Life Cycle Management of Concrete Infrastructures for Improved Sustainability

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Summary

Lifecon LMS is a delivery of an open and generic European model of an integrated and predictive Life cycle Maintenance and management planning System (LMS), that will facilitate the change of the facility maintenance and management from a reactive approach into a predictive approach. LMS is working on life cycle principle, and includes following (integrated) aspects: Human requirements, lifetime economy, lifetime ecology and cultural values.

Keywords: Facility Management, Life Cycle, Lifetime, Reliability, Decision making, Optimisation

1. INTRODUCTION

LIFECON LMS addresses the rapidly increasing need of maintenance, repair and modernisation of eldering European civil infrastructures, such as bridges, harbours, tunnels, power plants and off - shore structures, as well as building stock. The deteriorating civil engineering structures and buildings make a great impact on resources, environment, human safety and health. Currently the repair and modernisation is reactive, why the need of long term lifetime planning is obvious. Infrastructures (in LIFECON: including buildings, excluding roads and railways) represent about 70 % of national property in European Societies. Operation (excluding traffic), maintenance, repair, modernisation and renewal of the infrastructure is consuming about 35 % of all energy, and producing about 30 % of all environmental burdens and wastes. The influence of business buildings on productivity of work of organisations, and on safety and health of people is important. At the time being the maintenance and repair are reactive, and the need of maintenance and repair is mostly realised at a very advanced stage of deterioration, causing huge investments in repair measures, or even the need of demolition.

The main innovative aspect of Lifecon LMS is a delivery of **an open and generic European model of an integrated and predictive Life cycle Maintenance and management planning System (LMS)**, that will facilitate the change of the facility maintenance and management from a reactive approach into a predictive approach. LMS is working on life cycle principle, and includes following (integrated) aspects: functionality, performance, monetary economy, economy of nature (=ecology), safety, health and comfort.

2. The generic Life cycle Maintenance and management planning System: "Lifecon LMS"

2.1 Content of the Lifecon System

Lifecon system consists of the following modules, which altogether are buildiong the system:

- Reliability Based Systematics
- System description in a genric handbook
- Condition Assessment Protocol model
- Degradation Models for Service Life Prediction
- MR&R (Maintenance, Repair, Rehabilitation) planning methodology
- Methods for Optimisation and Decision Making
- Demosntrative IT prototype
- European Validation and Case Studies

These modules, their main contens and the interaction in the system are scheduled in Fig. 1.In this open system the modules can be applied in varying contens and combinations for different cases of application. This flexibility is the most important power of an generic and open system.

