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Inspection and maintenance KPIs to support decision making integrated into Digital Twin tool

Irina Stipanovic[1,2] | Sandra Skaric Palic[1] | Joan Ramon Casas[3] | Rolando Chacón[3] | Emir Ganic[1,4]

Correspondence

Dr. Irina Stipanovic
Infra Plan Consulting
Luke Kaliterne 7
10000 Zagreb, Croatia
Email: irina.stipanovic@infraplan.hr

[1] Infra Plan Consulting, Zagreb, Croatia
[2] University of Twente, Faculty of Engineering Technology, Enschede, The Netherlands
[3] Universitat Politècnica de Catalunya, Barcelona, Spain
[4] University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia

Abstract

In the H2020 European project ASHVIN “Assistants for Healthy, Safe, and Productive Virtual Construction Design, Operation & Maintenance using a Digital Twin”, a set of Key Performance Indicators (KPIs) and Performance Indicators (PIs) to plan and control productive, resource efficient, and safe maintenance are being developed for transport infrastructure. This paper is presenting PIs and KPIs for the assessment and monitoring of the following aspects: Productivity, Resource Efficiency, Cost, Health & Safety during the operational life cycle stage, which is mainly focusing on the inspection and maintenance planning. Quantifiable and measurable PIs and KPIs are proposed and applied on two demonstration projects, highway bridge in Spain and airport runway in Croatia, as part of transportation infrastructure. Proposed PIs and KPIs are integrated into digital twins of the analyzed assets and into decision making tools for risk based maintenance planning. This paper presents the overview of the proposed digital PIs and KPIs applied on two demonstration projects and the integration into decision support tools for efficient and sustainable maintenance planning.

Keywords

Inspection, Digital twins, Key Performance Indicators, Decision support tool, Maintenance planning

1 Introduction

Decisions regarding when to perform an inspection, condition assessment, when to apply maintenance action, and which maintenance technique to use are all part of the maintenance decision makign. The parameters of the inspection policy, the maintenance threshold of deterioration level, and the expense and results of maintenance procedures all play a role in these choices. The maintenance strategy optimization is built sequentially, with the goal of minimizing lifetime maintenance costs, while ensuring structural and user safety and minimizing the impacts on the end-users and environment. Four Key Performance Indicators proposed in ASHVIN project, productivity, resource efficiency, health and safety and cost, are used to develop risk based maintenance strategy.

To design a measurement system that is as comprehensive as feasible, a mix of the quantitative and qualitative approaches needs be used [1]. The qualitative assessment is occasionally the only method utilized to assess the state of an asset when there is no sufficient data or when the integrity is in dispute. Alternately, where data is available, quantitative approach is always preferred since it is traceable and repeatable. In the following chapters for each KPI a list of associated performance indicators is proposed. These indicators are derived, calculated, or directly collected from project-related data, generic data, measurable data, or from expert judgement.

2 Key Performance Indicators

Infrastructure management decision-making procedures and activities use performance goals as their primary input. Performance goals are specific objectives set to achieve a desired outcome. When setting performance goals, it is important to identify the relevant KPIs that will be used to evaluate progress and success. This can help ensure that goals are measurable and achievable, and that progress can be tracked over time.

Key performance indicators (KPIs) are used as metrics to monitor the performance of infrastructure and ensure the effectiveness maintenance and repair activities. Once the KPIs have been identified infrastructure managers and asset owners can use data monitoring and condition assessment tools to collect the necessary data to measure and track these KPIs. For example, data from pavement condition surveys or bridge inspections can be used to meas-

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ure PCI (Pavement Condition Index) and BCI (Bridge Condition Index). This data can then be used to inform maintenance and repair activities and optimize the allocation of resources to improve the condition and performance of transport infrastructure. Once the performance goals are defined and criterion in the form of a KPI, collection of PIs that constitute the KPI, can be performed. Figure 1 shows the flow of the assessment process ("from data to dashboard") in sub-steps. Additionally, an illustration is given of how a benchmark can be created from existing project data that will allow a comparison of different maintenance strategies using determined KPIs [2].

