AN OVERVIEW OF THE MOST ADVANCED FRAMEWORKS FOR BRIDGE ASSET MANAGEMENT

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Abstract. During this paper it will be discussed some important novelties related to the topic of bridge asset management. In a first step, it will be covered the problematic of bridge assessment through the use of Key Performance Indicators. An emphasis will be made to the outcomes from the COST Action TU 1406 (www.tu1406.eu). Then, it will be discussed how these indicators can be used in the management of existing bridge stock. It will be introduced the problematic of performance predictive models and how maintainability could be integrated for the Life Cycle Cost analysis. At the end it will be discussed the difference between the management of a single and a network of bridges, what type of optimization models and decision-support algorithms can be used. An example is shown through the main results from the research and development project SustIMS – Sustainable Infrastructure Management Systems. The main objective is to show operators how the standardization of this procedure, and how these frameworks would contribute for a more sustainable and efficient management of their bridge stock.

Keywords. Asset management, bridge management system, predictive models, Life Cycle Cost, optimization models, sustainability

1. Introduction

In bridge asset management, the main requirement is to ensure that the expectations and needs of all users are met or exceeded. It is a challenging task for owners and operators, since it involves vital assets to the community. From the owner point of view it means that assessment and management are closely connected to quality control (QC) which means that system is developed concerning that products meets its requirements. From QC side it is necessary to define the goals to be achieved and to identify the investment needs and priorities based on Life Cycle Cost (LCC) analysis. From assessment and management side it is important to support the decision-making process regarding their preservation.

To keep the structures safe throughout their life, they require regular maintenance actions whose costs are generally supported by the operator. Accordingly, it becomes important to define strategies to maximize the societal benefits, derived from the investment made in these assets. This investment should be planned, effectively managed and technically supported by appropriate management systems. This process can be completed by improving the planning of maintenance strategies that will not only consist of defining the goals to be achieved, but that should also identify the investment needs and priorities based on a LCC criteria. The need to manage roadway bridges in an efficient way have led to the development of bridge management systems (BMS) all over the world. Although, they present a similar architectural framework, several differences constitute a divergent mechanism that may conduct to different decisions on maintenance actions. Therefore, a discussion at a European networking level, seeking to achieve a standardized approach in this subject, will bring significant benefits. Accordingly, a COST Action started in Europe in 2015 with the aim of standardizing the establishment of QC plans for roadway bridges (COST 2014).

This COST Action TU1406 is divided into different steps through Working Groups (WG), a first step (WG1. Performance indicators) was to establish overall recommendations for the assessment of roadway bridges, namely, used methods for the quantification of performance indicators. A second step (WG2. Performance goals) would be the definition of standardized performance goals, which include the definition of threshold types to specific key performance indicators. Thirdly (WG3.Establishment of a QC plan), a guideline for the establishment of QC plans in roadway bridges would be developed. Additionally, the guidelines will be tested with real results (WG4. Implementation in a Case Study) and recommendations to practicing engineers will be given (WG5. Drafting of guideline/recommendations) (Matos *et al* 2017).

In this paper the main outcomes with work related of the COST Action TU1406 are presented. The additional beneficial side of the Action is to connect asset owners, consultants and academics to improve the overall framework of existing road bridges.

2. Problem of bridge assessment through the use of Key Performance Indicators

As structures are aging, the assessment of bridges and other industrial structures is becoming increasingly important. Structural codes have been developed only for new design, but they often are not appropriate for assessment since there are significant differences between design and assessment. Design uncertainties arise from the prediction of load and resistance parameters of a new structure. These uncertainties represent the variability of a large population of structures caused by the unequal qualities of material, the different construction practices, and the variability of site specific live loads. Also a conservative design does not result in a significant increase in structural cost while a conservative assessment may result in unnecessary and costly repairs or replacement (Rücker *et al.* 2006).

Within the last years, significant research has been developed worldwide regarding the condition assessment of roadway bridges, namely through the use of non-destructive tests, monitoring systems and visual inspection techniques. Obtained values, which will provide information regarding the assessed bridge state condition, were then compared with previously established goals. As a result, there are nowadays several ways of evaluating a bridge condition. More recently, the concept of performance indicators was introduced, simplifying the communication between consultants, operators and owners. However, large deviations are still verified on how these indicators are obtained and, therefore, specific actions should be undertaken in order to standardise this procedure (COST, 2014).

As mentioned before for the assessment of existing bridges, as well as for the evaluation of maintenance strategies, life cycle analysis is used. Management systems, capturing different degradation processes, are very often used in relation to such life cycle analyses methods. Such management systems, developed for a structural condition assessment, are usually based on deterministic performance prediction models which describe the future condition by a functional correlation between structural condition attributes, such as the structural age, and the mechanical, chemical and thermal loading processes. The practical implementation of such models requires detailed information about its variables (Strauss *et al.* 2016).

