level road network was covered with single-layer porous asphalt, which is higher than in any other European country. However, on the high-level road network the noise performance is established only once in a type test, and there are no further conformity of production (COP) tests. Evenness, skid resistance, rutting, ravelling, and tearing are annually monitored on those pavements, but no acoustic properties. Low-noise pavements on the local road network are however treated differently, as the noise performance has to be proven to obtain funding from the national government. In this case both an initial COP test and checks after 2, 5, 8 and 11 years are carried out using the CPX method. In contrast to the initial test the following checks do not have financial consequences. The results are converted into SPB values and compared to the required noise reduction. The pavement has to be replaced with one which is at least as silent as the current one.

In Switzerland (see [43]) the use of noise abatement solutions is guided by the calculation of a so-called “Index of Economical Sustainability”, which is based on a cost-benefit analysis of the noise reductions achieved at the neighbouring residents’ locations for the different possible combinations of noise barriers and low-noise pavements. Porous asphalt and asphalt concrete with smaller chipping size are used as standardized low-noise pavements. While there is acoustic monitoring of pavements form the start (using CPX), it has no consequences.

In the UK (see [43]) the use of low-noise pavements is a key tool of the UK Highways Agency for preventing noise pollution (target: 60% of high-level network). The decision has been taken to use thin surfaces with RSI (road surface influence) values < 2,5 dB(A) within the UK HAPAS system. HAPAS contains a procedure for issuing noise performance certificates for low-noise surfaces, which include monitoring of noise levels after 12 months and of texture depth after 24 months. They are supposed to have a lifetime of 8-12 years. One the certificate has been issued, no further monitoring of laid surfaces is performed.

A key recommendation of [43] was that the widespread application of low-noise pavements should be accompanied by:

- A specification of minimum requirements for the acoustic performance during the guarantee period
- Initial conformity of production testing
- Set up a monitoring system to check the long-term performance

These recommendations are a combination of the practices detailed above and would make the full integration into an asset management system based on asset-related parameters very easy.

Moreover these recommendations could also be extended to noise barriers, as they are subject to a harmonized European standard (EN 14388 [44]) with supporting standards covering acoustic (EN 14389-1 [45]) and non-acoustic durability (EN 14389-2 [46]). The expected acoustic durability even has to be stated in the CE mark certificate. The EU project QUIESST [47] is currently investigating the associated measuring methods for acoustic performance and will provide guidelines for the use of noise barriers. From the investigations in HEROAD it can be deduced that condition monitoring of noise barriers with respect to damages and physical integrity, including corrosion of metal parts, cracks, deformation of elements or dislocation of posts. However, condition monitoring of the intrinsic acoustic properties of noise barriers is uncommon. Replacement will mainly be based on visible damage or deformation, or if the ambient noise reduction in the residential areas is deemed insufficient. However, it would also be possible to move to in-situ monitoring of the acoustic parameters specified in EN 14389-1.

7.3 Greenhouse gas emission (CO2)

As pointed out in 6.2 the relevant road asset in this field is the road pavement and its associated rolling resistance. As the current measurement and modelling methods are still in different stages of development, to date no country has included rolling resistance condition monitoring of pavements into their asset management system. Some indication of high or low rolling resistance could be inferred from other condition measurements (texture, unevenness) using the existing models. However interest in the field is high and several on-going projects (e.g. MIRIAM [27], MIRAVEC [30]) are striving to improve the available information and methodology.

Typical measures to reduce greenhouse gas emissions from road transport other than low rolling resistance pavements do not focus on road assets, but try to induce a shift to other modes of transport or promote the development and use of low- or zero-emission (electrical) vehicles.

Current research on the Swedish VETO model [23] and similar models as well as on measurement methods for rolling resistance may yield the possibility to monitor rolling resistance directly or via proxy parameters like evenness and texture which are already monitored routinely. This could enable a similar approach as for noise in the near future.

7.4 Air pollutants including particulate emissions

Air pollutants, including particulate emissions are a major concern for local air quality and are often addressed at a local or regional level. The monitoring and action planning required in [5] leads to the availability of good overall information on air pollution. Local air pollution can also be calculated using available models. However, the link to specific road assets which can be used to influence air pollution like in the case of noise is missing in many cases.

In the UK road transport accounts for around one third (33.5%) of total NO_x emissions, which is comparable to Austria (50%), France (54%) or Slovenia (58%). VMS are used in the UK together with management of the road layout and gradients during the construction phase in order to ensure a continuous traffic flow and avoid congestion. The strategy for managing air quality on the UK road network can be found in HA 207/07 0.

The generation of particulate matter through abrasion of tyres and road surface gives rise to substantial local concentrations of PM. These concentrations depend on speed, tyre and pavement type. There are indications that the choice of pavement can influence the resulting PM concentrations [49]. However, currently no asset-specific condition monitoring systems of PM apart from the ambient monitoring according to the requirements in [5] were reported to be in place.

PM generation from winter maintenance is closely linked to weather conditions and winter maintenance procedures. This problem is usually addressed by optimizing those procedures and not by any road asset properties.