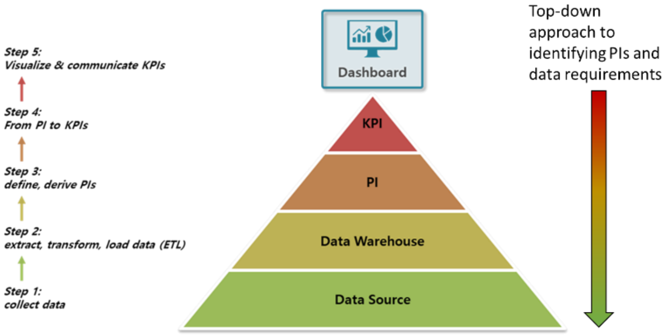

Figure 1 “From Data to Dashboard” - graphical representation of the approach [3]

When developing the structure and the scope of the infrastructure performance indicators for analysis decision making process can vary from strategic/network (top-down approach) level to tactical, operational/object (bottom-up approach) level (Stipanovic et al., 2017). In the ASHVIN project top-down approach was chose as it ensures that chosen indicators help measure infrastructure’s contribution to high-level desired outcomes and to decide whether strategic changes are necessary to ensure that infrastructure performance remains ‘fit for purpose’ [4].

2.1 Productivity

Major issue that the construction industry is facing, regarding its productivity, is the lack of space for standardization and mass manufacturing. A large portion of the work being done revolves around the delivery of unique items that must be made at the area where the products must be used. It is even more pronounced during the maintenance works since works are taking place on already built structures and all maintenance processes need to be adjusted to the existing conditions. The PIs proposed here are focusing on measuring productivity during operational and maintenance stage of structures, and to compare influence of different maintenance strategies or activities during its application on the users, environment, network, and other areas of impact.

2.1.1 Duration of inspection and maintenance works

Duration of inspection and maintenance activities have an impact on the performance of the asset. It is important to identify the time spent on the inspection works which requires closing of parts of the asset or influences the usage of the asset (e.g. closed lane and limited speed during the inspection will cause traffic jams) and the time required for performance of maintenance works which influence availability of the asset and/or the network. Duration of inspection and maintenance work is an indicator for which unit of time such as hours or days is used. The data may be collected from monitoring systems, i.e. tracking construction machines, from cameras or UAVs, or from the infrastructure management systems, see Figure 2.

Figure 2 Process flow for collection of PIs for duration of inspection and maintenance works

2.1.2 Service life

The information is needed to develop a life cycle model for a certain structure and plan type of maintenance activity in the future and the moment in time when it is performed. Different maintenance options have different service life, see Figure 3. If a maintenance option needs replacement sooner than another option, its productivity is lower. Service life of a certain maintenance solution is generally measured in years.

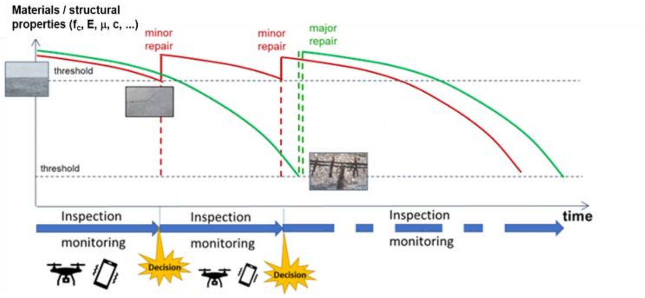

Figure 3 Comparison of service life of different maintenance solutions

Service life prediction is performed based on the collected necessary laboratory and field data for the development of different whole life cycle scenarios. Condition assessment and SHM data serves to build component performance curves, manage and integrate data and information related to service life prediction and finally asset management. Different degradation mechanisms may occur and it is important that the actual ones are recognized and understood to decide which PIs should be collected.

2.1.3 Prefabrication level

The measurements can be perceived from two generic categories quantitative and qualitative [5]. Quantitative assessments might provide a clear, index-style picture of how much of building is prefabricated. However, in some circumstances, employing the value or volume associated with prefabrication alone as the measurements could be problematic due to the possibility of using completely different prefabricated elements. Generally for assessing the prefabrication level, the degree of product readiness when delivered to the site, qualitative approach is preferable. The levels of prefabrication or pre-assembly can be determined from the design project and used for the assessment of the reconstruction design project, as PI for the productivity assessment.

2.1.4 Usage intensity

For transport infrastructure the average annual daily traffic (AADT) is often used to describe traffic volume characteristics of a roadway in a planning context. AADTs is an information available from continuous count stations or from road operators and stakeholders. Most often average daily traffic intensity is taken into analysis per user group, freight, commute, leisure etc. This PI can be collected from traffic monitoring stations.

