Life-Cycle of Engineering Systems: Emphasis on Sustainable Civil Infrastructure – Bakker, Frangopol & van Breugel (Eds)
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An overview of COST Action TU1406, Quality Specifications for Roadway Bridges (BridgeSpec)

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Life-cycle analyses are used in condition assessment of new and existing bridges as well as for evaluation of maintenance strategies. During the implementation of asset management strategies, maintenance actions are required to keep assets at desired performance levels. In case of roadway bridges, performance indicators, which can be obtained by inspections, non-destructive tests or monitoring systems, are established for components. These indicators, along with the definition of standardized performance goals, allow to assess the accomplishment of quality control plans. In Europe there is a large disparity regarding the way performance indicators are quantified and goals specified. Therefore, a discussion at a European networking level, seeking to achieve a standardized approach in this subject, will bring significant benefits. COST Action TU1406 aims to bring together research and practicing communities in order to establish a European guideline in this issue, based on the existing practices across the involved European countries.

1 INTRODUCTION

Roadway bridges are considered to be, maintenance wise, one of the most critical components of road infrastructures. Though they belong to the domain of public service, their management mechanism can be conducted by the state or under private public-partnership models. In both cases, QC plans, which compare, for each performance indicator, the assessed value with a pre-specified goal, should be outlined and accomplished.

However, those plans vary from country to country and, in some cases, within the same country which conducts to large variations in roadway bridges quality. Therefore, COST Action TU1406 aims to achieve European economic and societal needs by standardizing the condition assessment and maintenance level of roadway bridges (COST, 2014). Moreover, it is important to address new indicators related to sustainable performance in such plans. This constitutes a scientific advance as, currently, QC plans do not consider them.

In order to establish a standardization procedure to assess performance indicators, namely, those that should be considered in QC plans, as well as to define performance goals, a network of experts is needed. Such network should incorporate people from different stakeholders (e.g. universities, institutes, operators, consultants and owners) and from various scientific disciplines (e.g. on-site testing, visual inspection, structural engineering, sustainability, etc.).

To summarize, the current non-uniform way QC is developed for roadway bridges is a real problem. This is surpassed by establishing a guideline, which constitutes the main outcome of TU1406. Such guideline will comprise specific recommendations for assessing performance indicators, as well as for the definition of performance goals, being expected the impacts expressed in Table 1.

2 GENERAL BACKGROUND

In Europe, as all over the world, the need to manage roadway bridges efficiently led to the development of different management systems (IABMAS, 2014). Hence, nowadays, many countries have their own system. Although they present similar architectural frameworks, several differences can be pointed, as for example with regard to the condition assessment procedure. These differences constitute a divergent mechanism that may conduct to different decisions on maintenance actions.

Within the roadway bridge management process, the identification of maintenance needs is more effective when developed in a uniform and repeatable manner. This process can be accomplished by the evaluation of performance indicators, improving maintenance strategies planning. Therefore, a discussion at a European networking level, seeking to

achieve a standardized approach in this matter, will bring significant benefits.

Table 1. COST Action impacts.

Impact	Description
Environmental/ Sustainability	Decrease of bridge life-cycle, maintenance and repair costs; Increase of service life; Decrease of total energy consumption and carbon footprint; Increase of mechanical, durability and environmental performance.
Economic and societal	Improve user satisfaction; New job opportunities associated with new QC services; Improve economic efficiency; Increase competitiveness in structural engineering industry; Enhance risk management.
Well-being of general public	Decrease of maintenance, repair and reconstruction activities; Decrease of downtime situations; Decrease of disruptions; Increase of user comfort.
Research community	Better perception of the practice problems; Cooperation improvement between research and practice; Establishment of reliable comparisons between countries; Improvement on research developments and practical procedures; Reduction of the gap between countries.

In this context, a first step would be the establishment of specific recommendations for the assessment of roadway bridges, namely, the used methods for quantifying performance indicators. A set of reference time periods for these assessment actions should be also presented. A second step would be the definition of standardized performance goals. Finally, a guideline for the establishment of QC plans in roadway bridges would be developed. In these plans, it is emphasized the importance of advanced deterioration predictive models. Moreover, the concept of sustainable roadway bridge management, involving the evaluation of environmental, economic and social performance indicators during the whole lifecycle, is also highlighted.