7.5 Water and ground pollutants

Water and ground pollution levels can be readily measured or modelled, but this is usually not part of regular condition monitoring of roads. Pavements and their associated drainage systems form the most important asset for controlling the water and ground pollution levels. They are subject to condition monitoring; however the monitored parameters are not specific to this environmental issue.

In the UK drainage data for the drains present on the Highways Agency network is stored in the Highways Agency Drainage Data Management System (HADDMS). This is populated with inventory data for an estimated 40% of the network. However, drain performance data is not collected on a routine basis on any of the road networks. Chemical testing of the content of water run-off is performed.

In other countries no environment-specific condition monitoring and maintenance was reported. As atypical example in Austria drainage system inspection and maintenance is based on visual inspections, one immediately after construction followed by inspections once or twice a year depending on the type of drainage system component. These inspections are mainly concerned with detecting damage and obstructions of the drainage systems and ensure its proper functioning.

Countries with a high percentage of porous road surfaces like the Netherlands also benefit from the effects pointed out in 5.4, especially the avoidance of aerial dispersal, as long as the pavement remains unclogged. Declogging and correct disposal of the cleaning water are essential to maintain this beneficial aspect. Currently declogging as a standard maintenance measure is only performed in the Netherlands.

8 Conclusions and recommendations

This investigation has shown that road traffic noise is the environmental issue that is best recognized by national road administrations and where specific road assets to address the issue exist. Moreover condition monitoring methods are available to assess the noise-reducing properties of these assets and their development over time. However, the actual use of these methods varies from country to country. The existence of several different noise calculation models across Europe contributes to the lack of a uniform assessment of the role of road assets in noise abatement.

Due to the requirements from strategic noise mapping for the purposes of the Environmental Noise Directive a common European noise calculation method for road traffic noise is being developed in the CNOSSOS-EU [40] project. This calculation method includes parameters for quantifying the influence of road pavements on road traffic noise emission. However, due to the differing national noise calculation methods in use it will be very difficult to derive suitable input parameters for the CNOSSOS-EU method. For this reason a common standardized European method for the characterization of the pavement influence on road traffic noise emission, which is compatible with CNOSSOS-EU would be very desirable.

In addition to this also improved data on the long-term acoustic behaviour of noise-related road assets are necessary to achieve a holistic evaluation of their performance and benefits. These are prerequisites for the successful holistic integration of noise-related parameters into asset management. While substantial elements of such a system have been found in several countries, other desirable elements are still lacking.

The specific recommendations for noise can be summarized as follows:

- Available specific road asset condition monitoring methods for noise should be used
- In-situ acoustic measurement methods for the condition monitoring of noise barriers and pavements should be performed.
- Common European assessment methods for noise-reducing assets compatible with CNOSSOS-EU need to be promoted.
- Minimum requirements for the acoustic performance of assets during the guarantee period should be stated.
- Initial acoustic conformity of production testing of assets should be performed
- A monitoring system can be used to check the long-term performance and to derive deterioration models.

In the field of greenhouse gas emissions (CO_2) the further investigation of the pavement influence on rolling resistance is important. Improvements in both measurement and modelling methods are needed to yield asset-specific parameters that can be readily introduced into asset management. However, the potential benefits on a national and European scale are high, and therefore additional effort can be recommended. Specific recommendations for greenhouse gas emissions (CO_2) are:

- Improvement of measurement methods and modelling of the pavement influence on rolling resistance
- If modelling is successful, proxy parameters like texture and evenness can be monitored

- Direct measurements of rolling resistance will be needed, at least for validation purposes
- Ultimately the same approach as for noise can be followed

Concerning air pollution including particulate emissions the monitoring and modelling of ambient levels has reached a high standard. The situation is the same for water and ground pollution. However, in both cases there are difficulties in linking specific asset parameters, which can be monitored and managed, to the environmental key performance indicators relevant for the stakeholders. Any improvements in reducing the pavement contribution to vehicle fuel consumption will also help to reduce air, water and ground pollution levels. Specific recommendations for air, water and ground pollution are:

- Reductions in rolling resistance and consequently fuel consumption will also reduce pollutant output.
- The possibility of absorbing or catalytically converting air pollutants on pavements and structure surfaces need to be investigated.
- Optimization of the use of porous pavements in connection with well-equipped drainage systems will benefit water and ground pollution.

Finally some general recommendations can be given concerning the link between road assets and the desired environmental effects:

- The development of reliable models based on already monitored road asset properties like pavement texture may reduce the costs of condition monitoring and yield new insights.
- An assessment of the environmental effects of traffic management may yield additional pollutant reduction potentials.
- Further research investigating the links between asset parameters and the stakeholder-oriented E-KPIs is recommended.
- Consistent collection of data concerning the environmental asset performance over time is needed to establish deterioration models.
- The combined E-KPIs defined in EVITA can be used for overall environmental assessment, but the individual E-KPIs are needed to pinpoint the problems in specific areas.

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