2.1.5 (Un)availability of the asset and/or network during the maintenance / inspection works

Transport modelling is used to simulate transport disruption following an infrastructure failure (total or partial closure) due to performance of maintenance activities. Delay times for transport users are computed due to maintenance activities (e.g. bridge, tunnel, slope) along the network. Such disruptions influence the functioning of the transport network. Transport modelling can be used to evaluate the impact of these disruptions, whereby the disruption is modelled as a reduction in capacity of one or more links, nodes or services along the network, for a certain time extent. The capacity may fluctuate over time until the problem is fully resolved [6].

Unavailability of a certain asset in a transport network or a downtime, can be seen as the period of time that the road is unable to carry out its function, usually causing congestions and detours for users. Data about the unavailability of the asset can be collected from monitoring systems, i.e. from cameras, traffic management systems where the time of restrictions or special regulations are recorded, etc.

2.2 Resource efficiency

The construction sector is the largest producer of waste, and a major consumer of natural resources. In the European Union (EU), the construction industry consumes about 50% of all materials and, in terms of volume, generates the greatest waste stream (35%) [7]. Most of the resource consumption has been linear, with materials eventually being disposed away as waste. The approach has negative consequences causing amongst other higher carbon emissions and widespread environmental pollution. Given that glass, concrete, steel, and aluminium (or other metals) make up the majority of construction waste, the embodied energy and equivalent CO2 emissions in construction and demolition waste are very large.

2.2.1 Environmental impacts due to the maintenance and inspection works

This PIs can be divided into impacts related to usage of materials and machines and the other related to congestions caused by performance of maintenance activities. During the maintenance works construction materials and components are being repaired and/or replaced. Due to the usage of new raw materials and machines to perform the works, those activities are creating environmental impacts, which can be evaluated using Life Cycle Assessment (LCA) models. The models are creating different performance indicators which can be used for the comparison of different maintenance solutions.

Required data about the quantities of materials and machines can be collected from the bill of quantities from maintenance design project. The information about the construction machines trajectories (actual travel distance and duration of works) can be collected from GPS tracking devices.

The unavailability of the asset which is causing congestions or detours will cause an increase of the pollution due to the longer trips of the vehicles. This PI can be collected from traffic monitoring stations and the impacts can be then calculated based on the predefined environmental impact categories and unit impacts.

2.2.2 Energy consumption (before and after maintenance)

Primary energy consumption is the amount of the energy needed to meet the demand for heating, air-conditioning and mechanical ventilation, and to produce domestic hot water for its occupants. There are numerous measures, structural and non-structural, which can improve energy efficiency of a building. Energy consumption is assessed before and after the implemented maintenance measures and the result is expressed as a gain in kWh/(m2year).

2.2.3 Energy demand covered by renewable use (before and after maintenance)

Implementing solution for transition from non-renewable energy sources like oil, natural gas, and coal to renewable energy can be expressed in the range from 0 to 100%. Energy demand covered by renewables (PVs, solar thermal, biomass, mini-eolica, geothermal, biomass, heat pumps, etc) is calculated as a % of the total energy used by a household/building.

2.2.4 Recyclability and reusability of the maintenance solution

In the maintenance and repair processes deconstruction is the process of methodically dismantling structures to recover parts for recycling and reuse. Deconstruction can be used in various ways to recover useable materials and drastically reduce deconstruction waste. Different maintenance solutions are assessed from two aspects on:

- How much of recycling and reuse of the existing structure is applied in the using maintenance design solution;
- What is the whole life cycle impact of the maintenance solution, namely future recyclability and reusability of the actual maintenance solution that is being implemented.

The indicator for recyclability/reusability of certain construction material/element can range from 0 to 100% and is expressed as % of the materials and components which can be recycled/reused.

2.3 Health and Safety

Within this KPI two main aspects are observed, first one from the structural safety perspective and second one from the human safety perspective, either workers during the maintenance works, or users of the asset during the operation and maintenance phases.

2.3.1 Structural safety

Safety aspects for existing structures are provided in national and international standards and recommendations [8, 9]. Required structural performance is usually related to the goals of structural safety and serviceability, or expressed as a target reliability, evaluated on the component or the system level. Indicators relating to structural performance in the context of safety, serviceability and durability often come with explicit definitions in relevant standards and codes of practice [10].