By developing new approaches to quantify and assess bridge performance, as well as quality specifications to assure an expected performance level, bridge management strategies will be significantly improved, enhancing asset management of ageing structures in Europe.

3 CURRENT STATE OF KNOWLEDGE

In the past few years, significant worldwide research has been done regarding condition assessment of roadway bridges, namely through the use of non-destructive tests, monitoring systems and visual inspection techniques. Obtained values, which provide information regarding the assessed bridge state condition, are then compared with previously established goals. As a result, there are currently several methodologies to evaluate bridge condition.

More recently, the concept of performance indicators was introduced, simplifying communication between consultants, operators and owners. However, large deviations continue to exist on how these indicators are obtained and, therefore, specific actions should be undertaken in order to standardize this procedure.

It is verified that QC plans should always address the assessed performance indicators and pre-specified goals. However, these latter values are even more difficult to obtain as they are highly subjective. As a result, a dispersion of QC plans is verified. Once roadway concession contracts are based on such plans, this may become an enormous problem for the future.

In the past a similar problem was addressed with roadway pavements. Although this was a worldwide problematic, in Europe it was solved through COST Action 354 (performance indicators for pavements) (COST, 2003). In a similar manner, during this Action, a network of experts in the field of roadway bridges will establish specific recommendations for assessing performance indicators as well as for the definition of corresponding goals. This activity will be supported in a data basis, gathered from different COST countries. The objective is to develop, for the first time, a guideline for the establishment of QC plans in roadway bridges.

Moreover, it will be also analyzed the possibility of incorporating new indicators related to sustainable performance of roadway bridges. Some of these indicators were evaluated with success within COST Action C25 (sustainability of constructions: integrated approach to life-time structural engineering) (COST, 2006). The final purpose is to establish detailed recommendations for assessing them as well as for the definition of specific goals, in a similar way as for the other indicators, and then integrating it in the developed guideline.

4 OBJECTIVES

The main ambition of the Action is to develop a guideline for establishing QC plans in roadway bridges, by integrating the most recent knowledge on performance assessment procedures with the adoption of specific goals. This guideline will focus on

bridge maintenance and lifecycle performance at two levels: (i) performance indicators, (ii) performance goals. By developing new approaches to quantify and assess bridge performance, as well as quality specifications to assure an expected performance level, bridge management strategies will be significantly improved, enhancing asset management of ageing structures in Europe.

In order to accomplish this main general aim, the following more specific objectives/deliverables have been considered: (i) to systematize knowledge on QC plans for bridges, which will help to achieve a state-of-art report that includes performance indicators and respective goals; (ii) to collect and contribute to up-to-date knowledge on performance indicators, including not only technical indicators but also environmental, economic and social ones; (iii) to establish a wide set of quality specifications through the definition of performance goals, aiming to assure an expected performance level; (iv) to develop detailed examples for practicing engineers on the assessment of performance indicators as well as in the establishment of performance goals, to be integrated in the developed guideline; (v) to create a database with performance indicator values and respective goals from COST countries, that can be useful for future purposes; (vi) to develop a webpage with information about the Action and its participants, as well as, video-streaming from presentations at training schools, workshops and conferences, e-lectures, written material (e.g. technical reports), etc.; (vii) to support the development of technical/scientific committees; (viii) to disseminate activities, such as Short-Term Scientific Missions (STSM), training schools and other teaching activities (e.g. e-lectures), for practicing engineers and researchers, regular workshops, a conference and special sessions at international conferences.

5 TARGET GROUPS/END USERS

The target groups and end users who will exploit the outcome of this Action are: (i) public/private owners, as their assets will be maintained in an upscale level; (ii) operators, as standardized procedures for reducing maintenance costs, guaranteeing the same quality-level, will be introduced; (iii) design and consultant engineers, as the assessment of roadway bridges performance will be established in a uniform way, according to the developed guideline; (iv) equipment and software companies, as a new perspective will be given, regarding the most suitable equipment and software for the assessment of roadway bridges; (iv) academics and researchers engineers, as they will take an advantage of their involvement in the guideline preparation; (v) students, as they will benefit from COST tools (e.g. training schools) and from the contact with different stakeholders, involved in this Action; (vi) relevant European, international and national associations, with which the main outcomes of this Action will be shared; (vii) standardization bodies and code writers, which will benefit from the developed guideline.