Deterioration could lead to a decrease of performance to such an extent that a structure could not be able to satisfy the basic serviceability and safety requirements before the design life has expired. In order to prevent the premature failure of a construction, structural codes provide several practical principles and application rules such as the use of protective systems for material exposed in aggressive environment, the construction detailing aimed at avoiding the initiation of degradation, the maintenance actions to be regularly performed, etc. (Strauss *et al.* 2016).

Each construction, during its life cycle, will face with deterioration depending on several factors such as the environmental condition, the natural aging, the quality of the material, the execution of works and the planned maintenance. Therefore, several design procedures based on the prediction of the deterioration that will likely act on the structure will be developed in the framework of COST Action TU1406. In addition, performance indicators for the present and future structural conditions on deterministic and probabilistic level will be defined and determined (Strauss *et al.* 2016).

In the work of COST Action TU1406 WG1, the objectives were the collection and analysis of practical and research based performance indicators (Matos *et al.* 2017):

(a) Technical indicators: the goal in the first step is to explore those performance indicators of bridge structures, in the course of international research cooperation, which capture the mechanical and technical properties and its degradation behaviour. These properties are already partly covered by norm specifications but not their complex time variable performance. Moreover, environmental condition, natural aging, and the quality of the material regarding to determined indicators will be investigated and evaluated in their meaningfulness. These considerations, however, also include service life design methods, aimed at estimating the period of time during which a structure or any component is able to achieve the performance requirements defined at the design stage with an adequate degree of reliability. On the basis of the quality of input information (mainly concerning with the available degradation models), as sketched in the above description, it is possible to distinguish among deterministic methods, usually based on building science principles, expert judgment and past experience, which provide a simple estimation of the service life, and probabilistic methods;

(b) Sustainable indicators: in addition to technical performance indicators, which characterize the ultimate capacity as well as serviceability conditions, sustainability indicators, environmental based, will be also formulated. These variables characterize the environmental impact of a structure in the course of its total lifecycle, expressed in terms of total energy consumption, carbon footprint (CO_2 emission), balance of raw materials, etc. These indicators can be separated into direct and indirect indicators, where the former are related to the construction/ maintenance itself and the latter are caused e.g. as a consequence of limited functionality;

(c) Other indicators: other sustainable indicators, economic and social based, may be used to evaluate a bridge performance. These indicators capture, based on the technical performance of a structure, additional aspects that may influence the decision process and typically represent the discounted (accumulated) direct or indirect costs associated with construction and maintenance. Summed up over the full life-time, they represent part of or the full LCC. They can, in the context of multi-objective optimization, be understood as a weighting scheme to arrive to a single objective function that is to be minimized.

With this kind of collection it is possible to address a general description, how performance indicators of existing structures are assessed, with what frequency and what values are obtained. Finally it is possible to draw out most common procedures and give recommendations to prevent unnecessary actions. Additionally, performance goals may be considered as a characteristic that will be satisfied during its lifetime. According to different levels of a bridge, it is also important to reach the goals at different levels (Figure 1).