In order to determine structural safety of the existing structures the first step is to assess the condition. Data gathered during a condition survey should therefore capture any changes in the system's overall reliability which is the crucial parameter for systems in use under challenging environmental conditions for lengthy periods of time. Predicting changes of reliability through time can be used to inform planned maintenance and repair for a specific system. The applicable standards and codes of practice across different countries frequently include clear definitions for indicators relating to structural performance in the context of safety, serviceability, and durability [11, 12]. PIs that can be used for defining structural safety are

- Condition Index,
- Reliability Index,
- Risk reduction.

Data acquisition depends on the purpose of the data acquired. When the first level of data gathering is performed then mostly visual inspections are taking place. In order to get better digital records of the actual condition and location of damages of civil engineering structures, visual inspections are performed using UAVs or LiDar scanners. Those technologies are also used to collect 3D-point cloud data and create digital twin models of existing structures.

2.3.2 Human health and safety

It is hard to completely eliminate all safety dangers due to the nature of building operations and maintenance. However, by doing routine safety audits and having protocols in place to report, evaluate, and deal with potential risks, many common safety issues can be avoided. Implemented safety management procedures prepared for all high-risk construction projects before work commences highly increase the overall safety. The scope of the project, any potential safety concerns, the risk management strategy and the procedures for safety management (e.g. responsibilities, check list, warnings, etc.) should all be covered in the Safety Management Plan (SMP). Safety management is required by law for construction activity but maintenance is often outside of these legally binding obligations. Therefore, it is important that SMP addresses maintenance activities while taking into account alternatives that can be used if the main infrastructure system fails safeguards both users, workers and companies involved from unnecessary risk. One of the PIs can be record of the existence of SFM for the maintenance phase. Generally, health and safety in the maintenance processes can be analysed in the following contexts>

- Safety during maintenance works for workers,
- Safety during maintenance works for users,
- Fire safety (or fire vulnerably) during maintenance,
- Indoor and outdoor air quality during maintenance.

2.4 Cost

Cost as a KPI is one of the most widely used evaluation indicator for the comparison of different maintenance solutions. Costs can be divided into two main groups, direct ones, which are directly born by the owner during the entire life span of an asset and indirect costs which are related to the society, to the end users, environment, community etc. Since they are occurring along the whole life cycle of a structure, it is important to develop a life cycle cost model (LCCM). The main objective of the LCCM is to determine direct and indirect impacts (or costs) of planned and unplanned disruptions causing inspections and maintenance activities, which can then be used for the comparison of different maintenance strategies. [8, 9] [11, 13].

2.4.1 Direct costs

Direct costs are expenditures that an asset's owner directly bears throughout the duration of its life. Costs associated with design and construction, maintenance, and end-of-life are the three categories into which direct costs are typically subdivided.

2.4.1.1 Maintenance cost

For the calculation of maintenance costs first the maintenance scenario that most accurately describes the estimated required maintenance over the life cycle of the object has to be determined. This means determining the different necessary maintenance activities, their accompanying frequencies and their estimated unit costs, which includes workers and machines costs. All the years in the asset's life cycle during which that maintenance action occurs are given credit for the associated annual maintenance cost (based on the frequency attributed to that activity). As a result, a maintenance schedule is created, by which the total maintenance may be determined. The total maintenance costs for the object during its life cycle is therefore calculated by the following Equation (1):

$$MC_{tot,disc} = \sum_{t=0}^{T} \frac{MC_{t,nom}}{(1+r)^t} \times (1+\chi) \qquad (1)$$

Wherein:

MC_{tot} = the total maintenance costs during the life cycle of the object (€)

$MC_{t,\,nom}$ = maintenance costs for year t (€)

t = year in life cycle from 0 until end of life cycle T

r = the discount factor (%)

χ = an additional percentage to cover unassigned, indirect, engineering and other costs.

Required data about the quantities of materials and machines can be collected from the bill of quantities from maintenance design project. The information about the construction machines usage (actual travel distance and duration of works) can be collected from GPS tracking devices, which can be visualized in digital platform.

