Tomorrow's Road Infrastructure Monitoring and Management

TRIMM

Collaborative project FP7-285119

Seventh Framework Programme

Theme: Advanced and cost effective road infrastructure construction, management and maintenance

Deliverable D2.6

Guidelines for Implementation of Monitoring Systems and Indicators

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n°285119

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Due Date	30/10/2014
Delivery Date	11/11/2014
Work Package	Work Package 2 Asset Management
Dissemination level	PU - Public

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Abbreviations

Abbreviation	Meaning
NRA	National Road Administration
LCC	Life cycle costs
IRI	International Roughness Index
WLP	Weighted longitudinal profile
CI	Condition indicator
PI	Performance indicator
TP	Technical parameter
AMS	Asset management system
SCBA	Societal cost-benefit analysis

Definitions

Term	Definition
Asset	A physical component of a road system or network. An asset is considered worthy of separate identification if it delivers services or benefits to the community which are of sufficient current or future value to warrant control and management on an individual basis.
Asset management	System and activities with the purpose to maintain value and function of entities such as roads (consisting of asset components) or components of roads such as bridges, pavements, road markings, ITS, etc.
Impact	Influence on subjects that is not related to desired function, such as impact related to environment on global, regional or local level subjects.
Performance	Capability to deliver desired function.
End user service level	A quality-related performance criterion for asset condition, such as safety, cost, environmental impact.

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Executive Summary

The aim of this deliverable is to provide a review of the work carried out in work package 2 of TRIMM, dealing with asset management in the light of new monitoring techniques investigated in the course of work packages 3 and 4 of the project. The deliverable recaps the finding of the preceding WP2 tasks that looked at available condition and performance indicators (CI and PI) for pavements and bridges, as well as existing transfer functions that allow these indicators to be assimilated into an asset management system.

The report summarises the most prevalent approaches used by national road authorities (NRA) in asset management and aims to raise the reader's awareness about aspects that need to be considered and weighed up when introducing a new monitoring technique into an established asset management framework. A brief review of some of the pavement and bridge monitoring techniques investigated in TRIMM focuses on those techniques that went as far as providing a CI or PI for use in an asset management system. Following the description of a schematic asset management framework and its components (and how these were covered within the TRIMM project), the deliverable aims to give a guideline on how to implement the information gathered in TRIMM when evaluating a new monitoring technique for the use within an existing AMS. This is followed up by a short case study to exemplify some of the issues.

Given the unique boundary conditions faced by every NRA in terms of their respective stakeholders, budgetary constraints or even political/societal motivations, the exact methodology of incorporating a new monitoring technique would have to be considered on a case by case basis. This deliverable can be seen as a generic guideline on what factors need to be considered in the analysis of a monitoring technique when weighing up the pros and cons of introducing it into an available AMS.

1 Introduction

The aim of this deliverable is to provide a generic guideline for road operators on how to implement (new) monitoring techniques into their existing asset management system, using the information and experience collected in the course of the TRIMM project. Given state-of-the-art knowledge on condition indicators, performance indicators, maintenance measures and their respective monetary effects as well as inter-relations (see Figure 1), all of which were established in preceding deliverables of this work package, the guideline intends to help road operators understand the following:

- Possible application areas of (new) monitoring techniques
- What trends need to be considered in monitoring, given changing societal needs and technical advances
- Added value of monitoring on a network level, allowing market-driven maintenance
- Necessary procedures for a practical implementation of the TRIMM recommendations (see case study description in chapter 4)

The guideline does not give suggestions regarding the organizational structure of NRAs or how their individual business cases are to be set up.