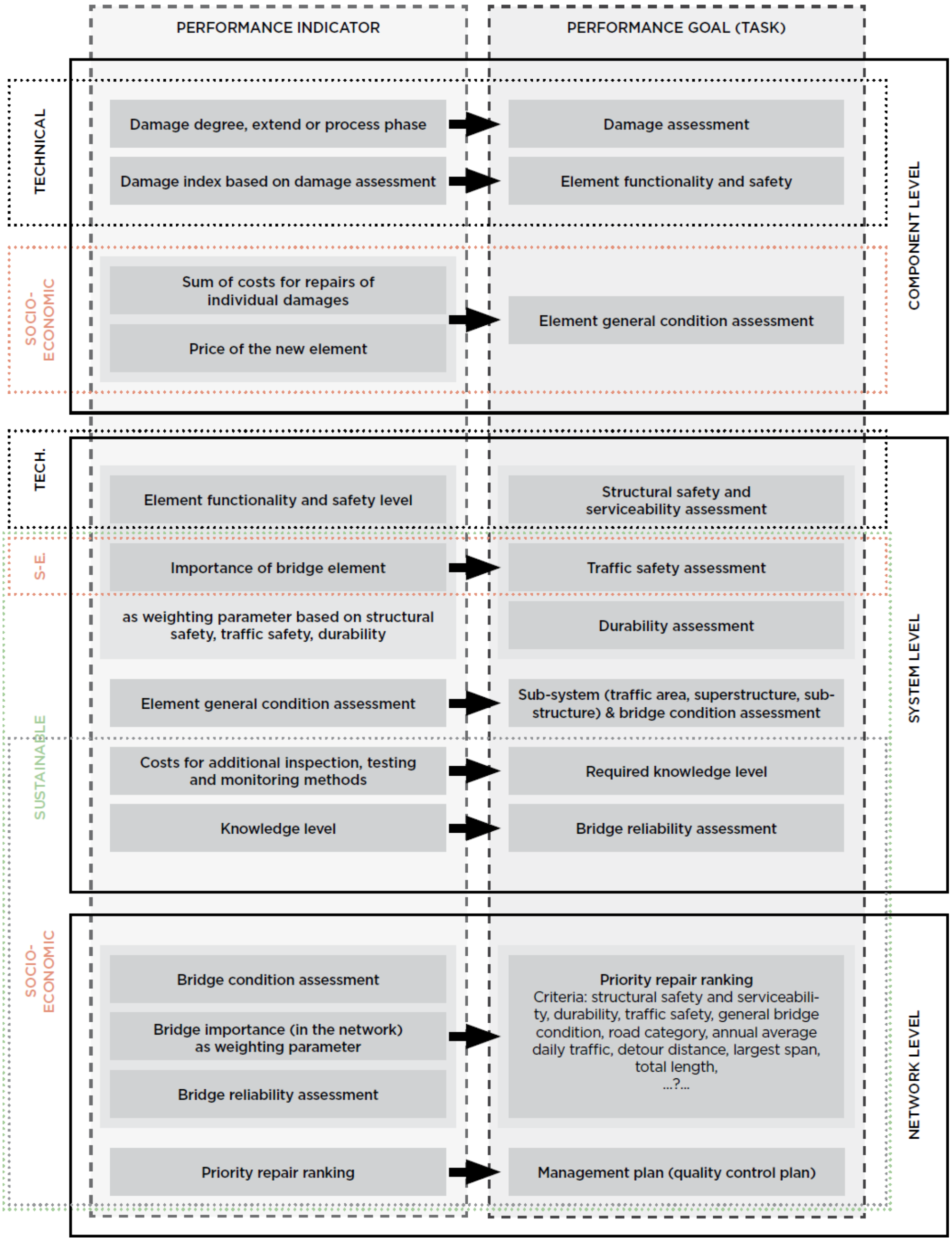

Figure 1. Interaction of indicators and goals (tasks) related to structural performance within bridge management (Strauss et al. 2016)

Although different performance indicators interact (Fig. 1), their categorization into technical, sustainable and socio-economic indicators through component, system and network level is done in order to identify methods for their quantification and level of their influence to a certain performance goal. More detailed categorization with evaluation process (Figure 2) of damages as performance indicators should be related to detection methods, performance thresholds and evaluation methods, and finally the level and extend of their influence to a certain performance goal quantifiable in terms of monetary units (Strauss *et al.* 2016).

3. How indicators can be used in the management of existing bridge stock

Management of road bridges comprises coordinated activities to realize their optimal value, which involves balancing of costs, risks, opportunities and performance goals. Performance goal may be considered as a type of bridge property or behaviour that is required during its lifetime. Different types of performance goals need to be reached at different levels of a roadway bridge asset, as a part of its efficient and effective maintenance strategy (Strauss *et al.* 2016).

For explanation to Figure 2, functionality of a specific bridge element is a performance goal at the component level. Adequate performance of a complete bridge structure is a goal at the system level, but taking into account the relative importance into the network and the consequences of its collapse it may become a goal at the network level. Whether the goal will be (or is) achieved or not, may be assessed through the evaluation of various performance indicators, which additionally implies knowledge of their respective levels of influence to an observed performance goal. Performance indicator may be defined as superior term of a bridge characteristic that has the possibility to indicate the condition of a bridge. It can be expressed in the form of a dimensional performance parameter or as a dimensionless performance index (Strauss *et al.* 2016).

The former is a measurable/testable parameter that quantitatively describes a certain performance aspect and the second one is a qualitative representation of performance aspect (e.g. importance of a bridge component in the whole bridge structure or importance of a bridge in the complete network). To evaluate certain performance indicator, performance thresholds or criteria must be set. A threshold value constitutes a boundary for purposes such as: a) monitoring (e.g. an effect is observed or not), b) assessing (e.g. an effect is low or high), and c) decision-making (e.g. an effect is critical or not). A criterion is a characteristic that is relevant for the choice between processes e.g. such as maintenance actions or others (Strauss *et al.* 2016).

