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ASSET DIGITALIZATION MODEL AND ASSET HEALH MANAGEMENT

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Abstract:
Despite advancements in technologies like digital twins, asset digitization remains a significant challenge. The core issue lies in accurately and comprehensively determining how assets adapt to the management of complex systems introduced by digitization. This gap in understanding and executing asset digitization affects the organization of asset-related information. Digital assets are vital components within an interconnected digital ecosystem, not just mere pieces of equipment. Without a clear comprehension of how these assets integrate and function within this digital framework, our decision-making and management capabilities are impaired. This leads to operational inefficiencies, increased costs, and a decline in service quality and infrastructure reliability.
This article aims to tackle this challenge by focusing on asset digitization. It provides a practical example of advancing this field through the integration of various models. This involves defining and categorizing assets based on established standards, assessing asset criticality, and merging IoT-based monitoring models with the Asset Health Index (AHI) model. This integration provides a comprehensive view of asset digitization, addressing different levels of complex asset system management. It facilitates better connections between real-time monitoring and a deeper, long-term understanding of asset conditions and performance. The resulting synergy improves the effectiveness of asset digitization strategies, particularly in critical areas like infrastructure management.
The article presents a concrete example: the digitization of a bridge. This case study demonstrates how these practices positively impact asset management and maintenance during digital transformation, enhancing the safety, efficiency, and reliability of our digital infrastructures.

Keywords: Asset digitalization, Digital Maintenance, IoT, Asset health indexing, Civil infrastructure digitalization, Bridge Maintenance. INTRODUCTION

1. Introduction

1.1. Digitalization of assets

This paper explores the concept of asset digitalization, adopting it as a comprehensive term that includes both asset data design and the transformative processes that create new value (Gong and Ribiere 2020). While recognizing the complexities in the terminology of digitization, digitalization, and digital transformation (Raza et al. 2023), this work focuses on three key aspects:

- *Asset Digitization*: This involves establishing the fundamental data and information model for an asset, creating a detailed digital counterpart.
- *Asset Digitalization*: This goes beyond simple digitization by generating new processes, starting with the creation and continuous updating of the digital counterpart. The emphasis is on enhancing the asset's value proposition and management through new processes, which may not solely depend on current digital technologies.
- *Digital Transformation*: The paper positions itself as a contributor to digital transformation by addressing its broader impact on business and society, aligning with the wider vision of enterprise transformation and its influence on the digital society.

1.2. Digital Maintenance

The digitization of maintenance, within the broader scope of asset digitalization, is crucial for advancing digital transformation. This is evidenced by the extensive use of IoT platforms and Prognostics and Health Management (PHM) techniques in maintenance (Guillén et al. 2016; Compare et al. 2017; Errandonea et al. 2020; Marquez et al. 2020), which enable real-time asset degradation monitoring through extensive data collection.

Asset digitalization necessitates a technical design within an IT architecture that integrates various systems and platforms. While digitalization solutions often originate from a technological perspective, a maintenance-focused approach is essential to complement this view. This approach ensures the durability and reliability of digitalized assets in line with broader business objectives. It involves understanding and managing the digital functionalities of the IT solution and overseeing end-to-end processes for data and model handling, all centered on maintenance needs, without delving into specific architectural designs.

Considering the role of end users, information system providers strategically design their technical and commercial offerings around platforms and apps. A platform offers essential digital services to support end-to-end processes, similar to IoT and cloud platform concepts. Apps are connected to core functionalities desired by users, requiring a platform for seamless integration and operation in today's complex industrial systems. Intelligent Asset Management Platforms (IAMP) gather and analyze data from industrial assets, typically falling into categories like Enterprise Asset Management (EAM), Asset Performance Management (APM), and Asset Investment Planning (AIP).

In this context, a visual tool (Figure 1) suggested by Crespo Márquez (2022) integrates the Input-Process-Output (I-P-O) schema with the need for multiple models and apps throughout the comprehensive maintenance process. This representation transforms raw data from various business systems into specific models crucial for different aspects of asset digitalization. The I-P-O process aligns with the ISO 14224:2016 framework, with each block representing a function (e.g., ETL, Database, IAM, AI, and BI) to ensure an efficient approach to digital maintenance management. These functions use models to generate outputs linked to various IAM apps, supporting tasks related to each phase of the maintenance and asset management process.