1.1 Outline of the technical implementation guideline

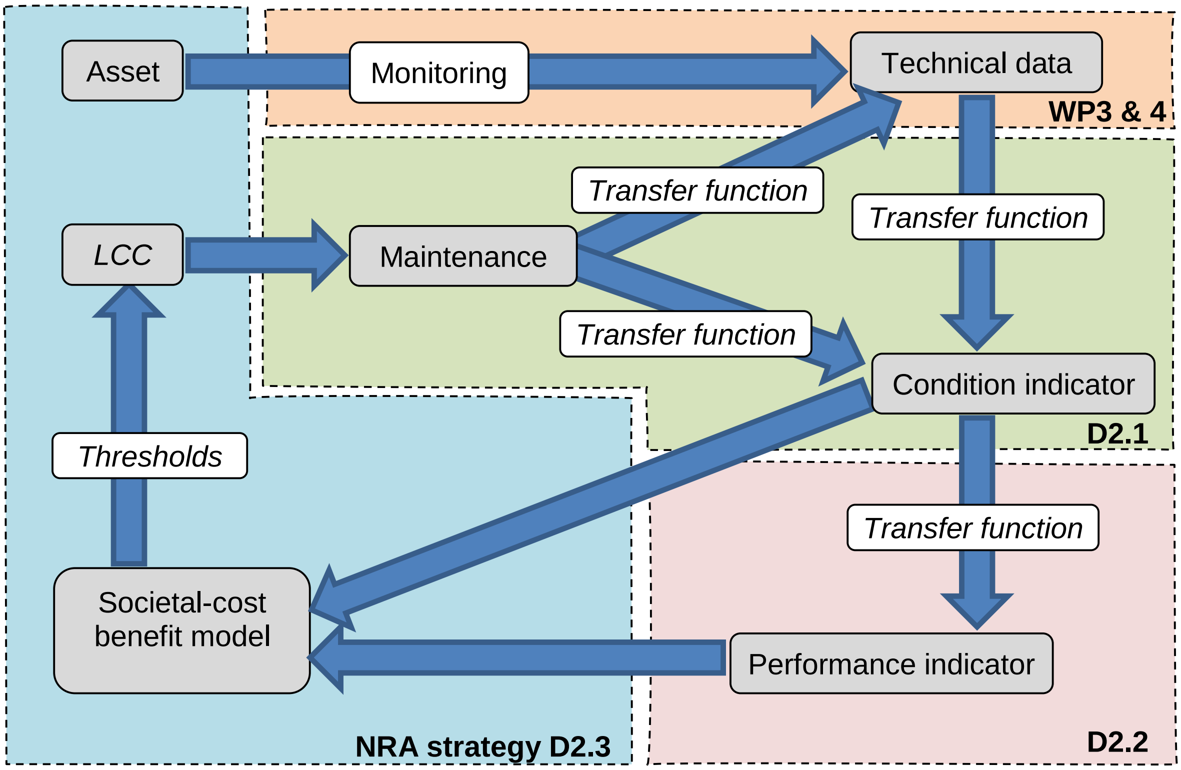

Figure 1: Outline of an idealised asset management framework including the work packages (WP)/deliverables (D) within TRIMM which deal with the components

Using the TRIMM findings as described in the deliverables of WP2, 3, and 4 takes for granted that an NRA aiming to implement the new monitoring techniques already employs a certain form of asset management system and thus relies on the use of condition (CI) and/or performance indicators (PI). In other words, the NRA is aware of the need for systematic data handling (collection and storage of data) and the calculation of CI/PI, but may have to reconsider their current threshold values in terms of when to apply maintenance measures once the new technical data is included in the system. Another point to consider is how to combine the new monitoring techniques with in-situ visual inspection: Are there short-comings in the monitoring system that can only be compensated by manual inspections or vice versa, or can certain aspects of manual inspection by completely eliminated through the new monitoring technique and is the added-value of this sufficient to justify its introduction?

The aim of this deliverable is not to provide a guideline for creating new CI that cater for customized NRA strategies, but rather to point out the key issues that need to be taken into consideration when introducing monitoring techniques into an NRA's existing asset management system (AMS). How to deal with the technical data from new monitoring techniques was covered in WP 3 and 4 and a brief summary is given in chapters 1.2.2 and 1.2.3.
In the light of preceding research in the field of asset management, in particular the ERANET ROAD program “Effective asset management meeting future challenges” (ERANET Road, 2010), TRIMM aims to show the added value of monitoring, particularly of the techniques investigated in WP 3 and 4.

1.2 TRIMM overview

1.2.1 Key aspects from WP2 concerning the implementation of monitoring

As the preceding tasks in WP2 dealt with the various aspects and relations required in an asset management system (AMS), this chapter aims to recap some of the key points that were raised which need to be considered when introducing new monitoring techniques into an existing AMS framework.

One of the key aspects to any asset management is the adequate **interpretation** of the technical data i.e. the monitoring results, which usually happens in the form of condition indicators or performance indicators as a representative yardstick of an assets' condition. While an enhancement to an already existing monitoring technique may improve a method's accuracy and/or coverage in time and space, and essentially build upon existing condition indicators, a new technique may require the development of completely new management procedures: new indicators with their respective thresholds, verification through combination with other monitoring results or manual inspections etc. In case of new technical parameters, the integration into an asset management system always needs to take into account the prevailing **national practices** and regulations. This means that even if existing condition indicators are used, the way they are calculated from technical data may vary from one country to the next due to different weightings, variations in the exact acquisition methodology etc.

An important point to note concerning the relationships (transfer functions) that were detailed in preceding WP2 deliverables is that these transfer functions are unidirectional. For example, the improvement in an asset's condition achieved through a certain maintenance action may be quantifiable, but considering the improvement alone would not allow any inference on the performed maintenance measure, as several interventions may achieve the same result in terms of changes to the technical parameters. Likewise, taking a combined condition indicator or a performance indicator would not permit the inference of individual condition indicators let alone technical parameters, as the inverse functions are ambiguous. In other words, while CI or PI express the need for and the urgency of carrying out maintenance from an NRA’s perspective on network level (and are thus adequate for prioritizing maintenance to restore acceptable technical conditions), they are not directly related to selecting an appropriate type/extent of maintenance on an object level.
Given that the **disaggregation of a PI to CI** does not work, an NRA's strategy has to be chosen very carefully and the exact state (technical parameters) of individual assets or objects may be masked by the higher-level indicators (CI or PI). For example, NRA's that have a centralised, network-wide strategy may skew network performance through expansion work (building new assets) whose good state covers up other asset's mediocre/unsatisfactory state within the same network i.e. strategic targets are hard to translate into technical parameters of individual assets (problem area hard to locate).

Task 2.3 dealt with a social cost-benefit analysis to demonstrate the use of monitoring information in asset management and allows a comparison of different monitoring alternatives. Two key boundary conditions for this kind of valuation are the **available databases** collected from monitoring systems which form the basis for any kind of condition prediction over time, and the actual **time frame considered** in the optimisation problem. The latter plays a particularly strong role when it comes to considering the benefits of monitoring and measuring these in terms of end user service levels. While safety, for example, may improve immediately once a maintenance measure is in place, environmental impacts vary strongly with the extent of the time frame: The road users’ CO_2 footprint due to improved pavement conditions takes several years to outweigh the impact caused by the use of resources for raw mineral extraction and fuel for construction vehicles along that particular stretch of road.