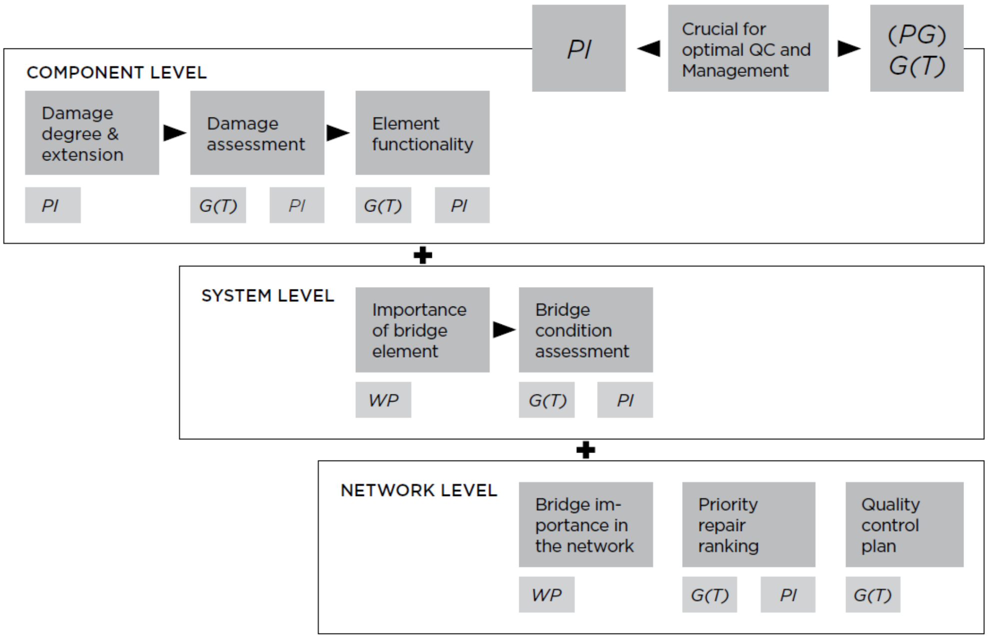

Figure 2. Interaction of indicators - PI, goals (tasks) - G(T) and weighting parameters - WP within bridge management (Strauss et al, 2016)

For more detailed example how these indicators can be used in bridge management can be seen in Figure 2. If divided into stepwise procedure then the steps would be:

1. Assessment of damage in component level. Upon damage assessment of a particular bridge element, damage index becomes an indicator for the next goal – evaluation of component functionality level.
2. At the same time the element functionality is an indicator at the system level, together with the importance of a bridge element as weighting parameter. These are important input for the following goal – bridge condition assessment.
3. From system level to network level it is important to add the bridge importance in the network as a weighting parameter to bridge condition assessment. The next goal would be priority repair ranking.
4. Priority repair ranking may be considered as an indicator for a QC plan.

Before going into this procedure it is necessary to select the most important indicators for achieving the goals which are crucial for optimal QC and to allocate them with appropriate weights. A common framework for the development of QC plan for structural systems was proposed by Hajdin in 2016 (Figure 3).

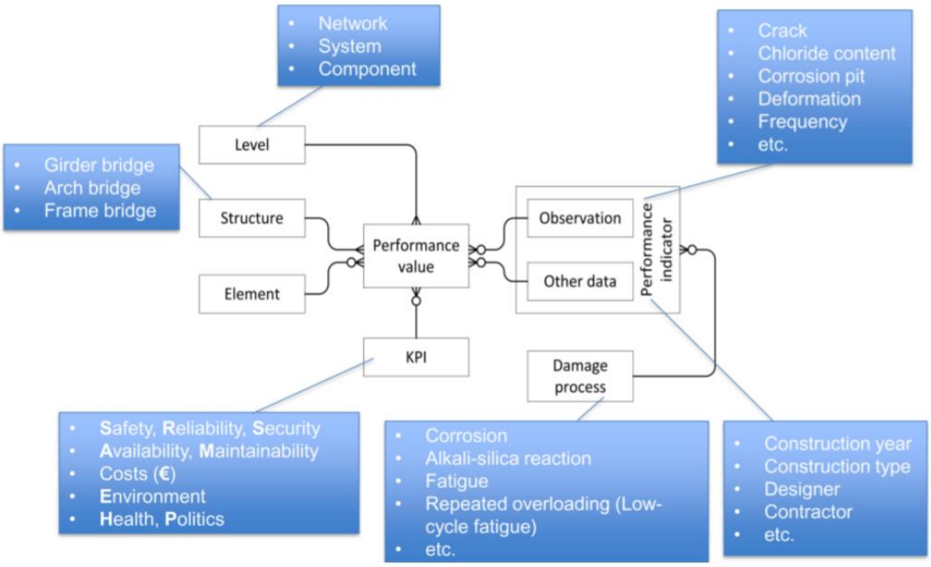

Figure 3. Common framework for the development of QC plans (Hajdin, 2016)

This framework presents relationships between the entities considered fundamental for bridge management throughout lifetime. Including information referred to structure, elements, observations, damage process and performance values. Performance values are used to determine Key Performance Indicators to be compared with Performance Goals. Including time into performance indicators it is possible plan management activities for short and long-term.