2.4.1.2 Total LCC

Life cycle costs include all maintenance and repair activities during whole life cycle of a structure together with initial construction costs and end of life for different scenarios. Calculation of total life cycle costs enables comparison of different investment alternatives based on the total costs that are associated with that alternative. Not only initial investment costs but also all costs that develop throughout the object's life cycle are taken into account. This entails costs made during operation as well as end of life costs. Depending on the level of analysis it can include direct or/and indirect costs. Direct costs are initial construction costs (€), nominal maintenance costs for year t (€) and nominal end-of-life costs (€). Indirect costs can include environmental costs and societal costs which can both be transferred into monetary units, explained in chapter 2.4.2.

The total discounted agency costs are the sum of the three sub cost categories and therefore calculated by the following Equation (2):

$$Total\ Costs = ICC + \left(\sum_{t=0}^{T} \frac{MC_{T,nom}}{(1+r)^t}\right) + \frac{EoLC_{T,nom}}{(1+r)^T} \quad (2)$$

Wherein:

ICC = Initial construction costs (€)

$MC_{t,\ nom}$ = nominal maintenance costs for year t (€)

$EoLC_{nom}$ = nominal end-of-life costs (€)

t = year in life cycle from 0 until end of life cycle T

T = year in which life cycle ends

r = discount factor (%)

Data about the quantities for initial construction costs are taken from the bill of quantities - as detailed as available at the design stage. The data can be then updated from the digital twin models.

For the calculation for maintenance costs over the life cycle, it is necessary to predict the service life of each unit / element, and these data can be updated based on the inspection and monitoring data. End of life costs require the information about the predicted service life of used materials / components, but it should be regularly updated with the information collected through inspection and monitoring.

2.4.2 Indirect costs

2.4.2.1 User delay cost

User delay costs are usually determined for the transport infrastructure networks. The calculation methods presented here are applicable for road networks, but they can be adapted for railway, waterway or airport infrastructure. The equations used for determining the user delay cost are based on the work of [14]. The total user costs are a summation of the two sub-categories; freight delay costs and passengers delay costs. Because the user costs are made during the life cycle of the structure, future cash flows will have to be discounted to determine a total present value.

The total discounted user costs are determined using Equation (3):

$$UDC_{tot,disc} = \sum_{t=0}^{T} \frac{TDC_{fr,t,nom}}{(1+r)^t} + \sum_{t=0}^{T} \frac{TDC_{car,t,nom}}{(1+r)^t} \quad (3)$$

Wherein:

$UDC_{tot,\ disc}$ = total discounted user delay costs (€)

t = year in life cycle from 0 until end of life cycle T

r = discount factor (%)

$TDC_{fr,t,\ nom}$ = nominal freight traffic delay costs in year t (€)

$TDC_{car,t,\ nom}$ = nominal commuters traffic delay costs in year t (€)

The traffic delay costs are the costs that represent the valuable time of the network users itself. This economic value of the user's time is dependent on several factors. The type of traffic (passenger vehicle or freight traffic), the amount of persons/cargo per vehicle and the type of cargo/person (business/leisure). The input data for the calculation of traffic delay costs should come from analysis of traffic flow models. The traffic model gives the values for additional travel time, depending on the traffic disruptions for two groups of users, namely freight and passenger's traffic. Different value of time is then used for each group of users.

2.4.2.2 Environmental cost

Introducing environmental shadow prices provides a way of monetizing environmental effects which enables incorporation of these effects with all other monetary costs into analysis. For an explanation and in-depth discussion the authors refer to the report by Bruyn et al. [15], where the environmental prices are constructed prices for the social cost or pollution, expressed in Euros per kilogram pollutant. Environmental prices thus indicate the loss of economic welfare that occurs when one additional kilogram of the pollutant finds its way into the environment. These prices can also be calculated for immaterial forms of pollution such as noise nuisance and ionizing radiation. In such cases the environmental price is expressed in Euros per unit of nuisance or exposure (in decibels, for example). Firstly, the LCA analysishas to be performed for functional unit determined for different construction and/or maintenance processes, which include usage of materials and machines. The outputs from LCA model are environmental impacts at midpoint level [15] which are then multiplied with environmental prices to weight them and produce a 'single score', as shown in Equation (4).

$$EC = \sum_{i=n}^{m} EE_i \times ECI_i \quad (4)$$

Wherein:

EC = environmental costs (€/functional unit, €/kg, €/m^2 or €/total)

EE$_i$ = environmental effects for impact category i (kg of impact category equivalent (ICeq)/functional unit (e.g. one bridge))

ECI$_i$ = the environmental cost indicator for environmental effect category i (€/kg of ICeq)

i = environmental impact category n until m.