1.2.2 Aspects of new monitoring techniques from WP 3

A general goal of WP3 was to advance the development of monitoring and evaluation techniques for the assessment of bridge condition, which provides an improved basis for maintenance planning. Bridge condition was considered in three aspects:

- Visual condition
- Mechanical condition
- Electrochemical degradation

Visual condition of a bridge is traditionally determined by an experienced bridge inspector on site. Purpose of the inspection is to detect any visible defects (cracks, spalling, colouring as indicator of corrosion, water leakages, etc.). Within WP3, a camera-based system was developed with the aim to enhance capabilities of visual inspection. The system provides a 2D visual model of the bridge that enables performing the inspection off-site. The main advantages are: objective documentation of bridge visual condition, comparison to previous years, and evaluation of captured visual models by different inspectors and creation of a database for training purposes. Furthermore, the database of visual models could be used in future by automatic image processing routines for defect detection, which are not developed yet. Detection of defects in the current system is performed manually by the inspector. Utilization of information about detected defects in asset management is the same as in traditional on-site bridge inspection. Tests of the system at different bridges concluded that the camera-based system is suitable for concrete bridges, but not for steel structures.

Mechanical condition of a bridge is determined by the mechanical functionality of all structural elements. The main condition aspects that were targeted are crack development, loss of prestressing force, loss of stiffness, and functionality of joints and bearings. The techniques for condition identification were:

- Identification of active damage zones using Acoustic Emissions
- Condition assessment of the main load-bearing elements using model-updating within finite element models
- Detection of movement restrictions at joints and bearings using influence lines and modal data

The Acoustic Emission technique proved to be able to determine the location of active damage zones (ongoing crack development) when using a sufficient number of sensors. While it was possible to determine increased cracking activity close to the load-bearing capacity limit during controlled load tests, no such level was achieved during normal bridge operation.

Condition assessment of the main load-bearing elements was performed using updating of a Finite-Element model of the bridge. The model-updating technique was used because direct measurement of structural element condition is mostly not feasible. The main aspects of the developed technique were probabilistic modelling of measurement uncertainties and automated continuous operation. The technique delivers statements of reaching pre-defined condition thresholds, such as loss of total prestress force > 20 % or loss of cable stiffness > 10%. The condition thresholds are bridge-specific and must be determined by an expert for each bridge individually. The technique delivers a statement about the threshold that was reached (damage extent), at which structural element (damage localization) and probability of threshold exceedance (identification reliability). This information can be used for targeted inspection of the given area for further maintenance or repair planning.

Functionality of joints and bearings was analysed using two independent techniques: influence lines identified from Bridge Weigh-In-Motion (B-WIM) data and resonant frequencies of bridge vibration. Both methods showed the ability to detect the presence of movement restriction at joints and bearings. Threshold values were stated based on change of influence lines and resonant frequencies. If the thresholds are reached, it is recommended to perform special inspections aimed at condition of joints and bearings to validate the identified condition and plan further maintenance actions (repair or replacement). Movement restrictions, if undetected, may produce consecutive structural damages. Therefore, their timely detection seems important.

Electrochemical degradation describes the progress of corrosion damage in the bridge. The work was concentrated on monitoring of chloride-induced corrosion of steel reinforcement in concrete bridges, which is the most relevant type of corrosion damage from the maintenance perspective. Different measurement techniques were tested and a combination of electrical resistance (ER) sensors and multi depth macrocell sensors was recommended as the most effective technique for early corrosion detection. Criteria for monitoring-based identification of corrosion condition were defined. These criteria are based on identified corrosion rate and classify the corrosion damage into 5 condition index levels ranging from 1 (very good condition) to 5 (very poor condition). Very good condition was defined as the state before corrosion initiation, whereas very poor condition was defined as the appearance of first cracks on the concrete surface, which corresponds to a corrosion rate of approximately 30 µm/year. The cracks are caused by voluminous corrosion products and allow rapid ingress of chlorides and acceleration of corrosion. Data acquired by the monitoring system enable prediction of future development of reinforcement loss.

1.2.3 Aspects of new monitoring techniques from WP 4

This chapter provides some excerpts of pavement monitoring techniques investigated in WP4 of TRIMM; for detailed findings on all monitoring techniques, please refer to deliverables D4.1 – D4.4. A brief overview of all techniques is provided in Table 1 below.

Table 1. Monitoring techniques investigated in the course of TRIMM

Methods in WP3	**Methods in WP4**
Image based bridge inspection	Identification of potential water ponding
Traffic loading and acoustic monitoring	Monitoring inventory
Corrosion monitoring	Monitoring surface condition
Monitoring of joints and bearings	Monitoring structural condition
Integrated Bridge monitoring method	Monitoring functionality

An example of a new monitoring technique investigated in WP4, which also led to a new condition indicator, is mentioned in Nitsche et al., 2014. This paper deals with the definition of ride quality in terms of a weighted longitudinal profile (WLP), which considers a broader spectrum of pavement unevenness compared to the international roughness index (IRI). Four classes of WLP were defined on a scale of 1 to 4, where 1 refers to very good ride quality (due to smooth roads) and 4 to very bad ride quality (due to rough roads). The novelty of obtaining the WLP was the so-called probe vehicle approach, which enables road network monitoring by conventional passenger cars. Theoretically, data acquisition could thus be outsourced and performed on a very large scale to accumulated sufficient information for statistical analysis of the road network.