6 SCIENTIFIC PROGRAMME

The scientific work plan of the Action ensures the working progress in support of the established objectives. It is organized based on the division of tasks (and subtasks) allocated for each WG and according to a timetable, Figure 1. At this moment, only WG1, WG3 and WG6 started. A description of all WGs, including the corresponding milestones, is further present, being WG6 dedicated to dissemination activities.

Activity/Months	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
Meeting	X			X		X		X		X		X		X		X
Workshop				X				X				X				
Conference																X
Training school								X				X				X
STSM	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Website	X			X		X		X		X		X		X		X
Milestone				M1				M2		M3				M4		M5

WG		Year 1				Year 2				Year 3				Year 4			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WG1	Technical indicators	x	x	x	x												
	Environmental indicators	x	x	x	x												
	Other indicators	x	x	x	x												
WG2	Technical goals					x	x	x	x								
	Environmental goals					x	x	x	x								
	Other goals					x	x	x	x								
WG3	Survey of European roadway QC plans	x	x	x	x	x	x										
	Procedures for the establishment of a QC plan							x	x	x	x						
	Selection of case studies							x	x	x							
WG4	Benchmarking										x	x	x	x	x		
	Application on a QC plan											x	x	x	x		
WG5	Standardized performance indicators				x	x	x	x									
	Standardized goals								x	x	x	x					
	Standardized QC plan											x	x	x	x	x	x
WG6	Dissemination	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Figure 1. Timetable.

6.1 *WG1: Performance indicators*

It is known that management systems are supported in QC plans which in turn are supported by performance indicators. Therefore, it is highly important to analyze such indicators in terms of used assessment frameworks (e.g. what kind of equipment and software is being used), and in terms of the quantification procedure itself. In this particular work package, the objectives will be the definition of:

(a) Technical indicators: the goal is to explore bridge structures performance indicators, in the course of international research cooperation, which captures the mechanical and technical properties and its degradation behavior. Moreover, environmental condition, natural aging, and quality of 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 dur-

ing which a structure or any component is able to achieve the performance requirements defined at the design stage with an adequate degree of reliability. Based on the input information quality (mainly concerning the available degradation models), it is possible to distinguish among deterministic methods, usually based on building science principles, expert judgment and past experience, which provide simple estimations of service life, and probabilistic methods;

(b) Sustainable indicators: in addition to technical performance indicators, which characterize the ultimate capacity as well as serviceability conditions, environmental based sustainability indicators will also be formulated. These variables characterize the environmental impact of a structure in the course of its total life cycle, expressed in terms of total energy consumption, carbon footprint (CO2 emissions), raw materials balance, etc. These indicators can be separated into direct and indirect, where the former are related to the construction/maintenance itself and the latter are caused e.g. as consequence of limited functionality;

(c) Other indicators: other sustainable indicators, economic and social based, may be used to evaluate bridge performance. These indicators, based on the technical performance of a structure, capture 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 life-cycle costs. They can, in the context of multi-objective optimization, be understood as a weighting scheme to arrive to a single objective function to be minimized.

The milestone for this task (M1) is the publication of a report on these performance indicators until the end of year 1. Such report will address a general description, how they are assessed (e.g. visual inspection, non-destructive tests and monitoring systems), with what frequency, what values are generally obtained and, finally, some general recommendations. This outcome will be one of the main inputs of WG5, being also used by WG3.

