Proceedings of the 2021 Joint Rail Conference
JRC2021
April 20-21, 2021, Virtual, Online

JRC2021-1033

ADVANCED ENTERPRISE ASSET MANAGEMENT SYSTEMS: IMPROVE PREDICTIVE MAINTENANCE AND ASSET PERFORMANCE BY LEVERAGING INDUSTRY 4.0 AND THE INTERNET OF THINGS (IOT)

Sandeep Bhanji
Parsons
Irvine, CA

Howard Shotz, PMP
Parsons
Austin, TX

Sravani Tadanki
Parsons
Oakland, CA

Youssef Miloudi
Berger-Levrault
Limonest, FR

Patrick Warren
Berger-Levrault
Albany, NY

ABSTRACT

Advanced Enterprise Asset Management (EAM) is an approach through which an organization's assets are systematically and proactively managed throughout their lifecycle - from installation through disposition. The objective of EAM is to prolong the service life and maximize utilization of the assets via adoption of leading-edge standards, practices, and technology. Organizations that implement advanced EAM benefit from reduced operating expenses (OPEX), reduced capital replacement expenses (CAPEX), increased uptime, and overall higher quality asset capability within their portfolio.

Successful EAM leverages ISO55000 & IAM 2.0 standards to implement predictive, proactive and reliability centered maintenance best practices.

Implementing an EAM provides leading edge technology to the rail industry to track and audit maintenance work using mobility tools, heads-up virtual reality displays, augmented reality expertise and the Internet of Things (IoT); combined with artificial intelligence and machine learning to bolster predictive maintenance and simulate asset performance based on different scenarios.

EAM will evolve rapidly following the world's rapid transformation into the IoT over the next decade. As rail and transit assets become outfitted with interconnected intelligent sensors whose outputs are collected via active and passive devices, real-time data is available for EAM to track, plan and upgrade assets.

As systems are modernized, EAM will leverage the IoT revolution to provide critical information to operations in planning railway management scenarios, including predictive maintenance functionality and edge analytics.

NOMENCLATURE

3D	Three Dimension
AI	Artificial Intelligence
API	Application Programming Interface
APTA	American Public Transportation Association
AR	Augmented Reality
BAYESIAN INFERENCE	A method of statistical inference in which Bayes' theorem is used to update the probability for a hypothesis as more evidence or information becomes available.
BI	Business Intelligence
BIM	Building Information Modelling
CAD	Computer Aided Design
CAPEX	Capital Expenditures
CMMS	Computerized Maintenance Management System
COAP	Constrained Application Protocol - It is a specialized Internet Application Protocol for constrained devices, as defined in RFC 7252
COTS	Commercial off the Shelf
DWG	AutoCAD Drawing File Name Extension in Native Format
EAM	Enterprise Asset Management
EDGE ANALYTICS	The analysis of data from some non-central point in a system, such as a network switch, peripheral node or connected device or sensor
EAI	Enterprise Application Integration
ENTERPRISE SERVICE	Implements a communication system between mutually interacting software applications in

BUS	a SOA. Used in EAI of heterogeneous and complex service landscapes
FoF	Factory of the Future
GIS	Geographic Information System
GTT	Gruppo Torinese Trasporti S.p.A. (Turin Mass Transit Agency, Italy)
IAM	The Institute of Asset Management
IFC	Industry Foundation Classes
IT	Information Technology
IoT	Internet of Things
IIoT	Industrial Internet of Things, a subset of IoT
ISO	International Standards Organization
KPI	Key Performance Indicator
LAMDA	Learning Algorithm for Multivariate Data Analysis
LORA	LoRa (Long Range) is an LPWAN protocol developed by Semtech.
LPWAN	Low-Power Wide-Area Network
MACHINE LEARNING	An application of AI that provides systems the learning ability to automatically learn and improve from experience without being explicitly programmed.
MES	Manufacturing Execution System
MDBF	Mean Distance Between Failures
ML	Machine Learning
MQTT	Message Queuing Telemetry Transport - A lightweight messaging protocol for small sensors and mobile devices, optimized for high latency or unreliable networks
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
OpenDATA	Data freely available in adequate format (weather, maps, fuel prices, etc.)
OPEX	Operating Expenses
PdM	Predictive Maintenance
PMML	Predictive Model Mark-up Language
PPP	Public Private Partnership
P3S ALGORITHM	Particle-Particle, Particle-Scaling function. Fast calculation of the Coulombic forces and energies of point particles with free boundary conditions.
RCM	Reliability Centered Maintenance
REST	Representational State Transfer – Architectural style for providing standards between computer systems on the web
SAMP	Strategic Asset Management Plan
SaaS	Software as a Service
SCADA	Supervisory Control and Data Acquisition
SGR	State of Good Repair
SIGFOX	Cellular style, long range, low power, low data rate form of wireless communications that provide wireless connectivity for remote sensors, actuators and other M2M and IoT devices
SQL	Structured Query language
SOA	Service Oriented Architecture
STREAMING-API	Used to read data in real-time from the web for consumers for precise, up-to-date results.
TAMP	Transportation Asset Management Plan
USD	United States Dollar
VAL	Véhicule Automatique Léger (Automatic Light Rail Vehicle)
VR	Virtual Reality