Environmental costs incurred during the life cycle of the structure are not discounted as recommended by [16]. The environmental effects per impact category can be determined using following Equation (5).

$$EE_i = \sum_{j=n}^{m} EE_{i,j} \times Mq_j \qquad (5)$$

Wherein:

EE$_i$ = environmental effects for impact category i (kg of impact category equivalent (kg ICeq)/functional unit)

EE$_{i,j}$ = environmental effect for impact category i per kg of material j (kg ICeq/kg material)

M$_{qj}$ = material quantity per functional unit for material j (kg material/functional unit)

j = the different materials n until m

Required data about the quantities of materials and machines can be collected from the bill of quantities from maintenance design project or BIM models. The information about the construction machines usage (actual travel distance and duration of works) can be collected from GPS tracking devices, which can be visualized in digital platform.

3 Mapping of KPIs and ASHVIN tools and methods

Accurate digital twins that represent the situation during operation provide the basis for analysis of different flexible predictive maintenance scenarios. Two interdependent tools GISI and RISA were developed to enable establishment of a risk-based predictive maintenance planning, a risk-based status assessment tool with KPI dashboard and a GIS integrator for digital twin-based asset management. A GIS application enables asset managers to monitor the anticipated state of various assets based on their digital twins using a set of asset management KPIs. Utilizing a visualization tool, maintenance schedules may be designed with a thorough understanding of an asset's status. The risk model considers different maintenance strategies and allows end-users to interactively review and utilize specific outputs of the risk assessment and the consequence modelling in the risk analysis. The GISI tool allows the visualization of condition assessment results and of risk calculated through RISA tool following the next steps:

- Classification and quantification of documented damages – definition of threshold values for different classes – geo-positioning of all detected defects,
- Definition of failure modes,
- Condition assessment based on the detected defects (e.g. Pavement Condition Index PCI or Bridge Condition Index BCI),
- Projections of future degradation based on current condition,
- Quantification of risk by combining probability of failure and consequences – changes in risk over time – definition of threshold values for performing actions (maintenance options),
- Mapping of risk – geo-positioning.

3.1 GIS integrator for digital twin-based asset management

In Figure 4 main components of the GISI tool are presented beginning with the acquisition of data with advanced technologies, drone equipped with high resolution camera. Condition assessment of the asset is performed based on the analysis of photos containing main groups of damages. The photos are also used to develop 2D or 3D model of the asset to be used for presentation of results in the platform. Based on the failure modes (e.g. cracks) and predefined threshold values (e.g. width, length) damages are categorized and labelled to develop and train damage detection model. The final result is the geo-positioned defects after applying the developed damage detection model on the 2D or 3D model of the asset.

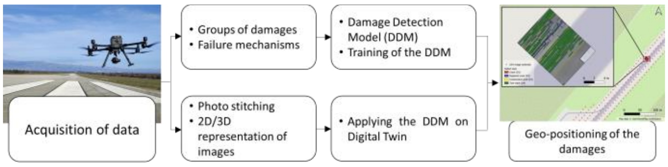

Figure 4 Structure of the GISI tool with main development processes

3.2 Risk-based status assessment tool with KPI dashboard (RISA)

The RISA tool, see Figure 5, uses the result of the GISI tool as a layer of assessed, categorized and quantified defects. Selection of maintenance strategy can vary from no maintenance just monitoring, to minor or major repair and finally replacement. RISA tool takes into account consequences of different maintenance options. Once the risk is calculated by applying the RISA tool, the result can then be returned into the GISI to visualize risk on the 2D or 3D model.