4. Problem of performance predictive models and how quantification of interventions could be integrated for the Life Cycle Cost analysis

The management systems rely on deterioration and maintenance models to predict future performance of the assets. The models can be either deterministic or probabilistic. A major disadvantage of deterministic models is that they do not consider uncertainties. This can be overcome by using probabilistic models. The most common probabilistic models for modelling deterioration are the Markov chains (Fernando *et al.* 2013). Markov chain is a random process that undergoes transitions from one state to another on a state space. The Markov property states that the next state only depends on the current state and not on the sequence of preceding states. The transition between states is defined by Eq. (1):

$$P^{\Delta t} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ 0 & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & p_{mn} \end{bmatrix}, \quad (1)$$

Where p_{ij} is the transition probability between states i and j from instant t to $t + \Delta t$. Although Markov chains can predict deterioration, these models are incapable of taking into account exceptional events, including manmade and natural hazards.

A decision is made based on the analysis of our predictions. Thus, the rational decisions depends to a large extent on its ability to collect information about the behaviour of the system and to make relevant inferences. There are three important aspects that influence our predictions (Sánchez-Silva, Klutke 2015):

1. time horizon;
2. ability to make inferences;
3. evolution of knowledge.

First, the accuracy of our predictions depends on how far into the future we want to go. Clearly, our ability to predict diminishes as the time horizon increases. For example, under normal conditions, it may be possible to make a reasonable estimative of tomorrow’s variations in the stock market, but very difficult to predict what would be its state in 5 years’ time.

Secondly, our ability to make predictions is generally based on past experiences and observations; our predictive models rely to a large extent on observed data. We may be unable to envisage events that have not been previously observed, which does not mean that such events will not occur. Our predictions often rely on the notion of causality; however, inferences about causality that are not properly grounded scientifically should be carefully analysed.

Finally, making predictions is a dynamic process. It changes permanently as new information and new technological developments become available. Furthermore, predictions may possibly change as our understanding of the system performance evolves. Despite the practical and conceptual difficulties in making predictions, they are unavoidable in decision making.

Good predictions require the appropriate understanding and management of uncertainty. Thus, in most engineering problems, the stochastic nature of the “laws” that describe the system performance (e.g., stochastic mechanics) plays a major role (Sánchez-Silva, Klutke 2015).

Investment decisions for engineered systems are based on predictions about the system’s future performance. Within this context, life-cycle cost analysis (LCCA) is the study of a system’s performance over a specific time period. LCCA provides a framework to support long-term decisions about resource allocation related to the design, construction, and operation of infrastructure systems. LCCA focuses mainly on finding the expected discounted value of a cost–benefit relationship $Z(\mathbf{p}, l)$ at time $t = 0$ as written in Eq.2.

$$E[Z(\mathrm{p}, l)] = E\left[\int_0^l B(\mathrm{p}, \tau)\delta(\tau)d\tau - \sum_{i=1}^{N(l)} C_i(\mathrm{p}, t_i)\delta(t_i)\right], \tag{2}$$

where p is a vector parameter used to describe the system performance. $B(\mathrm{p}, \tau)$ represents the benefits derived from the existence and operation of the project, $\delta(\tau)$ is the discount function used to compute the net present value of future gains and investments and $C_i(\mathrm{p}, t_i)$ describes all costs incurred (e.g., failure, repair, maintenance) throughout the lifetime t of the system. Note that $N(l)$ is the number of interventions in the time interval l, and it is usually a random variable (Sánchez-Silva, Klutke 2015).

The use of predictive models allows infrastructure managers to plan maintenance strategies (Mirzaei, Adey 2015) and integrating the models with LCC to make objective decisions. To support the decision-making process, optimization of maintenance schedules is commonly employed. Some early studies for maintenance scheduling are based on single objective optimization (Miyamoto A. et al 2000). Such works often seek to find a maintenance schedule that minimizes the total cost, whereas the performance is considered as a constraint (Estes, Frangopol, 1999; Yang, Frangopol, 2006). Single objective optimization results in a single optimal solution, which may provide the asset manager a little or no insight into the decision process. The task of maintenance planning naturally involves multiple conflicting objectives, as maintenance plans resulting in less deteriorated infrastructure assets also lead to higher costs. Multi-objective formulations have the potential to capture the complexity of the problems by exhibiting a set of solutions that represent the trade-offs between several objectives (Neves *et al.* 2006). A major advantage of multi-objective optimization is that the infrastructure manager can be provided with a set of optimal maintenance alternatives that are equally important without any preference information. Then, the manager can look to all the generated solutions and identify the most preferred, based on his/her preferences (experience, aspirations, available funds, etc.). Moreover, if the Pareto set is successfully approximated, it also includes the least cost solution.

A generalized framework for optimum inspection and maintenance planning was introduced by Kim *et al* in 2013. Such framework covers: (a) the damage occurrence, propagation and service-life prediction; (b) the relation between degree of damage and probability of damage detection; and (c) the effects of inspection and maintenance on service life and cost.

As budgets are usually defined for a network in order to distribute the available funds among all components, system-based approaches to maintenance management are of great importance. A framework for bridge network maintenance scheduling was proposed by Bocchini and Frangopol in 2011. This framework addresses optimal maintenance scheduling by minimizing the cost and maximizing the reliability based network performance indicator.