1. INTRODUCTION [1][2]

Strategic EAM is both an approach and a valuable tool in a rail systems' arsenal to manage assets strategically and proactively. EAM provides the right balance between the outcome of ongoing maintenance efforts and their cost to the organization. Through a disciplined EAM approach, an organization's assets are strategically and proactively managed throughout their lifecycle. This paper presents an overview of EAM and discusses a software implementation approach successfully used to manage a large-scale transportation network. The aim of this paper is to educate the rail community on the benefits of EAM, the current state of EAM technology, and a potential road map based on Industry 4.0 standard approach. This approach and technology are currently used internationally by European rail and transit agencies. North American transportation agencies and PPP entities who are planning to implement an EAM software in the next five (5) years will benefit from this approach.

2. MATERIALS AND METHODS [1][2][3]

This section discusses the basics of EAM and the benefits of using EAM within the rail sector. EAM has been successfully implemented in other industries and is now offering its benefits to rail industry. Several major transportation agencies have either implemented or are in the process of implementing EAM. Leveraging this technology, with various well-established standards such as ISO 55000 the IAM Framework will help agencies reduce costs, streamline maintenance, and deliver added value in the process while managing risks. We have also included an example of how RCM can be implemented on rail vehicles to reduce costs and to streamline maintenance practice.

2.1 Enterprise Asset Management [4][5][6]

The overall objective of EAM is to extend the service life and improve utilization of various assets to deliver greater value to all stakeholders; through cost reduction, risk reduction, and/or improved services for end users. Assets in the rail sector include rail vehicles; wayside signaling equipment such as switches; communication system including wireless radios; tracks; and others. Extended service life and improved utilization are achieved through adoption of leading-edge standards, practices, recommendations by independent entities such as APTA. Successful EAM leverages ISO 55000 & IAM 2.0 standards and implements predictive, proactive and RCM practices combined with modern technology that incorporates AI and ML capabilities. The agencies who implement EAM benefit from reduced OPEX, reduced CAPEX, improved uptime of equipment and overall higher quality asset capability within their portfolio. As a direct result of these improvements, agencies report increased ridership and increased revenues along with improved overall passenger satisfaction.

The rail sector is vital to a nation's mobility, mass transportation and transport of goods and products. The sheer cost, volume, and effort to maintain and keep the assets operational is massive. To meet various local, state, and federal regulations the assets need to be inventoried, tracked, managed and maintained – accordingly all EAM activities are critical. EAM will benefit greatly from the world's rapid transformation into IoT. As rail and transit assets become outfitted with interconnected intelligent sensors, whose outputs are collected via active and passive devices, real-time data is available for EAM systems to track, plan and upgrade work field assets. EAM will leverage the IoT revolution to provide critical information to operations in planning railway management scenarios; including predictive maintenance functionality, and edge analytics - a way to pre-process data so that only the pertinent information is sent to the management system for executable actions and analysis.

EAM provides three types of critical data: performance metrics, asset information including condition, and failure modes. With these three types of data the EAM helps maintenance operations increase the MDBF, lower maintenance costs, minimize downtime, reduce energy consumption, and minimize the MTTR. By establishing benchmarks, the EAM can establish set goals and can track progress allowing rail and transit agencies to set priorities and use their funds effectively and efficiently in attaining their TAMP and SAMP goals and objectives.