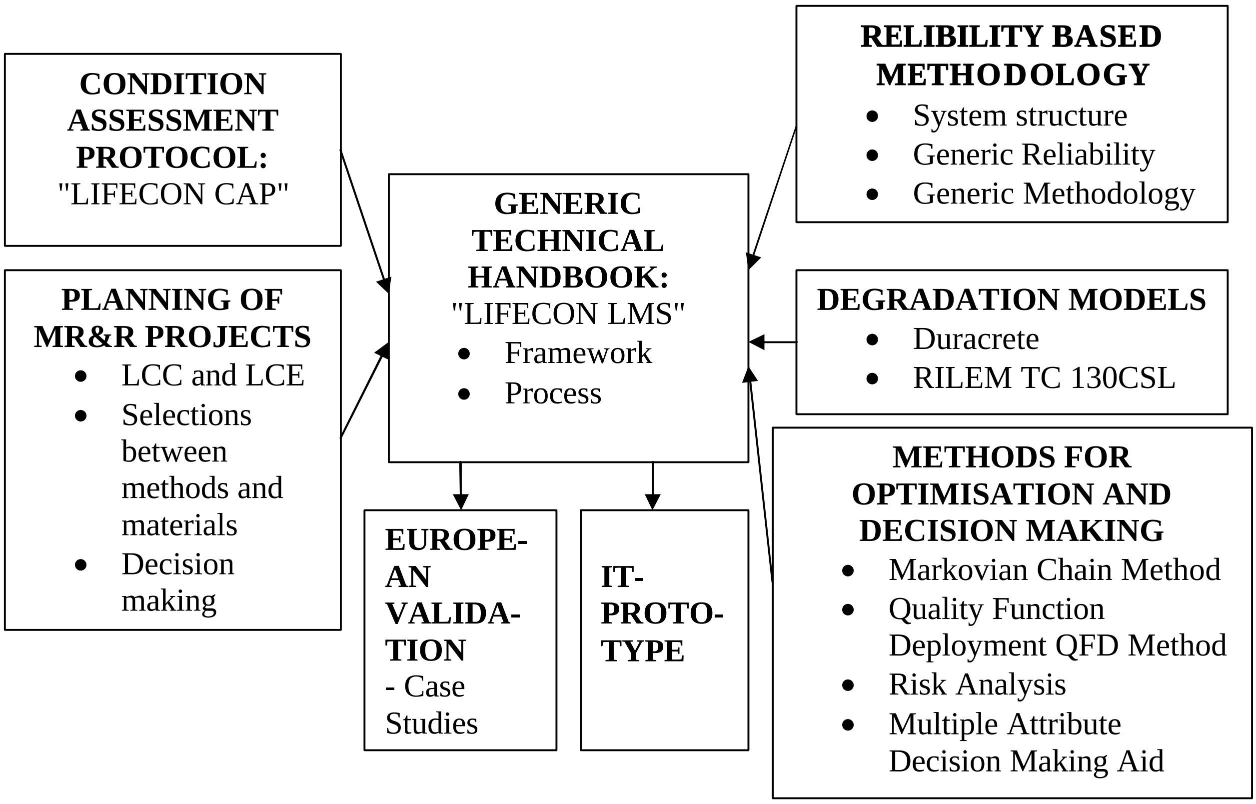

Fig. 1. Schedule of the content of Lifecon LMS.

2.2 Reliability Based Systematics

The lifetime performance modelling and the limit state approach are building an essential core of the lifetime management, MR&R (maintenance, repair, and rehabilitation) planning. Performance based modelling includes the following three classes:

1. Static and dynamic (mechanical) modelling and design

2. Degradation based durability and service life modelling and design
3. Obsolescence based performance and service life modelling and design

The serviceability limit states and ultimate limit states in relation to this classification are presented in Table 1.

Table1. Generic limit states .

Classes of the limit states	Limit states		
	Mechanical (static and dynamic) limit states	Degradation limit states	Obsolescence limit states
1. Serviceability limit states	1. Deflection limit state 2. Cracking limit state	3. Surface faults causing aesthetic harm (colour faults, pollution, splitting, minor spalling) 4. Surface faults causing reduced service life (cracking, major spalling, major splitting) 5. Carbonation of the concrete cover (grade 1: one third of the cover carbonated, grade 2: half of the cover carbonated, grade3: entire cover carbonated)	6. Reduced usability and functionality, but still usable 7. The safety level does not allow the requested increased loads 8. Reduced healthy, but still usable 9. Reduced comfort, but still usable
2. Ultimate limit states	10. Insufficient safety against failure under loading	11. Insufficient safety due to degradation: • heavy spalling • heavy cracking causing insufficient anchorage of reinforcement • corrosion of the reinforcement causing insufficient safety.	12. Serious obsolescence causing total loss of usability through loss of • functionality in use (use of building, traffic transmittance of a road or bridge etc.) • safety of use • health • comfort • economy in use • maintenance costs • ecology • cultural acceptance

The traditional reliability theory has been applied for mechanical limit states using statistical methods and deterministic safety factor methods, which are basing on the statistical background.. This reliability approach is applied also for degradation limit states, simply adding time as a variable.

The obsolescency limit states are different fro the nature, and they can better be handled with the methodology of quantitative or qualitative risk analysis and control..

2.3 System description in a generic handbook

The system is working on the "life cycle principle". It means that the system seeks to find the optimal methods of MR&R activity during a chosen time frame. This is done by the help of life cycle analyses, which enable to define the most cost-effective life cycle action profiles (LCAP) to be applied during the time frame. Although the economic efficiency is the most common aspect in the optimisation of LC action profiles, the ecological efficiency can also be taken into account in these analyses.