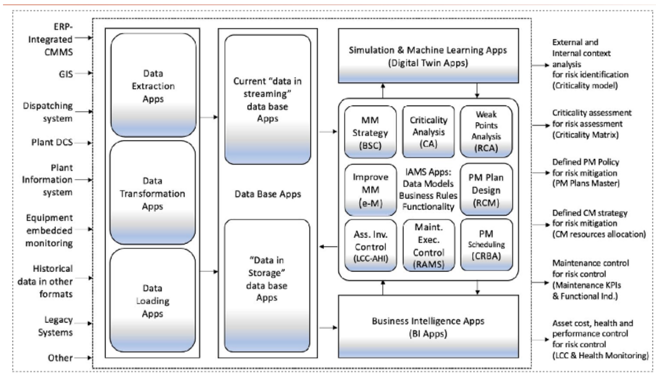

Figure 1. Schema of digital maintenance framework proposed by (Crespo Márquez 2022)

The diagram in Figure 1 illustrates a concept that not only identifies relevant apps across the full scope of management, from strategic to operational levels, but also clearly differentiates between apps and IT functional blocks. This approach is based on the framework for asset and maintenance management initially introduced by Crespo Márquez et al. (2009). This framework, extensively used in the management of network utilities through information technology systems (Gómez Fernández and Crespo Márquez 2012; Serra et al. 2019), has evolved to support both digital maintenance and the design of digital twins (Crespo Márquez et al. 2020; Crespo Márquez 2022).

1.3. Reference architectures

ISO/IEC/IEEE 42010:2011, titled "Systems and software engineering - Architecture description," broadly defines architecture as "the fundamental structure of a system, including the structure of system components, their relationships, and the principles and guidelines that govern their design and evolution over time" (ISO/IEC/IEEE 42010:2022 - Software, systems, and enterprise — Architecture description). In systems engineering, architecture is crucial for offering a framework that describes the interactions and organization of system components to meet specific objectives.

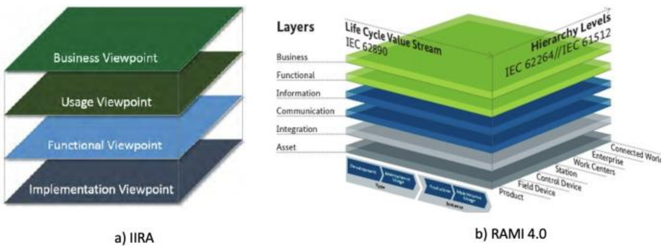

Figure 2. Layered reference architectures: a) IIRA; b) RAMI 4.0

This work primarily references RAMI 4.0 and IIRA (Figure 2) due to their significant influence and widespread acceptance in both academia and industry. These architectures share fundamental principles and approaches crucial for addressing the challenges of digitization in modern industry. They employ the concept of layers to structure systems, which facilitates modularity, flexibility, and incremental updates. RAMI 4.0 introduces two axes—lifecycle and hierarchy in system integration—while IIRA offers a more streamlined perspective. A significant contribution of RAMI 4.0 is the introduction of Autonomous Asset Services (AAS), which plays a vital role in the digital transformation of the industry, as elaborated in the digital twin section. Additionally, RAMI 4.0 explicitly includes the asset and system lifecycle, a critical aspect that needs to be managed effectively in the digitization process.

2. Use case

Bridges, critical in transportation infrastructures, present challenges in Total Expenditure (TOTEX) management. Controlling bridge condition is crucial for holistic management, impacting both individual bridges and the entire asset portfolio. Current tools for effective infrastructure management are limited, and climate change adds urgency to control demands, creating uncertainty in evolving conditions.

Most bridges lack a real-time online monitoring system. Affordable IoT networks enable widespread monitoring, generating extensive data requiring advanced analytics for meaningful insights. Thorough data interpretation enhances understanding and issue identification. Integrating data from multiple bridges offers a global perspective, aiding in predictive model development.

Due to a low initial level of digitization of bridges, during their operation and maintenance (O&M) phase in the middle period of their life cycle, this case study aims to answer the following research questions:

- How can a model-based approach effectively digitalize bridges for maintenance and management?
- How can the combined use of an IoT platform, short-term monitoring models, and long-term models like AHI enhance bridge digitalization and management?

The asset digitization process introduces a set of four models addressing different aspects of asset digitization and management for bridges. Firstly, the Asset Definition Model offers a comprehensive framework capturing the complexities of bridge data in various systems. Secondly, the Asset Criticality Model prioritizes bridge assets based on their criticality. Thirdly, the Bridge Monitoring Model demonstrates how IoT networks and signal integration enable real-time monitoring. Lastly, Intelligent Asset Management Models are designed to estimate the health index of bridges.