Another example of a new indicator investigated in the course of TRIMM is water ponding potential. Insufficient water run-off can lead to several problems: Splash and spray (reducing visibility for the driver) and – at a certain speeds – aquaplaning, which is a serious hazard as the driver cannot steer and, even worse, brake the car anymore. Furthermore, parts of the road where water accumulates

are more likely to undergo degradation as standing water can be detrimental for the following reasons:
- Surface layer: Loss of material properties and resistance to wear, such as bitumen stripping and loss of aggregate due to spray effects
- Surface layer: Freeze-thaw cycles on weaker material
- Base and sub-base layers: Water enters underneath ponds through cracks and weakens materials.

Traditional monitoring calculates the rut depth and, if crossfall is known, the theoretical water film thickness. These indicators are usually calculated from single transversal profiles using a simulated straight edge of usually 2 m or 4 lengths and then averaged over a certain section length. However, the form of a transversal profile can be very diverse and not all sections with poor water run-off can be detected by looking only at calculated rut depths. For example, a very steep section with 15 mm rut depth may be less dangerous than a transition zone with no gradient and very little crossfall and just 4 mm rut depth. Measuring and calculating water ponding can thus identify these sections more reliably and the road operator can prioritize in terms of maintenance, reducing the risk for the driver and optimizing the life-time of the road.

2 Framework

2.1 Part 1: NRA objectives

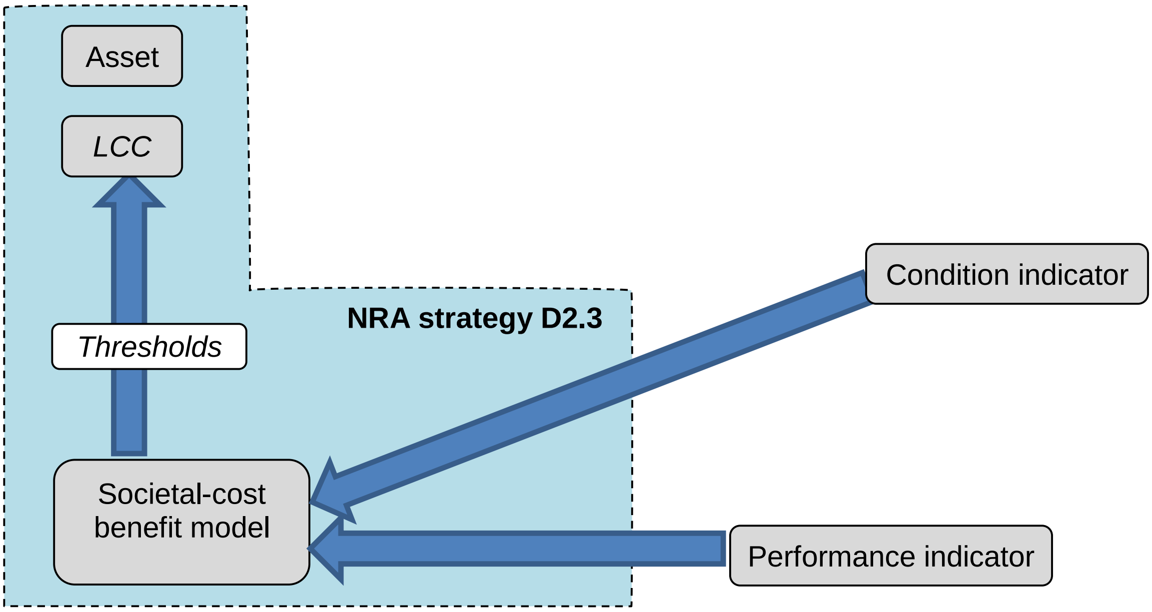

Figure 2. Outline of Part 1 of the asset management framework

Defining threshold values for condition indicators and performance indicators can be seen as an iterative process and strongly depends on the boundary conditions set by an NRA's policy. The values may vary over time, for example, in case of budget restrictions that may force an NRA to permit stronger degradation to its assets before taking an action. On the other hand, the thresholds may be politically motivated if, for example, an NRA's policy is to raise the network performance to a certain level. Either way, the policy always has to consider expectations between different stakeholders: what safety levels are desired by the road users and society, while keeping an eye on expenses in the interest of tax payers or owners and considering environmental aspects etc. Furthermore, the thresholds need to strike a balance between different sub-assets that may be evaluated using different PI/CI.

In terms of the NRA's strategy, the societal cost-benefit analysis (SCBA) dealt with in D2.3 of TRIMM looks at how PI/CI are used in AMS to optimise the assets' overall life cycle costs. With the information obtained from this model (which itself is reliant on known degradation rates through monitoring of technical data), an NRA may reconsider its current threshold values and adapt them in a fashion to optimise intervention plans: i.e. finding the ideal compromise between costs over a chosen reference period and achievable network performance. The SCBA's idea is thus to show how investments – in the form of maintenance and repair – can be optimised to achieve the NRA's strategic targets or objectives, such as ensuring a certain safety or availability level.