The term "integrated" means consideration of many attributes i.e. requirements or aspects at the same process of planning. Generic groups of attributes are: Human requirements, lifetime economy, cultural requirements and ecology. Consideration of all the various attributes is possible by using a hierarchial process of planning where the decision making is performed at different structural levels and by applying special multiple attribute decision aid (MADA) tools.

LIFECON LMS is a predictive and integrated life cycle management system for concrete infrastructures. The system makes it possible to organise and implement all the activities related to planning, constructing, maintaining, repairing, rehabilitating and replacing structures in an optimised way taking into account safety, serviceability, economy, ecology and other aspects of life cycle planning.

There are three versions of the LIFECON LMS:

1. Object level system

2. Network level system

2. Network + object level system

The object level system is designed for companies and organisations which own only a limited amount of concrete infrastructures. It is a practically oriented system which helps the maintainers to plan and execute the MR&R projects based on the inspection and condition assessment data. It provides maintainers with proposals for MR&R actions with optimised timing, composition of actions (project planning) and annual project programmes of infrastructure networks.

The network level system is designed for national road administrations and other organisations which are responsible for the upkeep of a large network of concrete infrastructures. The network level system is a tool for administration level operative planning and decision making. It makes it possible for the administration of an organisation to evaluate the necessary funding for MR&R activity and optional maintenance strategies.

The network + object level system is an integrated network and object level system. By a special interface system the optimality of the work programmes produced by the object level system can be compared and harmonised with the network level optimum before returning back to the object level and implementation.

The following activities are included in the LIFECON management system:

1. Assistance in inspection and condition assessment of structures,
2. Determination of the network level condition statistics of a building stock,
3. Assessment of MR&R needs,
4. LC analysis and optimisation for determination of optimal MR&R methods and life cycle action profiles (LCAP's) for structures
5. Definition of the optimal timing for MR&R actions
6. Evaluation of MR&R costs,
7. Combination of MR&R actions into projects
8. Sorting and prioritising of projects,
9. Allocating funds for MR&R activity
10. Performing budget check,

11. Preparation of annual project and resources plans
12. Updating degradation and cost models using inspection and feed back data

2.4 Condition Assessment Protocol Model

The repeated assessment of the structure condition is a decision process, which serves to identify necessary actions which lead to the most effective fulfillment of all defined requirements. One option is to "buy" additional information by inspection to obtain more reliable information on the current condition. This knowledge can be used to update models with the intention of improving the precision of future predictions. In summary the following aims were pursued:

- Integration of existing probabilistic service life models and reliability theory in the framework for condition assessment of concrete structures
- Provision of an organized system for collecting, rating and storing of data
- Ensure that information is only collected if necessary and information is suitable for the defined purpose
- The approach has to be applicable to users managing small to very large assessment projects, with or without a) large sampling effort and b) experience on and capacities for reliability analysis.

The main idea is to start with a low inspection volume and with basic investigation methods which will be increased or become more sophisticated if intermediate results suggest so.
Though the LIFECON project focuses on the management of concrete structures, such objects are never solely built of concrete. This manual is meant for the assessment of concrete, protective measures for concrete and imbedded re-bars and pre-stressing steel. Those materials (e.g. sealers) whose failure due to deterioration leads to concrete deterioration are included. Other materials are out of the scope. The developed framework can nevertheless be adopted to every type of material.