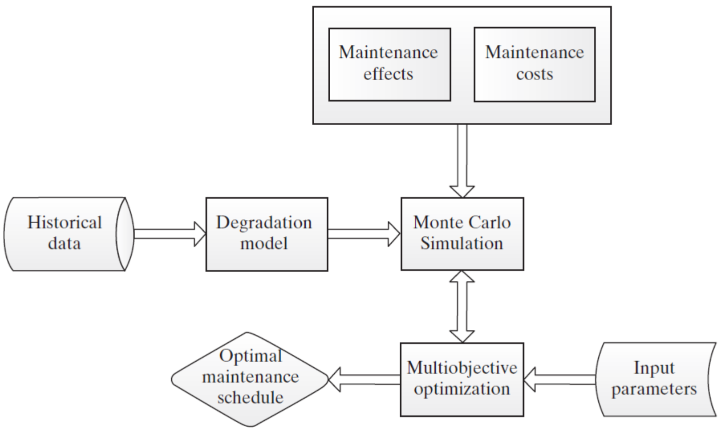

Figure 4. Flowchart of interactions among modules in maintenance scheduling (Denysiuk et al, 2016)

Presented computational framework for asset maintenance scheduling is based on Denysiuk *et al* (2016) work. This process begins with constructing degradation model based on historical data and the intervention module is developed on the basis of maintenance effects and costs. Optimal results can be achieved by performing a multi-objective optimization.

Intervention or maintenance actions can be either programmed or applied if the performance of the asset is inadequate. The former is usually referred as preventive, whereas the latter is denoted as corrective. When the action is applied, its impact on the asset performance can be modelled by the following effects: (a) improvement in performance at the time of application; and (b) delay and/or reduction in deterioration rate for a period of time after application. Since owners may have different preferences then optimization will be done according to provided parameters, which can be influenced by uncertainties due to a wide range of factors.

Nevertheless, an effective maintenance strategy must ensure adequate level of safety. These requirements can be expressed by imposing an upper bound on the asset condition state, which also guarantees the user specified threshold. To guarantee the feasibility of generated solutions during the optimization, a constraint handling technique based on a repair method is developed (Denysiuk *et al*. 2016).

5. Difference between the management of a single and a network of bridges, what type of optimization models and decision-support algorithms can be used

Several bridge management systems have been developed in the last decades with the purpose of optimizing the selection of maintenance actions to maximise the benefits and to minimise the costs (Frangopol *et al.* 2001). As shown in Fig. 2 there are different levels for performance indicators and to improve the maintenance planning it is important to optimize the management in all the levels. In this chapter the differences of management of a single bridge and a network of bridges is presented.

In an efficient management of single bridge, which was described in chapter 4, it is important to develop a consistent framework for all components including degradation and maintenance models. In most bridge management systems it is possible to develop plans over time and to identify possible maintenance alternatives. Based on the alternatives, LCC can be calculated and compared. By expressing the possible futures, the concept of a "candidate" is suggested (Patidar *et al.* 2007). It consists of a sequence of future time periods of agency activities. Activities mainly include do nothing scenarios, but there are also a number of specified actions that must be done on different components of a bridge for example cleaning of bearings, replacement of expansion joints etc. An example of road bridge optimization model is provided from the work of Denysiuk *et al.* (2016) in Figure 5 where four different solutions (S1, S2, S3 and S4) are highlighted to analyse maintenance scenarios of different parts. The least cost solution (S1) corresponds to do-nothing scenario and more expensive solutions involve more maintenance actions. The optimization at the bridge level will most likely lead to different maintenance scenarios.