Most rail and transit systems in the US are old and frankly antiquated and in a need of proper SGR. They mostly rely on paper-based or spreadsheet technology. EAM systems offer public transit organizations a way to modernize – to move away from cumbersome and costly manual processes and integrate disparate systems that have been siloed between departments. Many transit systems still use paper documents to initiate maintenance orders and repair schedules. Such agencies can modernize their systems and use EAM which will aid in better planning of maintenance and will offer benefits such as metrics and other maintenance-related information. Additionally, electronic calendars will better aid the scheduling of repairs or replacements. Finally, some tools provide real-time information that the agencies will benefit from. Such tools will provide the maintenance managers see the big picture of the situation and will help coordination between various departments.

A unique characteristic of rail organizations is that they manage linear assets which are not typically present in most other business sectors. Because linear assets are widely dispersed, their characteristics and conditions tend to vary along their length due to uncontrollable environmental factors. Linear assets also invariably encompass numerous discrete sub-assets. Specific requirements to be addressed for linear assets include:

- What sections of a linear asset need maintenance or repair?
- How often does a linear asset segment need to be inspected or repaired?
- What is the annual maintenance cost of one specific linear segment of an asset versus another segment?
- Why do linear segments differ is performance and operating cost?

Organizations answering to the above questions consistently and accurately help optimize asset maintenance. By identifying these requirements, organizations recognize that linear assets have differences to be considered such as:

- Managing linear field-based assets that are not in a typical hierarchical arrangement
- Precise location data with alignment between geospatial coordinates and linear reference points
- Field work solutions that provide the following:
  - Tightly link to EAM to provide real-time asset history
  - Identify correct replacement parts for implementing in the field
  - Coordinate field work with asset management policies
- The ability to report on costs accurately based on the following criteria or requirements:
  - Linear segments/patterns
  - Public agency
  - CAPEX and OPEX

Management involvement in EAM is the highest-ranking factor for a successful implementation (Figure 1). It is clear from industry experience that EAM implementation projects succeed when implemented under the initiative and guidance of management and with the participation of all stakeholders. A successful EAM implementation requires the following:

- Support from stakeholders
- A detailed, in-depth preliminary study of requirements
- A precise definition of objectives
- Careful preparation of the participants

Stakeholders not familiar with EAM processes and philosophy should be educated to gain support and participation. Figure 1 provides examples of how various criteria are weighted based on their importance and cumulative values. This illustrates how various implementation factors influence the decision to implement EAM. These factors and weighted values will differ between agencies. Management support is highest and vendor support is lowest. Agencies should compile such factors individually to determine the criterion weighting and ranking.

Factor	Importantance (%)		
Rank	**1st**	**2nd**	**1st + 2nd**
Involvement of Management	20	26	46
Appropriate EAM	23	12	35
Training	9	16	25
Return on Investment	14	10	24
Allocated Budget	5	14	19

Change Management	11	8	19
Project Management	9	10	19
Technical Support by Vendor	9	4	13

FIGURE 1: EAM IMPLEMENTATION SUCCESS FACTORS AND THEIR RELATIVE IMPORTANCE

Organizations who are seeking to implement an EAM tool should:

- Optimize costs and maintenance efforts by leveraging EAM software
- Streamline maintenance efforts
- Assess and manage risks associated with maintenance practices

2.2 IoT Platform for Asset Management and Predictive Maintenance [7][8][9][10][20]

"Industry 4.0," also known as "the fourth industrial revolution," preaches a complete revolution of industrial process and envisions huge efficiency gains via integration (Figure 2). The concept is based on complete virtualization of the organization, numerical design tools, automation of the logistics and the routing of the parts, smart machines, 3D printing, cyber-physical systems, predictive maintenance, and control of the whole organization via an intelligent system.

> An EAM manages fixed, linear, and rolling stock installations by providing these features:
> - Control of fixed and linear installations and rolling stock (asset condition, warranties, work history, etc.)
> - Multi-scale interactivity linking CAD plans, BIM models (via IFC or API) and GIS models
> - Management of maintenance processes: curative, preventive, forecasting, safety, new work, disasters, inventory, vandalism
> - Integration of regulatory reports and inspections
> - Monitoring of reports & central control dashboard
> - Customizable graphic KPIs (e.g. MDBF)
> - Availability of rolling stock for operation
> - Budget management
> - SCADA, Operating Aid System connectors, fuel terminals
> - IoT platform connected objects, real-time optimization of equipment, forecast maintenance, artificial intelligence

FIGURE 2: INDUSTRY 4.0 ENVISIONS A HIGHLY CONNECTED ENVIRONMENT ENABLED BY INDUSTRIAL IOT

In Europe over the next ten (10) years, Industry 4.0 is expected to change the way organizations operate to create USD 1.47 trillion (1.25 trillion Euros) of additional value-add.