2.5 Degradation Models for service life prediction

The degradation models include mathematical modelling of corrosion induction due to carbonation and chloride ingress, corrosion propagation, frost (internal damage and surface scaling) and alkali-aggregate reaction. Models are presented on a deterministic and a probabilistic level. Deterministic models only include parameters obtainable throughout structure investigations, without making use of environmental data. Probabilistic models are applicable for service life design purposes and for existing objects, including the effect of environmental parameters. For each probabilistic model a parameter study was performed in order to classify environmental data.
The application of the models for real structures is outlined. The objects of the case studies have actually been assessed in order to obtain input data for calculations on residual service life. Each degradation mechanism will be treated separately hereby demonstrating:

- possible methods to assess concrete structures
- the source of necessary input data
- approach used in durability design
- application of models for existing structures
- the precision of the applied models
- necessary assumptions due to lack of available data
- possible method to update data gained from the Condition Assessment
- range of magnitude of input data
- output of the calculations

The use of probabilistic models for the calibration of the Markov Chain approach is described.

2.6 MR&R (Maintenance, Repair, Rehabilitation) planning

The purpose is to offer an assisting decision making tool, which takes into account LIFECON basic requirements of human conditions, economy, culture and ecology, when considering best choices between different repair methods, systems and materials. Method of combination of RAMS (Reliability, Availability, Maintainability, Safety) and QFD(Quality Function Deployment) Method consists in principle of 3 phases, as presenteds in Fig. 2.

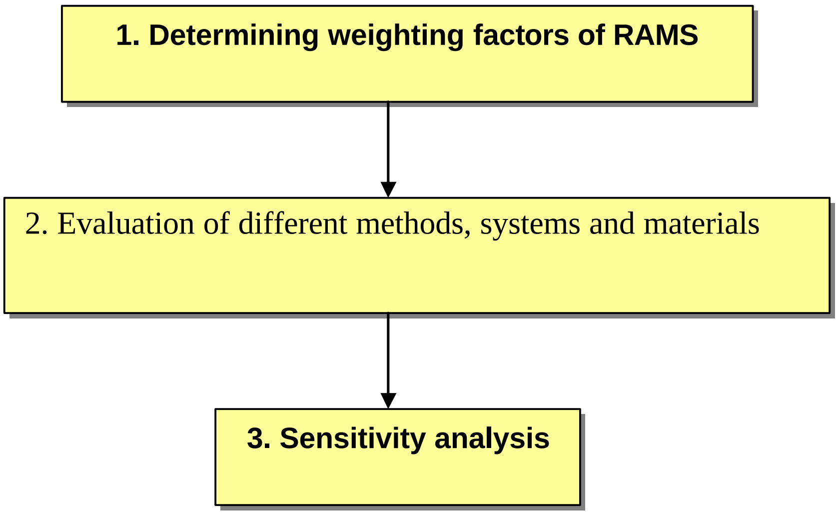

Fig. 2. The phases of combined RAMS and QFD mehods in the optimising MR&R planning.

The real challenge of successful LCC analysis lies in making unbiased assumptions, which produce fair comparisons of alternate designs or maintenance policies. As with any evaluation process, it is always easier to assess or evaluate smaller entities. That is why it is recommendable to build a Cost Breakdown Structure (CBS) for the different MR&R methods, using commensurate subtitles and units to compare the costs of the different methods. An example of a possible CBS for building elements or services.

2.7 Methods for Optimisation and Decision Making

A methodologyis proposed that is able to rank the alternatives in order of preference (preference is measured by means of human requirements, lifetime economy, lifetime ecology and cultural criteria). The decision maker could decide at different phases of maintenance planning:

- Network level: Network level (among all the objects of the stock), which one(s) is (are) identified as having priority for intervention?
- Object level: which part(s) of the object is (are) identified as having priority (e.g. during condition assessment)?
- Module, Component, Detail and Material levels: what are the best solutions to keep or upgrade the level of requirements in performance?
- Framework identifying and explaining the 6 steps are presented in Fig 3.