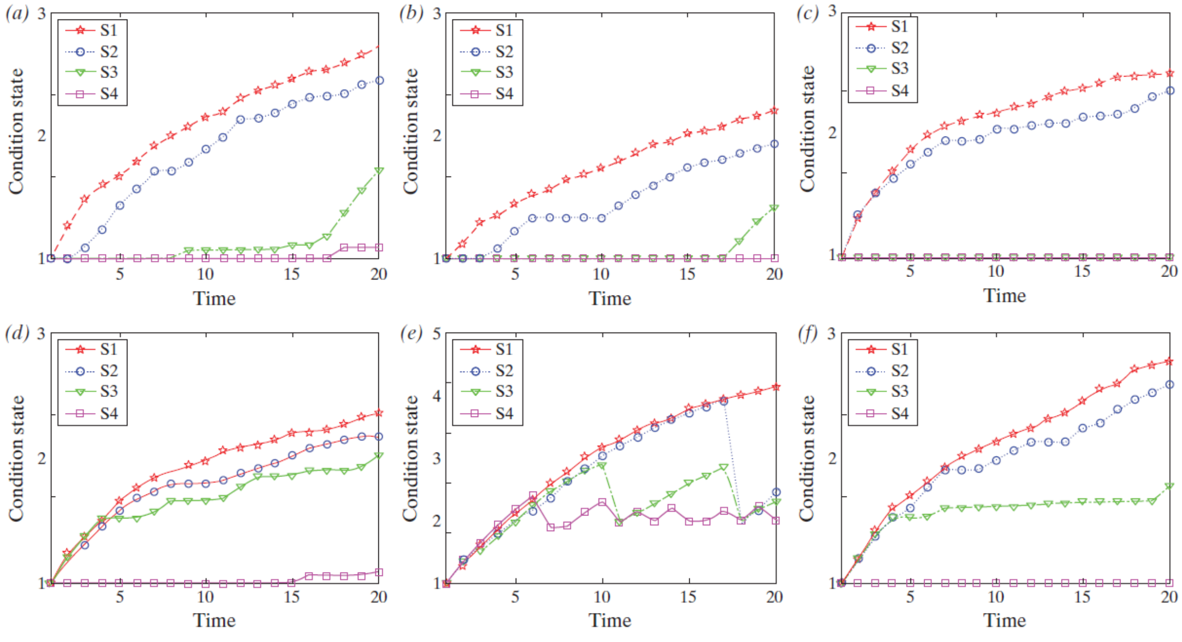

Figure 5. Performance profiles of bridge components for 20 years. The plots illustrate the degradation process under different optimal maintenance scenarios, represented by the solutions located in different regions. (a) bearings, (b) piers, (c) abutments, (d) railings, (e) expansion joints and (f) deck.(Denysiuk et al. 2016)

On the other hand in network-level bridge management, where a variety of objectives and constraints are faced, it is necessary to identify a set of goals and a set of performance indicators for each goal, as it is shown in Fig 6. According to previous work of COST TU1406 WG1 (Strauss *et al.* 2016) decision can be made based on different indicators which have separate goals. In network of bridges the decision has to be made implicitly, so that alternatives can be ranked and best alternative selected. The ranking may be based on temporal alternatives or on a cost-minimization rule, where preference order is adequately represented. If there are more criterions, then multi-criteria decision-making (MCDM) should be considered.
MCDM provides a systematic approach to evaluate multiple conflicting criteria in decision making as shown in Figure 6. It is normally used to identify and quantify decision-maker and stakeholder considerations about various non-monetary factors, in order to compare alternative courses of action (Kabir *et al.* 2014). An examples of MCDM have been provided in the framework of COST TU1406 by Bukshs *et al.* (2017), in using analytical hierarchy process and multi-attribute utility technique.

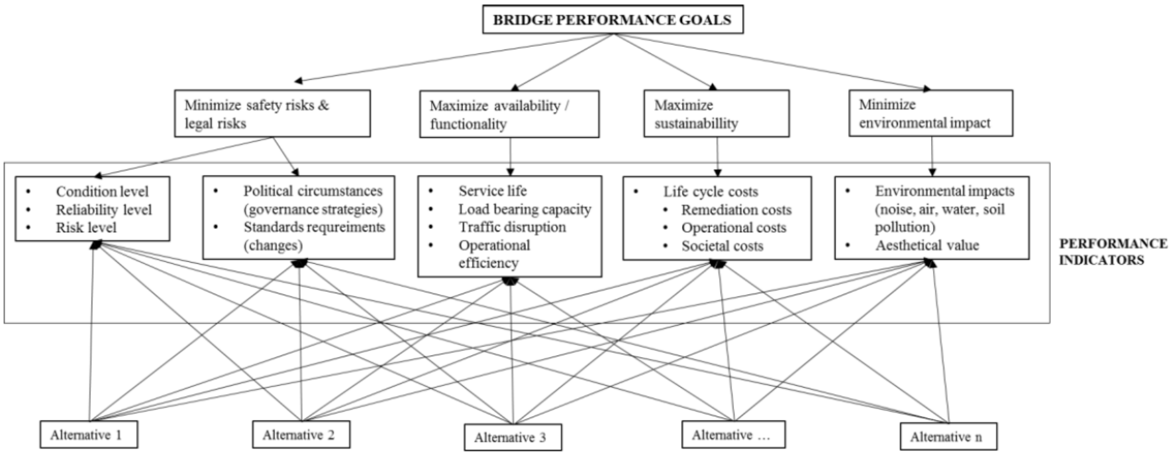

Figure 6. Multi-objective bridge performance goals and performance indicators (Rashidi, M., Lemass, B. 2011)

In conclusion of the application of optimization algorithms the most important goal is to minimize costs and/or to maximize the infrastructure's performance. The optimization of the maintenance strategy for each component or bridge, in an aggregated manner with "multiple-objectives", enables the maintenance actions to be performed on different elements of the same infrastructure's sub-stretch, optimizing the design, the planning and the intervention resources.