2.1. The Asset Definition Model

This model describes the comprehensive asset data/information which is implicitly present within the diverse information systems and apps currently utilized for the asset management. Takes the IEC 81346-1:2022 standard and ISO 14224:2016 as guidelines for this purpose.

The proposed asset definition incorporates four distinct aspects, or specific ways of viewing an object:

- Physical Asset Registration Code. A physical asset code refers to a tangible object or entity that can be touched, seen, and measured.
- Asset Class. Connected to the assets' technology and to the definition of technical aspects unique to the asset, regardless of its final functional location. Subclasses (or types as per the IEC 81346 standard) can be utilized to detail groups within a class, establishing distinctions within the same class.
- Asset Functional Location. Refers to a specific physical or logical location where an asset is installed or used.

- Asset Reference System. The choice of a coordinate reference system for an infrastructure system or network is influenced by factors such as location, precision requirements, and available resources.

According to the four dimensions necessary to establish the asset definition model, the bridge under study has a specific physical asset registration code, a particular asset class and subclass, is located in a specific functional location and geolocated under an established reference system.

2.2. The Asset Criticality Model

An asset criticality model is pivotal in infrastructure management, enabling the prioritization of assets based on their criticality and importance within the organization. This analysis, crucial for risk reduction, must be meticulously conducted, considering factors such as large-scale applicability, consistency with the scope, and compatibility with changes and the asset management system (Jinzhi et al. 2022).

Once the criticality of assets is determined, the framework facilitates integration with other models. This includes the model for establishing a preventive maintenance plan, specifying tasks and their frequency (using methods like RCM, MTA, RCBA, etc.). It also connects with the asset monitoring model, particularly recommended for critical assets with significant impacts on infrastructure effectiveness, efficiency, and performance. Additionally, it links with models for establishing optimal scheduling and resource allocation for a maintenance plan, as well as the model for examining assets to study their degradation and life cycle cost, encompassing the asset degradation and life cycle cost models.

Digitalizing bridges allows for more effective management, real-time monitoring, and a comprehensive assessment of their condition, which is essential to ensure their performance, safety, and durability over time. Additionally, the risk associated with the functional failure of a bridge not only impacts infrastructure but can also have serious implications for public safety and health, underscoring the urgency of implementing digitalization models to mitigate this risk.

2.3. Bridge Monitoring Model

The digital transformation of an asset, particularly those requiring or benefiting from state monitoring, is accomplished by connecting it to data obtained from the physical world through customized monitoring solutions. Developing an asset monitoring model is a complex process that involves signal integration and the creation of a comprehensive Extract, Transform, Load (ETL) process, which converts signals into valuable asset-related information. Advanced systems perform this transformation by deploying sensors via an Internet of Things (IoT) network. This network comprises sensors, nodes, and cloud computing, with nodes playing a crucial role in grouping sensors, ensuring effective communication, and transmitting data to cloud platforms and applications.

The proposed design is based on an IoT framework that includes acquisition and local processing layers at the measurement points (sensor nodes), an information transport network, and a processing server responsible for hosting essential services for processing, exploiting, and presenting information to end-users (Figure 3).

To digitize the monitoring process, information from the strategically located IoT/Cloud network points on the bridge is integrated. The use case solution combines both hardware and firmware design to support local processing, device control, wireless communication, data storage, power supply, sensors for real-time structure monitoring, real-time operating system tasks, and sensor monitoring tasks, along with local information processing and wireless control.

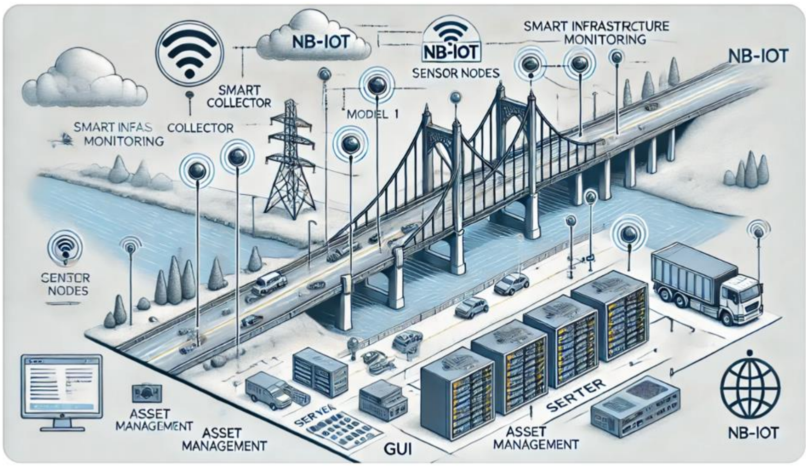

Figure 3. The IoT Network

The server plays a crucial role by centralizing the processing and management of monitored structures. To adapt to scalability, a microservices-based development is adopted, performing tasks such as gathering information from deployed nodes, storing it in a database, and processing data according to different asset digitization models.