6.2 *WG2: Performance goals*

The main objective is to define a set of goals for the previously identified indicators. These goals will vary according to technical, environmental, economic and social factors. Specific recommendations will be given in order to ensure that the definition of such goals should be the most general as possible. In particular, it will be established:

(a) Technical goals: it will be analyzed what goals are actually used for technical performance indicators in roadway bridges and its components (e.g. bearing, joint, etc.). It will be also evaluated which are being defined in the course of international research cooperation. There will be an open discussion within the experts' network in this field, in order to determine the most important factors for the definition of such goals as well as the most suitable threshold values. It will be established goals, both for deterministic and probabilistic methods, for time-varying indicators and for different assessment procedures (e.g. visual inspection, non-destructive tests and monitoring systems);

(b) Sustainable goals: specific goals will be defined for environmental based sustainable indicators. This task is much more difficult to perform than for technical indicators, as the historical data basis is much smaller. Nevertheless, an open discussion will be established within a network of experts in this field, in order to identify the most important factors for the definition of these goals as well as the most appropriate threshold values;

(c) Other goals: the definition of goals for other sustainable indicators, economic and social based, is extremely difficult as it largely depends on the established agreement between the owner and the roadway operator (concession model). Nevertheless, it will be important for the future of Europe definition of such goals, or at least to provide some recommendations, so that standardized procedures can be implemented. In order to achieve this objective, an open discussion will be developed among a network of experts.

The milestone for this task (M2) is the publication of a report on performance goals until the end of year 2. Such report will address a description of the most important technical, environmental, economic and social factors, how to compute each goal, with what frequency, what values are generally obtained as well as some general recommendations. This outcome will be one of the main inputs of WG5, being also used by WG3.

6.3 *WG3: Establishment of a QC plan*

The desired service quality of the whole bridge can be affected by a single dysfunctional component or by the combination of several dysfunctional components. The decrease in bridge service quality clearly depends on the degree of components' dysfunctionality. This dependency can be modelled, among others, by Bayesian nets, which provide the time variation of each bridge component performance.

However, in order to assure a desired service quality with minimum interruptions, bridge owners launch preventative actions when the risk of service impairment, interruption or losses in life cycle costs reaches a predefined level. Implicitly, owners define herewith the accepted risk which can be different from country to country, based on social equity principles. This accepted risk depends upon the estab-

lished performance goals for each component or combination of bridge components.

The QC plan mirrors these findings and is used for maintenance planning by setting criteria for triggering maintenance interventions. Clearly, these QC plans have to be established for each individual bridge. They perform the basis for the asset management of this type of roadway infrastructure. The objective is to establish a procedure, based on Bayesian nets or other heuristic rules used worldwide, which would allow bridge owners to set a QC plan for each individual bridge.

The milestone for this task (M3) is to prepare a report with detailed explanation of the steps towards the establishment of a QC plan for different types of bridges until the middle of year 3. This outcome will constitute the basis of WG5, being also used by WG4.

6.4 *WG4: Implementation in a case study*

During this task a set of roadway bridges, belonging to different COST countries, and preferably with identical typologies, will be identified. Then, for those bridges, performance indicators will be obtained. Such values will be then compared with prespecified goals and, finally, a QC plan will be implemented. Different methodologies for obtaining such indicators, as well as different threshold values, will be used as basis for benchmarking.

Then, a QC plan will be applied to such bridges, according to the established recommendations. The main objective of this study is to show the existing dispersion between obtained performance indicator values and its goals. It is important to note that this will reflect the existing dispersion among QC plans. Also, it will be tested and validated the implemented QC plan, according to given recommendations. Obtained results will be discussed within a high level of network of experts in this field.

There are several ongoing national research projects in COST countries with which a close interaction may be established within this scope. Namely, some of the roadway bridges which will be used as case study may be selected from those projects. Additionally, there will be several industry stakeholders (e.g. owners, operators, etc.) involved in the process.

The milestone of this task (M4) is to prepare a data basis from benchmarking, until the middle of year 4. Obtained results will validate the outcomes of WG1, WG2 and WG3, and will be used by WG5.

6.5 *WG5: Draft of guideline/recommendations*

The developed work will be used for writing a guideline and recommendations, for the implementation of a QC plan for roadway bridges that could be adopted by roadway agencies. The main goal will be the preparation of a document that can be easily adopted by engineers facing new and existing bridges management.

Therefore, the format and content should follow existing codes/guidelines/recommendations used today by agencies. Hence, the first step will be the analysis of existing documentation and work developed in other similar research programs and by standardization committees at national and international level.