6. SustIMS – decision support tool for managing maintenance

In previous chapters the main attention was drawn on the fulfilment of the performance goals through optimization of decision-making by looking different performance indicators. Good example of an advanced framework for asset management was developed in Portugal. The system is called SustIMS, short name for Sustainable Infrastructure Management System. It is a result of a collaboration project between Ascendi IGI, Universidade do Minho and the Universidade Nova de Lisboa, co-financed in the scope of the QREN, which was developed during 3 years, between the end of 2012 and 2015.
SustIMS is an intelligent road infrastructure's management system, differentiated from the traditional Data Base systems, not only because it encompasses historic and real time information, but also because it predicts the future performance of each element, recommending the best maintenance and rehabilitation strategies and supporting the decision making process (Neves *et al.* 2016).
The main goal of the application is to minimize costs and/or to maximize the infrastructure's performance. The optimization of the maintenance strategy for each element, in an aggregated manner with "multiple-objectives", enables the maintenance actions to be performed on different elements of the same infrastructure's sub-stretch, optimizing the design, the planning and the intervention resources. The management platform enables to(Neves *et al.* 2016):

- Preview in advance the future costs of all the infrastructure, reducing the financial risks throughout the life cycle, and consequently the associated costs;
- Optimizing the maintenance strategies for all elements combined, thus reducing the number and duration of the traffic interruptions and, consequently, minimizing the operational and environmental costs caused by the traffic by-passes, traffic jams and accidents;
- Integrating, in the same platform, information from visual inspection and from monitoring systems, enabling a real time analysis of the infrastructure's effective situation.

Considering the element level performance models, the SustIMS platform has the capacity to simulate optimized scenarios through the application of maintenance and/or rehabilitation actions, with the goal to ensure the fulfilment of pre-established conservation state limits for each one of the infrastructure's elements.

Unlike the performance models, the optimization cannot exceed the pre-established parameters and the variables of time and cost are not an option, but an imposition that the software uses to simulate different optimized scenarios (Neves *et al.* 2016).

In the optimization process, the software simulates and returns a list of 100 scenarios with detailed information regarding the actions that were considered and the costs associated to each of the scenarios and presents, graphically and in detail, the evolution of the element condition throughout the period of time considered for the simulation. Given a maintenance strategy, the performance is defined by the conservation states exclusively calculated from an intensity matrix of Markov process. The future performance is foreseen with basis on the intensity matrix, using the Monte Carlo method. In this case, a solution is equivalent to a maintenance strategy that represents a plan of actions to be applied to this component (Neves *et al.* 2016).

Bridges are modelled as a set of different components, namely the bearing supports, intermediate supports, abutments, expansion joints and deck. The degradation of a bridge is assessed by the integration of the conservation state of its components, which are estimated using individual degradation models. In this case, the maintenance strategy is defined as a set of the maintenance strategies for each of its components, individually and simultaneously optimized (Neves *et al.* 2016).

The second stage of optimization is based on the information from the individual optimization of network level, with the goal to manage resources in an integrated manner. At this stage, the solutions represent the combination of the maintenance strategies. The number of variables corresponds to the number of bridges considered in the optimization process. The objectives are defined by the statistical measures of the conservation states of each of the road elements and maintenance costs (Neves *et al.* 2016).

The integrated optimization "multiple-objectives" considered four main goals (Neves *et al.* 2016):

- Minimization of the average value of the elements' conservation state;
- Minimization of the average value of the maintenance costs;
- Minimization of the variance of the elements' conservation states throughout the years;
- Minimization of the variance of the costs throughout the years.

After the search process that results in a set of optimal solutions the decision making takes place. This process consists in the choice of one single solution from a set of compromise solutions. The heavy metric method is used to support the decision making process. The decision maker provides their preferences, attributing a weight to each of the objectives in issue. The method returns a single solution of compromise that reflects the preferences defined (Neves *et al.* 2016).

7. Conclusions

There are three important conclusions to be drawn from the overview of most advanced frameworks for bridge asset management:

1. Within the last years, significant research has been developed worldwide regarding the condition assessment of roadway bridges. As a result, there are several ways of evaluating a bridge condition. The concept of performance indicators have been introduced, but large deviations are still verified on how these indicators are obtained and, therefore, discussion at European level in COST Action TU1406 have been started.
2. Management system has to include quality control, where relationships between the entities considered fundamental for bridge management throughout lifetime have been described. Including time into performance indicators it is possible plan management activities for short and long-term.
3. The most important goal of optimization algorithm, in bridge and network level, is to minimize costs and/or to maximize the infrastructure's performance. The optimization of the maintenance strategy for each component or bridge, in an aggregated manner with "multiple-objectives", enables the maintenance actions to be performed on different elements of the same infrastructure's sub-stretch, optimizing the design, the planning and the intervention resources.

In generally, most advanced asset management frameworks are based on forecast and optimization models and using them enables the reduction of life-cycle costs.

8. Acknowledgements

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