Current predictive maintenance processes, in their classic silo configuration, are still trying to adapt to the connected ways of Industry 4.0. Traditionally delivered maintenance operations are inherently flawed or fall short for the following reasons:

1. Current maintenance solutions are not adequate to achieve Industry 4.0 as they focus on single piece of equipment or sensor. The current approach cannot provide a critical evaluation of total line health nor can it predict the impact of a single piece failure or equipment wear on all the production lines or the quality of the products produced.
2. With the growing market of IoT and the Industry 4.0 paradigms, maintenance software needs to be improved in terms of asset availability and maintenance operations, predictive maintenance and analytics, and improved master data and its integral role in lowering asset-related risks.
3. Many in rail and transit industry do not necessarily follow the disciplined approach recommended by RCM. RCM is another tool that helps to streamline maintenance operations with reduced costs and time.

One of this paper's authors was part of a project to develop an RCM approach for a fleet of rail vehicles for a US transit agency. The agency's maintenance expenses, and downtime, were both high and management decided to implement RCM on the fleet. The objective of this exercise was to identify predictive maintenance opportunities within typical reactive maintenance work. For example, if a rail vehicle's propulsion system resistors were being replaced – have technicians visually inspect, analyze and follow the maintenance guidelines to replace the propulsion system capacitors as well. This is a valid predictive maintenance opportunity provided the capacitors are due for replacement within a near future service window. Instead of bringing the vehicle in twice for repair. once for resistor and later for capacitor, perform both activities at the same time. Implementing such a system within the maintenance department will require cooperation from management and cooperation from other departments such as vehicle engineering, operations, parts storage shop, and procurement. Once all stakeholders are engaged and cooperating, the organization will identify significant cost savings progress and reduced downtime. These activities are achievable within modern EAM software.

Accordingly, new predictive maintenance software should encompass the core of Industry 4.0, Smart Transportation, and Smart City maintenance paradigm: maintenance is no longer a standalone function with the independent aim to minimize downtime. Instead, maintenance is a production function whose aim should be to optimize production output, costs, and quality.

3. RESULTS AND DISCUSSION

Section 3.1 discusses first-hand experience with the Turin Metro in Italy and the benefits of implementing EAM in transportation. This section also discusses how the agency improved its KPIs despite the heavy mileage demands on rail vehicles and subsystems. From that point of view, it is a classic textbook-style case study that highlights the benefits of EAM. Section 3.2 discusses how IoT can be leveraged to support asset management as well as to develop predictive maintenance, another function of RCM. The key takeaway from this subsection is the mantra "integrate and observe." Section 3.3 discusses EAM and virtual reality. It discusses how VR can be seamlessly integrated with EAM and offers benefits such as 3D modeling and accurate field reports.

3.1 Railroad Case Study: Metropolitana di Torino[12]

The Metropolitana di Torino (Turin Metro, Italy) began revenue service in 2006 to coincide with the hosting of Winter Olympics in the city, the number of annual passengers traveling along the 13.2 km (8.2 miles) line had grown from nine million in 2006 to 42.5 million in 2018. The driverless Automatic Light Rail Vehicle system boasted a punctuality rate of 99.8 percent in 2009 on top of a 99 percent uptime for its fleet of 52 vehicles, and the entire network was controlled by just a four-person control-room team.

FIGURE 3: A TURIN METRO AUTOMATIC LIGHT RAIL VEHICLE (VAL) IN OPERATION

A COTS EAM was configured and deployed to monitor the maintenance of the VAL trains, its 14 stations, and the centralized control center.

The EAM was able to manage stock levels; locate 1 of 4,000 spare parts in the GTT warehouses; and keep uptime high by logging repairs and establish work orders during preventative maintenance cycles.

With the carriages clocking up to a combined 4.5 million km (~2.8 million miles) in 2009, knowing the MDBF of a component was critical. Especially for heavy wear parts and life-safety components such as lights, brake units, smoke detectors, or security cameras. GTT engineers had to perform approximately 300 preventative maintenance work orders for every 15,000 km (~9,320 miles) traveled.

In case of unexpected component failure, alarms were sent to the control center automatically, which were turned into work orders. The replacement parts ordered online, and repair time was scheduled.