2.2 Part 2: Data acquisition

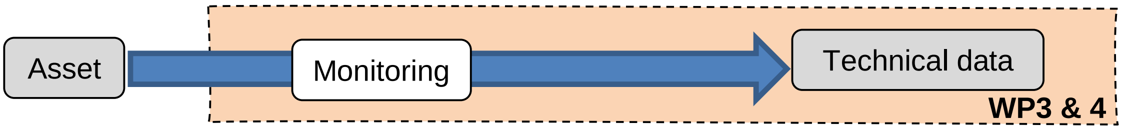

Figure 3. Outline of Part 2 of the asset management framework

As mentioned in the introduction, any form of asset management requires a solid foundation in terms of technical data on the assets in question. The quality of the data as well as the spatial and temporal coverage determine the accuracy of the available degradation models that allow conditions to be predicted over time and thus lead to the formulation of a maintenance plan.
NRA's have to be aware that even the most advanced techniques underlie an inherent uncertainty due to stochastic parameters regarding the construction of the assets or external factors (material properties, geometries, load conditions etc. which in reality may deviate from design). This issue may be dealt with by probabilistic life-cycle modelling of individual assets, whereas condition monitoring in general can be regarded as a more practical approach, yielding sufficient information in most cases to make objective decisions on intervention.

To make the most of the information collected from monitoring, NRAs have to handle the acquired data in a systematic fashion, ensuring consistency over different parts of the network (allowing direct comparison) or at least ensuring compatibility of different acquisition methods in order not to render past data obsolete.

2.3 Part 3: Low-level data interpretation and relations

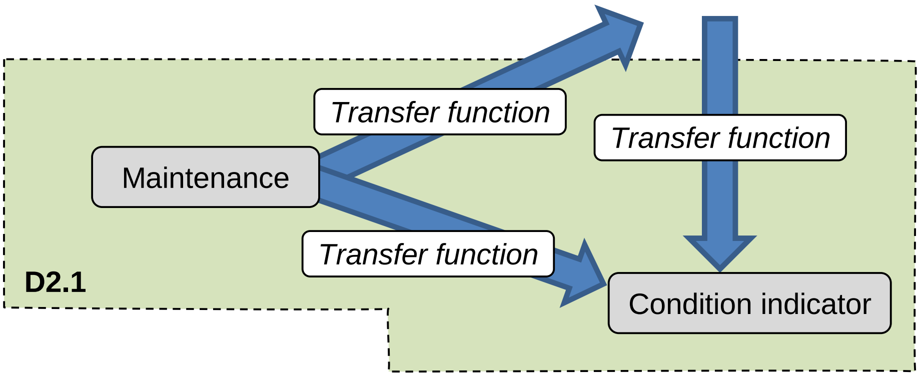

Figure 4. Outline of Part 3 of the asset management framework

While the transfer functions between technical data and condition indicators collected in TRIMM were generally found to be well established in previous works e.g. COST 354 or projects within the ERANET Road Programme 2010, it is not yet clear whether they will be suitable for handling data obtained with new monitoring techniques. An extensive list of CI was shown to be available in D2.1, yet only experience with future monitoring techniques will show whether these existing CI can accommodate the new technical data or whether completely new indices are necessary for interpretation. Table 2 gives some examples of TRIMM monitoring techniques and their respective technical parameters, as well as potential CI or PI which were defined in the course of the project.

Table 2. Examples of how technical parameters from TRIMM techniques are used to define a condition or performance indicator

Monitoring method	Technical parameter	CI/PI
Traffic loading and acoustic monitoring	AE activity	Load bearing capacity
Corrosion monitoring	Corrosion rate [µm/year]	Condition category [1-5]
Integrated Bridge monitoring method	Pre-stress forces, concrete cross section	Stiffness reduction [%]
Monitoring functionality	Vibrations, vehicle dynamics	Weighted longitudinal profile, ride quality

2.4 Part 4: High level data interpretation and relations

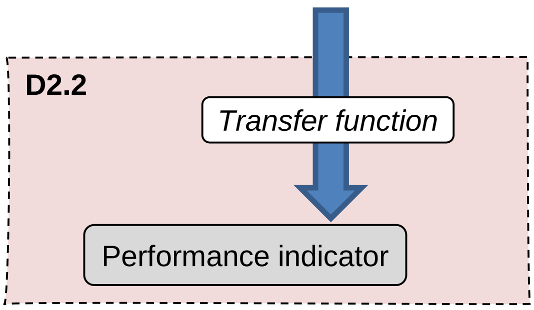

Figure 5. Outline of Part 4 of the asset management framework

The higher level transfer functions between CI and PI researched in TRIMM were found to exist for some applications, but were far from extensive. The reason being that not all NRAs manage their network according to a top-down strategy (see chapter 3.2), which would typically rely on such network-wide performance indicators to define a desired benchmark. A more technical interpretation on the level of condition indicators seems to be the more widespread approach.
Given the rarity of these transfer functions and the aforementioned possibility of having to define new transfer functions between TP and CI when introducing (new) monitoring techniques into asset management, the transfer functions between CI and PI may also have to be defined from scratch.
Currently, the existing transfer functions rely on known weights between the conditions indicators (CI) and performance indicators (PI). Again, NRAs have to be aware that the introduction of (new) monitoring techniques may call for the definition of (new) weight factors. Furthermore, the weights assigned at this stage are a question of the NRA'S policy, as the importance assigned to each CI may in some cases indirectly reflect the importance attributed to the different stakeholder, particularly when it comes to balancing different interests via PIs.