Due to the objective proposed, this working package will have a strong interrelation with all the other working packages, becoming an output for WG6 (dissemination). Finally, the milestone of this task (M5) is the development of a new guideline for the establishment of QC plans in roadway bridges until the end of year 4.

7 DISSEMINATION PLAN

The success of this Action can be measured by the impact it has on the civil engineering community composed by, among others, infrastructure owners and operators, standardization bodies, scientific community, practicing engineers and other professionals.

The Action will enable useful synergies and disseminate the results to several target groups and end users. In order to achieve this, a specific WG6: dissemination of results, was introduced. This WG will assure the effective dissemination mechanisms to publish the progress and results of the Action. Among these tools are: (i) website, leaflets, posters, TV channels, radio stations, newsletters and online service news; (ii) workshops, conferences, training schools and STSM (Short Term Scientific Missions); (iii) Conferences, peer-reviewed articles and reports issued by the Action; and (iv) Guideline and link to standardization.

A website was developed – http://www.tu1406.eu – containing information about the Action itself which will be continuously updated. Any expert may join the action by filling a google form which is available in this website. Also available are a facebook page and a LinkedIn account accessible by https://www.facebook.com/tu1406ca and https://www.linkedin.com/company/tu1406.

Workshops, conferences, training schools and teaching activities will allow to explain the performed scientific work between researchers, industry and stakeholders, as well as the practical approach of the developed guideline. STSM are specially promoted to early-stage researchers that encourage the synergy among institutions, accelerate the learning of students and provide academia and industry with highly trained staff.

The achievements of this Action will be published in international conferences, as they bring together researchers, academia and industry in an

open-discussion forum, in peer-reviewed articles, as they are an important tool to prove the impact and accuracy of obtained results and to make them available for the future, and in technical reports (state-of-art reports and others) which will have the involvement of peer-reviewers from other countries.

The guideline to be achieved will include the establishment of QC plans in roadway bridges, comprising performance indicators assessment and its goals, as well as the obtained results. This recommendation report will be developed in close cooperation with scientific and practicing community and linked to European and international standards.

8 CURRENT DEVELOPMENTS

In order to achieve the proposed objectives, the Action will take place with the completion of several steps which were framed in the existing working groups. At this moment, the most active is WG1, dedicated to performance indicators.

Being involved in the Action such diverse stakeholders as researchers and infrastructure owners/operators, different bridge performance indicators perspectives were expected.

Therefore, the first step within WG1 was to collect information from owners/operators by gathering documents related to inspections and quality control plans. These documents were then subjected to a screening process that allowed to discard non relevant data and to structure information into chapters in order to be assigned to the respective working groups.

The information derived from this process, in order to be more easily used, was inserted in a structured database, Figure 2. This database will be the subject of interaction between working groups WG1, WG2 and WG3. Each involved country in the action has nominated a person responsible to perform these tasks.

Due to the considerable number of countries and experts involved in the process, and also to the expected amount of information, the database was accompanied by a glossary aimed to establish a common language between all participants, allowing to understand the context in which expressions and definitions are used.

The information is structured in four different levels: (i) performance level; (ii) damage; (iii) performance indicator/index; and (iv) performance assessment.

The performance level concerns to the identification of the component to which the information regards, namely the infrastructure level, the infrastructure system, the component and material.

The damage relates to the type of impairment the identified component has suffered and also the impairment itself.

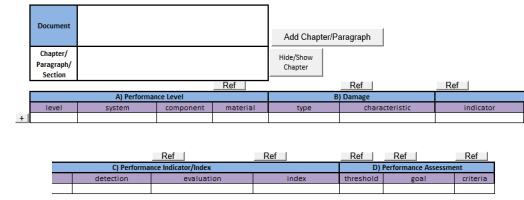

Figure 2. Owners/operators database.

The performance indicator/index information relates to the damage indicator and type, how the detection is made and evaluated.

Finally the performance assessment information concerns to the threshold, goal and criteria of the performance indicator.

The second step of WG1 consists of gathering information from researchers. As for owners/operators, an adequate database was developed to assist in the process, Figure 3.

From these databases it will be possible to analyze information from several different types of sources in order to establish a guideline that is as comprehensive as possible, allowing to identify key factors that are responsible for bridge performance.