2.4. The Intelligent Asset Management Model

Once the information and data from the asset are captured, processed, and stored, and the critical asset is appropriately structured with its operating and maintenance conditions monitored, it becomes necessary to connect data models with human knowledge and reasoning to digitize the decision-making processes. This digitization is achieved through intelligent asset management models embedded in the Intelligent Asset Management Platform App (IAMP App) (Marquez et al. 2020).

In the framework proposed by Crespo Márquez (2022) in Figure 1, various decision-making processes are outlined, including Root Cause Analysis (RCA), Reliability-Centered Maintenance (RCM) or Maintenance Task Analysis (MTA), Condition Based Maintenance (CBM), Maintenance Resources Optimization models (MRO), Reliability, Availability, Maintainability, and Safety Analysis (RAMS), Asset Health Indexing (AHI), and Life Cycle Costing (LCC).

Within the IAMP App, these intelligent asset management models are configured. By interacting with simulation tools or artificial intelligence, they enable personnel responsible for the operation and maintenance of the asset to make informed short-term, medium-term, and long-term decisions.

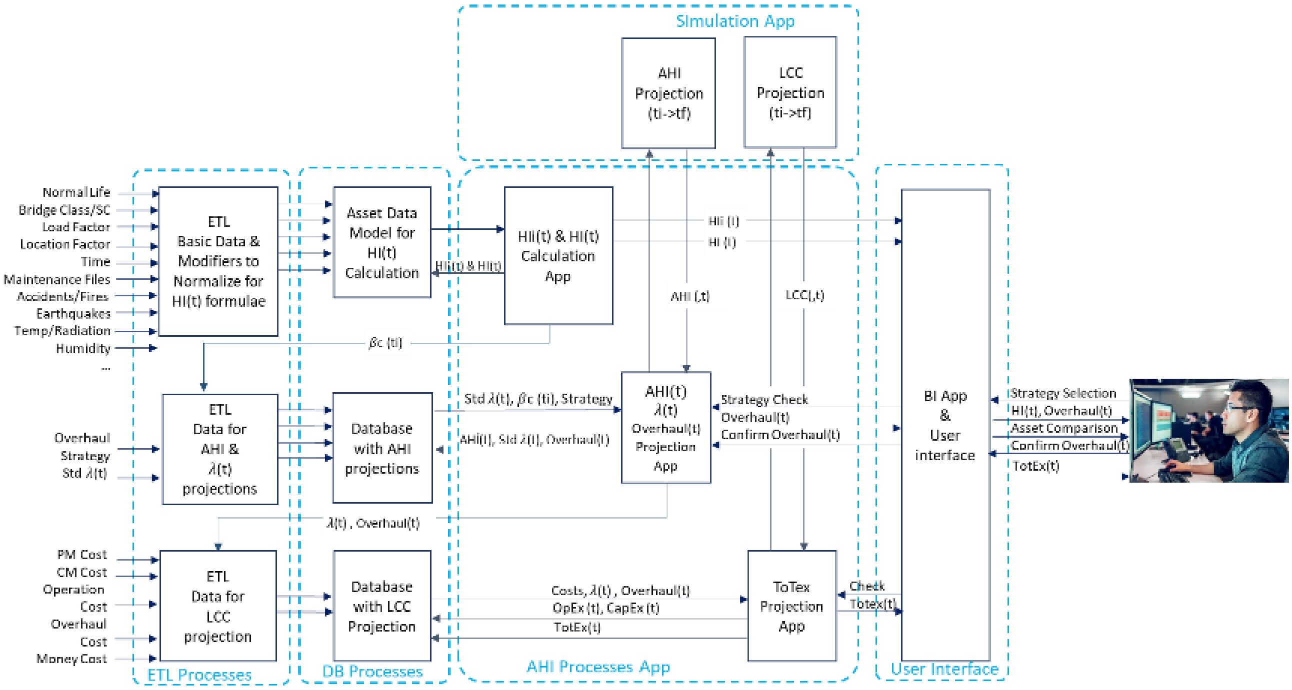

Figure 4. The AHI model presentation using the DMM framework.