3 Guideline on implementation

In order to provide recommendations on implementing the TRIMM findings, one has to consider the ambitions of the NRA in question. Is the goal of asset management a purely financial one i.e. to operate on principles of market economy, or do strategic requirements take priority e.g. reducing the no. of traffic deaths, hours of congestion etc. regardless of costs? While most NRAs include all of these aspects in their mission statement, the actual importance assigned to each ambition is very mixed.
The following chapters will give an overview of the two most typical strategies (bottom-up and top-down) according to which an asset management process can be formulated, followed by checklist of points that need to be considered when introducing a new monitoring technique into as existing AMS that runs according to one of these approaches.

3.1 Bottom-up approach

A bottom-up approach in terms of introducing monitoring into an NRA's asset management system represents a scenario where industry provides new techniques or technical advances in monitoring certain asset properties. Ways of utilising this new set of information need to be found depending on whether the data constitutes completely new information (and/or complements existing monitoring results) or simply replaces older monitoring techniques by providing the same data but of a higher quality. In case of the latter, existing management procedures can continue to be employed while the former may need an overhaul or adaptation of existing condition indicators to incorporate the new technical parameters. A brief guideline of introducing a new monitoring technique into a bottom-up system is outlined below.

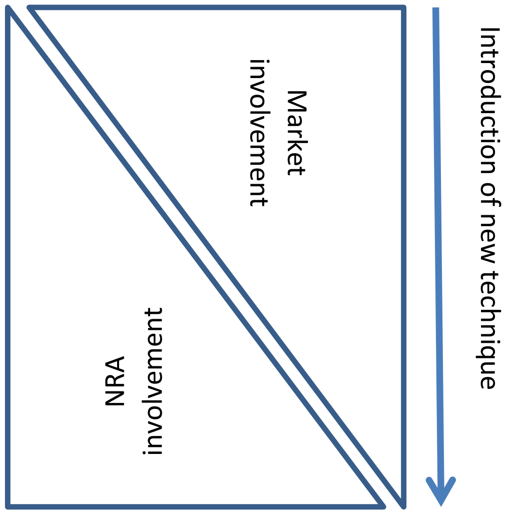

Figure 6. Schematic diagram of processes within the bottom-up approach

- Qualitative evaluation of a (new) monitoring technique (see also approach described in D2.4):

The technical parameters delivered by a monitoring technique need to be assessed in terms of their quality i.e. the coverage, frequency and accuracy with which they are available. The road operator needs to assess if this quality represents an improvement over other existing monitoring techniques and thus if the added-value justifies such a deployment. The cost-benefit-analysis detailed in D2.3 would pose such a tool.
The added value could arise from improving the available information and thus having a more accurate prediction of condition degradation over time, or from providing unprecedented information in the first place.

- Systematic data handling: Incorporate new data:

In order to make full use of the potentially added-value, the NRA needs to ensure a systematic way of handling the data obtained from the monitoring technique. A database of monitoring information is a prerequisite for any form of asset management as it allows condition trends to be established and provides information of degradation over arbitrary reference time frames.

- Interpretation:

Systematic handling also involves the systematic processing of available data in order to provide useable results e.g. condition/performance indicators. As the recorded technical data is usually of no direct use to road operators, means of interpreting the data and turning it into a meaningful parameter are suggested in D2.1, which provides the relations between technical data and condition indicators. For pavements, relationships were developed for a number of pavement condition indicators in COST 354 while for bridges (where such relationships were not found in literature) a methodology for calculating bridge CI from technical parameters was proposed in the deliverable.
The acquired data can thus either replace preceding monitoring results (as the same measurement data is provided) or complement existing CI/PI by finding a means to map the measurement data

against available CI/PI i.e. all condition indicators need to be related to measurable data in quantitative terms.

- Integration into AMS:

While the threshold values associated with data from new monitoring techniques may be recommended by the technical experts in charge of the technique, the final decision in terms of acceptable risk underlies the NRA's policy.

3.2 Top-down approach

The top-down approach poses a scenario where new strategic targets are defined by stakeholders or the NRA. A lot of monitoring information acquired today serves the purpose of asset compliance (bottom-up approach to assess technical quality) rather than management (Burns et al., 1999). Top-down approaches may thus need to think outside the box and perhaps employ completely new monitoring techniques to obtain information that allows an evaluation of their status with regards to their objective e.g. customer satisfaction surveys.
If monitoring has not been used before, the NRA essentially faces the task of introducing a complete asset management system into their organisation, whereas if they already have experience with monitoring, the existing AMS may simply require some adaptations (e.g. new transfer functions) to accommodate the new techniques. A brief guideline of introducing a new monitoring technique into a top-down system is outlined below.

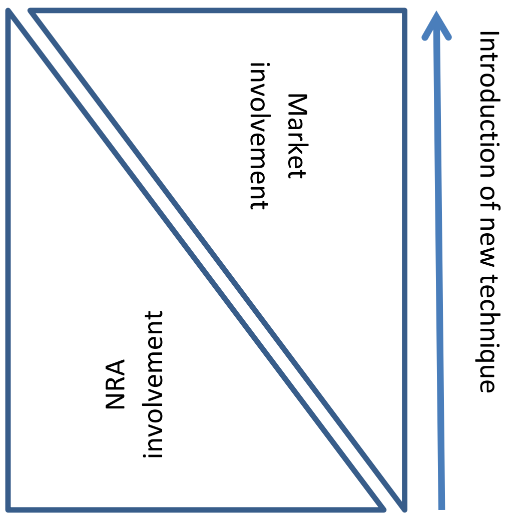

Figure 7. Schematic diagram of processes within the top-down approach

- Define NRA's ambitions

Depending on an NRA's organisational structure, their strategy may be defined in terms of object-related targets, operational targets, sectional targets or network-wide policy objectives. A network-wide strategy, for example, could benefit from using a cross-asset management approach whereby all assets are maintained within the same framework. While object or regional strategies tend to employ a bottom-up approach that may – to a certain extent – only look at the condition of individual assets, a blanket approach that looks at the entire network, but on a more abstract rather than technical level, would require the use of indicators that are mutual to all assets in question. Performance or condition indicators that are not just valid on a project level but pertain the same meaning regardless of the region or network size investigated would allow a more objective and reproducible decision making process.