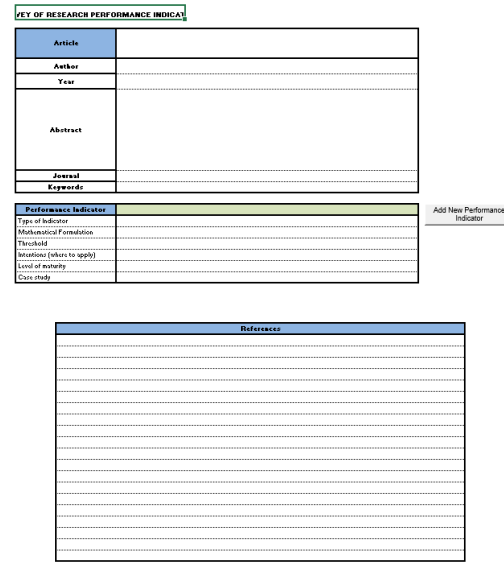

Figure 3. Researchers database.

9 IMPLEMENTATION: EXAMPLE OF PORTUGAL

Besides the Chair of this Cost Action being Portuguese, Portugal has 20 members, from universities, owners, institutes and consultants, distributed by working groups 1 to 6.

Specifically as regards WG1 – Performance indicators and the establishment of a database, Portugal

had two main contributions from bridge owners, namely Infraestruturas de Portugal, S.A. and Brisa, S.A.

Infraestruturas de Portugal (IP) is the Portuguese general concessionaire for roadways and railways, managing 14 000 km of roads and over 5 200 roadway bridges.

The IP's Roadway Bridge Management System (SGOA) is based upon the assessments made by the technical staff involved in the process.

Principal Inspections are conducted according to a determined periodicity aiming to evaluate the structural safety of bridges. These inspections are mainly a close visual observation conducted by civil engineers to all accessible parts of the structure. After the on-site observation, these high qualified professionals write down a report where observed condition is recorded, including a comparison with the previous condition and an analysis of the hypotheses for the evolution of structural behavior. The inspections reports also record photos, drawings, descriptions of the observed defects and repair cost estimates. Conclusions are set up as a condition rating (CR) for each of the bridge components, from which a global CR for the bridge is assigned, corresponding to the urgency level of intervention.

Repair priorities among the set of managed bridges are defined according to the global CR of each bridge, that goes from 0 (excellent condition) to 5 (very poor condition). Maintenance and small repairs to restore user's safety are managed apart from this prioritization.

The IP's quality control plan defines the need of repairs in bridges with CR equal to 5, within a maximum of 2 years, along with a set of traffic restraints or provisional interventions to restore safety to an acceptable level. Bridges classified with a CR equal to 4, should be repaired within a maximum of 2 years but with no need for traffic restraints or intermediate intervention. Bridges with a CR equal to 3 should be repaired within 5 years or re-evaluated in the next inspection.

Brisa is one of the major motorway operators in the world and the largest private road concessionaire in Portugal, managing over 1 600 km of highways and motorways.

A similar approach is used in Brisa's bridge management, with periodic visual inspections supported by a Quality Control Plan (QCP). This QCP establish specific thresholds to certain defects and characteristics, determines the need of further research as tests or monitoring, specific periodicity to the assessment and actions to eliminate the defect.

A Condition Rating is assigned based on the inspections conclusions and the comparison with QCP descriptors. The evaluation of the extension and relevance of the observed defects will determine a condition rating for each bridge component and, considering the different functions and structural relevance of each component, a global condition rating is assigned, representing the whole structure. The grades used by Brisa for the condition rating are similar to those described above to IP, due to the use of the same commercial software GOA®. The assigned rating to the whole structure, using the same five grades scale, distinguish the bridge deterioration and correspondent need for repair, enabling the establishment of repair priorities.

In Portugal there are other concessionaires and municipalities which use an identical procedure as that described for Infraestruturas de Portugal. This process, as previously explained, is being developed for the involved COST countries and coordinated within the WG1.

The corresponding database will be constructed in a step-wise procedure along the COST Action TU 1406 lifetime, being expected that the final report for the applied database would be held on 2016.

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