In the proposed use case for the digitization of the bridge, the ETL processes, database processes, and Intelligent Asset Management Systems are integrated, supported by mathematical and simulation modeling. (Simulation App), and facilitating the representation of results in business intelligence tools (BI App/User Interface).This integration of various processes, as illustrated in Figure 4, enables the following:

- Determining the Bridge's Health Status: By calculating the Asset Health Index (AHI), it supports short and medium-term decision-making regarding necessary operational and/or maintenance activities based on the asset's current condition.
- Projecting AHI with Simulation Tools: This allows for medium and long-term decision-making by comparing different scenarios and potential strategies for major maintenance or overhaul of the analyzed asset.

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- Estimating the Asset's Life Cycle Cost (LCC): This estimation considers past and projected operations and maintenance activities throughout the asset's useful life.

The integration with the IoT network enables the processing of monitoring data from the platform, facilitating the calculation of input indicators for the proposed health index model. The model's robustness allows for flexible validation and recalibration of processes to accurately reflect the asset's condition, thus refining decision-making.

In a case study example, the health index is calculated for four bridges of different classes, technical locations, and operating and maintenance conditions. The results for each bridge are depicted in Figure 5, where the x-axis represents age (operating time), the y-axis shows the obtained maintenance index, and the ball's diameter indicates the deviation from the predicted deterioration for each bridge. This deviation reflects the difference between the calculated health index and the initially predicted health index, excluding health and reliability modifiers.

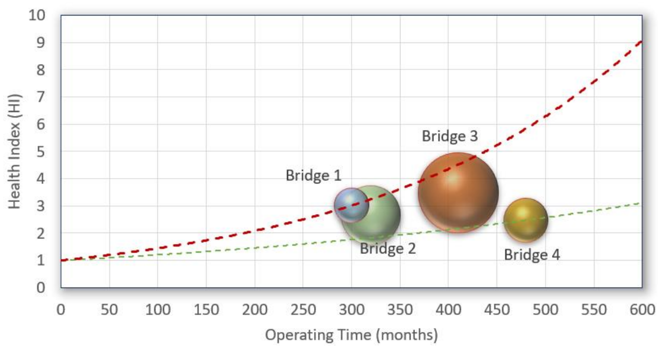

Figure 5. AHI versus age projection. Representation of current health index versus the initially estimated for bridge age.

It is observed that Bridge 1 has the most unfavorable health index, even though it has the least number of operating hours. Despite this, as indicated by the ball diameter, this aging rate aligns quite closely with what was expected, unlike Bridge 3, which, with higher age, was expected to have a more favorable health status. This could be attributed to:

- Experiencing worse operating and/or maintenance conditions than initially planned, such as increased heavy vehicle traffic beyond the initial consideration or exposure to more adverse weather conditions than those anticipated in the bridge design. To determine these causes, data mining or establishing KPIs will be necessary to identify the reasons for these deviations in the health index.
- The calculated health index does not align with the actual health status of the bridge, and therefore, recalibrating the model based on the knowledge of expert personnel from the installation will be necessary.

3. CONCLUSIONS

This research delves into the crucial facets of maintenance digitization, acknowledging the existing gap in its effective implementation despite the strides in IoT platforms and digital twin technologies. The proposed framework not only aligns with the creation of the Asset Administration Shell (AAS) and its digital twin but also underscores a model-centric approach to asset and maintenance management in the digitization process.

The research acknowledges the challenges posed by infrastructure assets lacking historical monitoring records and proposes a solution enabling the integration of monitoring variables with the characterization of technical aspects affecting comprehensive asset health degradation. The model's adaptability allows for refinement based on actual degradation processes, encouraging meticulous recording and interpretation of significant data and events.

The limitations of the proposed methodology will depend on the availability of information about the physical assets, specific knowledge about their behavior, and the ability to accurately approximate their health status. However, the flexibility of the model will allow for easy recalibration and adjustment of the asset health calculation, enabling representation through successive adjustments until replicating expert knowledge about the physical asset is achieved.

In summary, this study furnishes a framework for the effective digitization of maintenance, emphasizing practical implementation, model-based perspectives, and the strategic integration of an asset health index model, ultimately contributing to the advancement of digitization practices in the realm of maintenance management.

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