- Consider stakeholder interests and future trends

Ultimately, an NRA's ambitions may be strongly steered towards meeting certain stakeholder interests: Road users, owners, operators, neighbours, financing body, society (PROCROSS, 2012), who may – to a greater or lesser extent – all have a say in the NRA's goals. Dealing with contradicting interests would thus have to be accounted for in the form of weighting the different stakeholders accordingly. While some interest groups demand a more immediate result e.g. safety for road users, other interests can be treated on a long-term scale, such as climate change, changes in traffic volume and axle loads or risks in ageing infrastructure.
Future trends which also affect the implementation, for example, are the expected traffic volumes and axle loads, as well as political decisions that may influence an NRA's structure and thus call for different monitoring means (e.g. outsourcing).

- Define condition/performance indicators necessary for achieving these ambitions

These indicators can either be selected from an existing compendium of CI/PI (see D2.1 and D2.2), providing they suit the desired interpretation purpose, or alternatively, customised from scratch to fit the given purpose. In case of cross asset management, PIs need to be employed which are mutual to bridges and pavements to integrate all assets into the same framework (CIs may still differ substantially).

- Select appropriate monitoring techniques

Once the indicators needed for the task on hand have been selected, the NRA needs to decide which monitoring technique to employ in order to produce the required output. Depending on whether the indicator is a condition indicator or performance indicator, this choice can be more or less straight-forward. Given that the indicators cannot be disaggregated, the NRA has to decide what type of monitoring to employ because several options may produce the same indicator, but at different costs and varying quality. In other words, the choice includes what type of sensors to deploy (justification of direct costs) and how to handle the acquisition for the purpose of asset management (frequency and quality of data to allow effective decision making).

3.3 Checklist for the introduction of monitoring techniques into asset management

Prior to introducing a new monitoring technique into an asset management system, the road operator will want to consider all relevant aspects that weigh up the usefulness (added-value) of monitoring against its possible draw-backs. Some of the issues raised in the course of work package 2 of TRIMM are summarised in the following checklist. By answering these questions, NRAs should be able to obtain a more objective view of the monitoring techniques and allow a transparent decision of whether to introduce the kit into their given AMS or not.

1) What is the value of the information provided by sensors to justify deployment?
   i. Direct costs of sensors/monitoring system
   ii. Value of the information gain, whereby the value of monitoring data is the difference in costs incurred when taking a decision with and without this information (Srinivasan et al. 2013). Such considerations can be fairly complex when trying to account for inter-disciplinary use of the data in different fields of road infrastructure management.
   iii. Is the added value limited to project level or is there a gain on a network level?
2) Are there short-comings in the monitoring system that can only be compensated by manual inspections or vice versa?
   i. What are the costs of these short-comings? (In terms of information loss and monetary charges)
3) What are the application areas of (new) monitoring techniques?
   i. Are the acquired data relevant for NRA objectives?
   ii. How can the acquired data be used in decision making?
   iii. Are adequate CI/PI available?
4) What technical advances are expected to influence the technique in the future?
   i. Foreseeable costs due to necessary upgrades?
   ii. Cost-savings due to improved hard-/software?
5) Can changing societal needs be accounted for with this technique or will it be obsolete in terms of the technical problems arising the foreseeable future?

4 Case study: Implementation of a new monitoring technique into an existing AMS

This chapter aims to combine the knowledge gained from D2.5 “Inventory of the needs in road asset management” with the assessment of the TRIMM monitoring techniques performed in D2.4 “Added Value of Advanced Road and Bridge Monitoring”. In a case study, one of the reviewed monitoring techniques (in terms of the three step procedure proposed in D2.4: Inventory, qualitative assessment and quantitative assessment) will hypothetically be introduced into an NRA’s existing asset management system to see how the technique aligns with the administration’s objectives.
For the purpose of this example, the Austrian NRA (ASFINAG) and automated image based bridge inspection will be used.

Review of the Austrian NRA:

- ASFINAG is part of the ministry for transport, innovation and technology (BMVIT), whose key performance indicators for the operation of a road network are **road safety, smooth traffic flow** and **emission mitigation** for neighbouring residents.
- ASFINAG itself places great importance on availability of the network, information for road users, safety and promoting intermodality.
- The NRA is fully owned by the government, but not funded by it (budget stems from toll, rest areas and traffic penalties).
- The maintenance system is implemented in cooperation with BMVIT (PIs of highest importance mentioned above)
- Bridge management is performed on a probabilistic basis, grouping structures (and components) into condition classes 1 – 5. The rating is based on the Austrian guideline for the assessment of road bridges (RVS 13.03.11).
- Intervals for inspection: routine inspections (inspection drive) every 4 months, major inspections every 2 years, detailed inspections every 6 years.