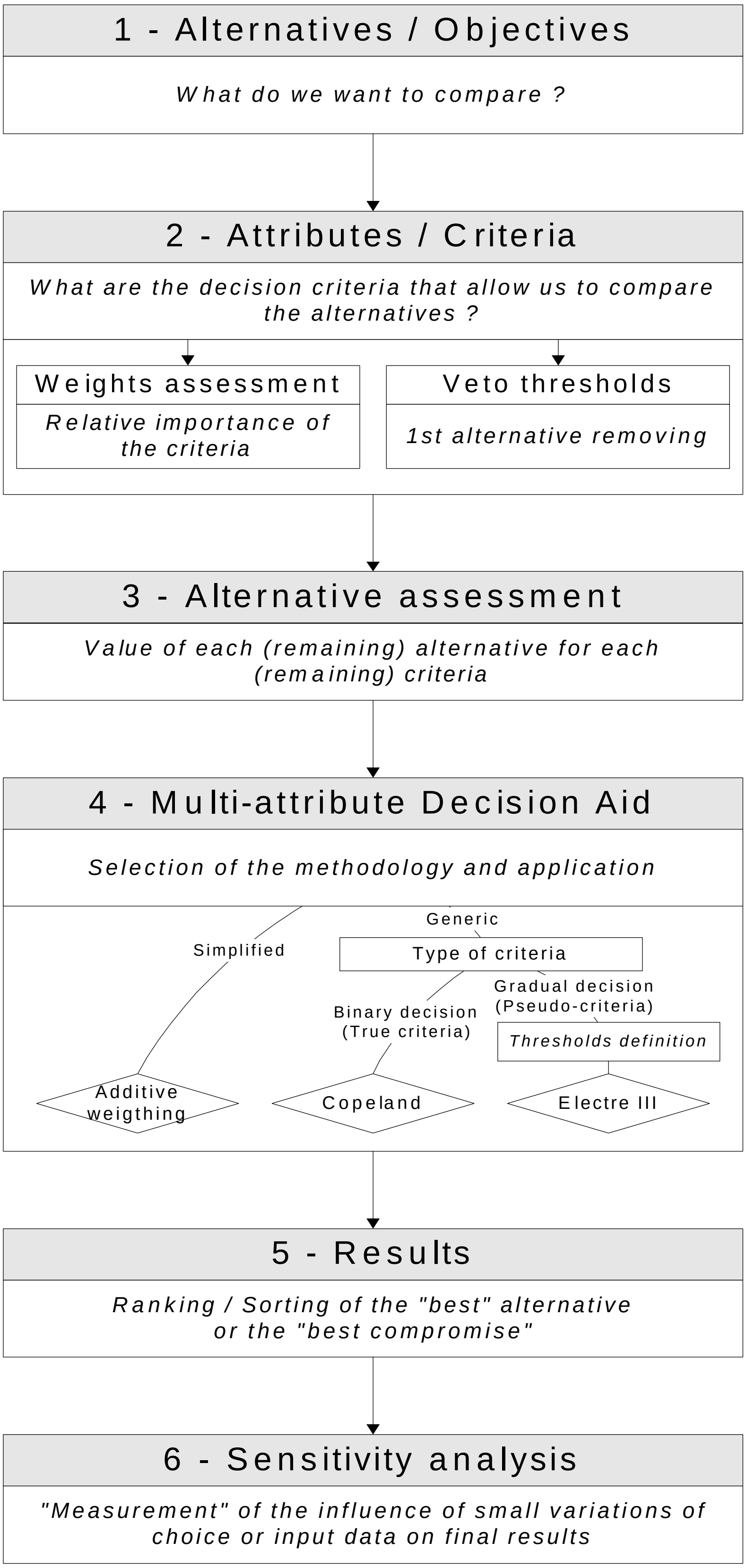

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Fig 3. MADA Flow-chart.

2.8 IT Prototype

A demostrative prototype includes the main modules of generic user requirements, and some modules of the object structuring and MR&R algorithms. The prototype is aimed at demonstration of the Lifecon LMS, and as a core for development of more focused software tools.

2.9 European Validation and Case Studies

Nine case studies were then selected using specified criteria. The structures to be considered were limited to bridges, buildings, wharves and tunnels. These case studies were to be selected to provide a range of common reinforced structural types and cover the range of conditions to which and in which a structure would typically be found in the duration of its lifetime. Engineers responsible for the construction/repair works on the objects selected are invited to tackle the maintenance strategy using the LIFECON management system in parallel with or subsequent to their normal approach.

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