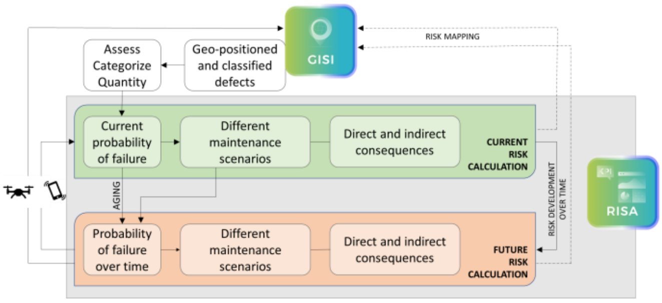

Figure 5 Structure of the RISA tool and the interactions with the GISI tool

4 Implementation on demonstration projects

4.1 Demonstration project – Bridges

Routine load tests are meant to verify standards on the design and construction of the bridges. The load tests represent an ideal milestone for twinning bridges. On the one hand, specific, bespoke structural models are performed. On the other hand, measurements quantifying the structural response are taken. If both results are matched using not only basic comparisons but comprehensive digital twinning, the asset enters the service phase not only physically, but also virtually. The bridges demonstration project (Figure 5) is aimed at establishing requirements, procedures and for the generation of the most realistic virtual replica of the physical bridges that can be used during operation. Presently, current numerical methods focus primarily on the virtual reproduction of the assets. Models are generally calibrated with existing laboratory or real tests. The twinning of these bridges also includes the integration of data from sensors for model updating or hybrid simulations within the realm of such simulations [17].

Figure 6 Demonstration project railway bridges

Data collected (during load tests) include deflection, inclination, acceleration, environmental conditions (temperature and humidity), images and video (drone footage). This data is translated into performance indicators. Several performance indicators are investigated within this demo. Using drones for inspection instead of manual visual inspection enables undisturbed traffic flows across the bridges and entire railway line. Individual structures and the whole network is available with the consequence being the decreased or abolished user delay costs.

For the development of life cycle management plan a service life of structural elements and equipment needs to be predicted based on the inspection and monitoring data in order to optimize maintenance planning. Overall aim is to use information from continuous monitoring for updating the safety and serviceability models and to combine the outputs from the model with the predefined threshold values. The thresholds values which represent satisfactory and non-satisfactory performance will trigger the action, such as detailed inspection, sampling, running numerical model with the updated information, maintenance or repair activity, strengthening etc.

4.2 Demonstration project – Airport

The goal for the airport demonstration project is digitalization of airport infrastructure with the purpose of optimizing maintenance and operational planning. The main idea for this demonstration project is the use of images of operational areas of the airport collected with unmanned aerial vehicles (UAVs), see Figure 7. In this demo, a digital twin is developed containing detailed structure information about the runway layout, materials, drainage systems and signage. It will be combined with the Airport Operational Database (AODB) and inspection data performed with Unmanned Aerial Vehicles (UAVs). Deep machine learning techniques are then applied on drone-based images for the automation of the visual inspection and damage detection procedures. The developed methodology for digitalization and automation of inspection and monitoring processes of operational areas, are then integrated into GIS based predictive maintenance tool. Collected data is transformed into single PIs and eventually combined into four KPIs productivity, costs, resource efficiency and health and safety. Final intention is to integrate use of UAVs into continuous monitoring practice and risk-based maintenance planning.

Figure 7 Demonstration project airport – runway operational area of the airport

5 Conclusion

The main objective of the work presented in this paper was to present a set of KPIs and PIs to plan and control productive, resource efficient, and safe maintenance. Four main KPIs have been agreed at the early stage of the project, namely productivity, resource efficiency, cost and health and safety and applied as a main structure of the KPI framework, which presents a basis for the development of the ASHVIN applications and tools.

During the implementation of asset management strategies, maintenance actions are required in order to keep assets at a desired performance level. As the focus on an efficient delivery of asset (buildings and infrastructure) performance increases, so does the interest in the relations between economy, environmental and societal goals. The implementation of asset management should increase the integration of network, system network and asset performance requirements. In doing so, asset managers and owners face a number of challenges. Therefore, the work described in this paper describes the quantification methodologies for each PI identified for four KPIs, in order to support decision making and development of optimized maintenance plan. The overview includes description of PIs with suggestions on how to meaningfully implement data, PIs and KPIs for physical assets into digital twin models.

Accurate digital twins that represent the situation during operation provide the basis for analysis of different flexible predictive maintenance scenarios. Two interdependent tools GISI and RISA were developed to enable establishment of a risk-based predictive maintenance planning, a risk-based status assessment tool with KPI dashboard and a GIS integrator for digital twin-based asset management. The GISI tool allows the visualization of condition assessment results using safety PIs. The RISA tool uses the result of the GISI tool as a layer of assessed, categorized and quantified defects. Selection of maintenance strategy can vary from no maintenance and just monitoring, to minor or major repair and finally replacement. RISA tool takes into account consequences of different maintenance options and illustrates the risk for different maintenance strategies. Once the risk is calculated by applying the RISA tool, the result is then returned into the GISI to visualize impacts on the safety on the 2D or 3D model.

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