Review of the chosen monitoring technique:

- Creates 2D images of bridge components, which will allow second opinions and support for decisions without the need to go on site.
- Comparisons over several years' worth of data will become possible to track progress of defects such as surface scaling/delamination, deformations/mid-span deflections, fractures and moisture areas.
- Trending and thus deterioration forecasts will become easier as greater consistency in bridge assessment can be developed when using photo records.
- Fewer traffic disruptions during inspection due to faster and possible less-frequent assessments.
- Direct associated costs: data collection system, operation and updating, storing and extracting data.

Qualitative assessment of this monitoring technique within the given NRA (see also chapter 7.1.1 in D2.4 – Added Value of Advanced Road and Bridge Monitoring):

- The condition indicators listed in the detailed description of this technique agree well with the features listed in the Austrian guideline for bridge assessment. Thus an assessment of bridge components using automated image based bridge inspection would cover a majority of the points covered by the guideline RVS 13.03.11 for manual inspection. Seeing as one of the stakeholder's main interests is smooth traffic flow, the automation of image capture during bridge inspections would be a means to reduce traffic disruption.
- In terms of qualitative advantages over the current bridge monitoring techniques within ASFINAG, the technique would be a potential replacement for on-site manual inspections (routine or major) or a fast complementary means at times when more frequent inspections are required (particularly towards the end of a structure's service life or when it enters a critical condition e.g. between detailed inspections) to formulate an up-to-date decision of how to proceed in the maintenance strategy.

- Taking into account future developments in software engineering, it may soon be possible to process a continuous photographic record automatically to identify degradation processes. This can help to confirm subjective decisions and depending on the possible resolution, perhaps identify trends that might not have been recognised during manual visual inspection.

Quantitative assessment of this monitoring technique within the given NRA:

- The currently used BAUT database for bridge management already features the upload of photographic evidence of certain bridge components. However, it is not a compulsory, routine part of on-site inspections. Initial costs of introducing automated image based bridge inspection would thus encompass the programming of an interface to the existing BAUT database.
- The gain in terms of reducing traffic disruptions can easily be measured by comparing the time it takes to perform manual on-site inspections to the same degree of detail (e.g. regular drive-by routine inspection or major inspection) with the time and personnel it takes to scan a bridge automatically and perform the assessment in post-processing at the office.

To summarise this hypothetical introduction of a monitoring technique into an existing AMS, the following recommendations or guideline regarding implementation steps can be given:

1. Analyse who the beneficiaries of the new technique (automated bridge monitoring) would be e.g. Can the NRA acquire unprecedented information for optimising their maintenance strategy or is the acquired information the same but using fewer personnel hours? Are there and draw-backs?
2. List all the technical parameters (and subsequently all pertinent CIs) which can be obtained from automated bridge monitoring and see how these compare to CIs currently used in ASFINAG's AMS.
    a. If corresponding CIs are available in the existing ASM:
        i. Qualitative assessment of whether the technique can replace in-situ visual inspections or whether conventional bridge inspection can be supported: Can some indices be substituted by the new monitoring techniques or is the data purely complementary?
        ii. quantitative assessment of the benefits of the technique over conventional inspections
    b. If corresponding CI are not available in the existing ASM:
        i. Extend transfer functions to encompass the new CI (likely to require in-depth research followed several years of data for adequate weighting) i.e. transfer functions which link new CI to – if possible – existing PI and pertinent maintenance measures.
        ii. Come up with alternative transfer functions that provide an entirely new PI i.e. define an alternative way of expressing network quality/performance that agrees with the strategic ambitions of the NRA

3. Analyse if and how data consistency can be ensured over the years in order to develop advanced prediction models of the asset's condition.
4. Validation of the new technique by comparing with systems used up until now: put actual figures to the costs and benefits.

5 Conclusions

The work carried out in TRIMM has pointed out that successful asset management, which is per se an optimisation problem between predicting future asset condition, knowing the effects of maintenance on asset condition and estimating road user costs as a function of road condition, requires a consistent and relevant set of indicators, which are defined unambiguously and relate to the needs of the road operator in question. Work package 2 of TRIMM showed that one of the gaps lies in the full availability of transfer functions between technical parameters and condition/performance indicators, which form the basis of any meaningful interpretation of monitoring data. Once these relationships are fully established, further analysis would need to go into the topic of prioritising NRA objectives.

WP2 has summarised the most prevalent CIs and PIs, and highlighted how transfer functions typically work and which ones are currently available. The main key to implementation of new monitoring techniques lies in the NRA's thorough up-front consideration of which performance or impact indicators it will actually be able to handle in its existing management system, or which indicators are relevant to the stakeholders it needs to cater for.

While the maximum benefit from monitoring is obtained in scenarios where the decision maker's knowledge on, for example, asset degradation is highly uncertain and the monitoring system is very accurate, an exact quantification of the value of such additional information can be answered by a cost benefit consideration demonstrated in D2.3. One has to keep in mind though, that while an SCBA clearly offers the advantage of weighing up different monitoring alternatives and expressing the outcome in monetary terms, the ultimate decision of whether one monitoring system is favourable over another may not only be a monetary judgement. Optimising asset management is a multi-dimensional problem which may require considerable changes in the boundary conditions in order to become truly efficient, for example, reconsidering the organisational structure of the NRA in question to allow interdisciplinary use of the data or adapting the time scale of reference according to which asset management is performed.

This deliverable has sketched some of the aspects that must be taken into account by NRAs when introducing a new monitoring technique into their asset management system. These considerations can be seen as a guideline for transparent and reproducible decision-making when it comes to opting for or against a certain technique in order to improve an NRA's asset management process as a whole.

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