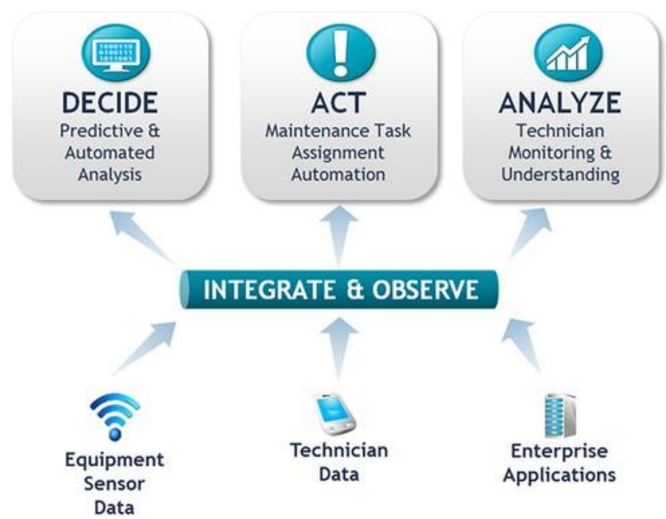

FIGURE 4: THE PREDICTIVE MAINTENANCE PLATFORM IS ABLE TO LEVERAGE DIFFERENT REAL-TIME DATA TYPES TO HELP GENERATE HOLISTIC DECISION-MAKING

In June 2010, six (6) additional stations were opened to extend the Metro to 13.2 km (~8.2 miles) and a new extension was started in 2014. By 2014, the ratio of preventative to corrective maintenance increased from the initial ratio of 2:1. After this extension in 2014 the Metro's operations EAM was linked with other GTT systems such as GIS.

GTT also manages the extensive bus, tram, and train systems in the city. The implementation of the EAM solution allowed the client to significantly improve the following KPIs:

- Reduce spare parts cost stock by 5%

- Increase MTBF by 30%
- Reduce MTTR by 35%
- Reduce energy consumption and reduce maintenance subcontracting costs by 20%

3.2 EAM Innovation: Leveraging the IoT Platform for Asset Management and Predictive Maintenance [11][13][14]

An EAM software solution will help improve the productivity of many agencies around the world. These agencies, which operate across multiple sectors such as transportation, manufacturing, oil & gas, and healthcare have expressed their need for an EAM/CMMS software capable of keeping up with their planned transition to Industry 4.0. The specific needs expressed by the agencies made it clear that classic EAM software must implement some new features to address the challenges of Smart Transportation, Smart City, and Smart Building. Cloud computing will allow improvements for technical support and service. Within the cloud, the EAM solutions have already integrated performance monitoring and cost analysis to best enhance asset lifecycle.

Costs are reduced through the use of cloud computing. Railroad organizations don't need to always rely on IT support with the use of cloud technology and moving to the cloud does not impact application performance. Using cloud computing will result in increased business agility due to ease of managing users' experience and data. This used to be a complicated process with multiple steps and required participation from many different departments which could take months or longer.

Using cloud technology, maintenance personnel can be more mobile. Instead of having data on a single computer, maintenance workers can access data from any device anywhere via the cloud.

In response to this need, an EAM vendor developed a universal IIoT data powered predictive maintenance platform integrated into its EAM software solution. The EAM delivers the following using an integrated approach (Figure 3).

The platform can gather internal data from IIoT sensors on the machines, from technicians, traditional BI tools, and external data such as OpenDATA (i.e., weather data). This data will be injected into digital models of the actual assets present in the organizations; models have automatically generated thanks to machine learning algorithms. The aim is to have a continuous streaming analytics engine that provides automated alerts based on forecasted failures identified by the predictive models.

Moreover, this information is injected into the EAM software to give a holistic overview to decision-makers on maintenance operations; such as recommending to use a machine beyond its maintenance cycle to support a production peak, knowing that the machine will not fail and even if it does, notification to maintenance is relatively quick, thanks to real-time data coming from IoT.

Leveraging a SaaS solution allows the rail sector to capitalize on their IIoT data as well as sharing between different actors. The goal is to take advantage of all enabling technologies to optimize maintenance activities and to optimize cost and/or productivity and/or quality, in order to improve maintenance activities.

The universal IIoT data powered predictive maintenance platform functional architecture works within a robust integration model (Figure 5).

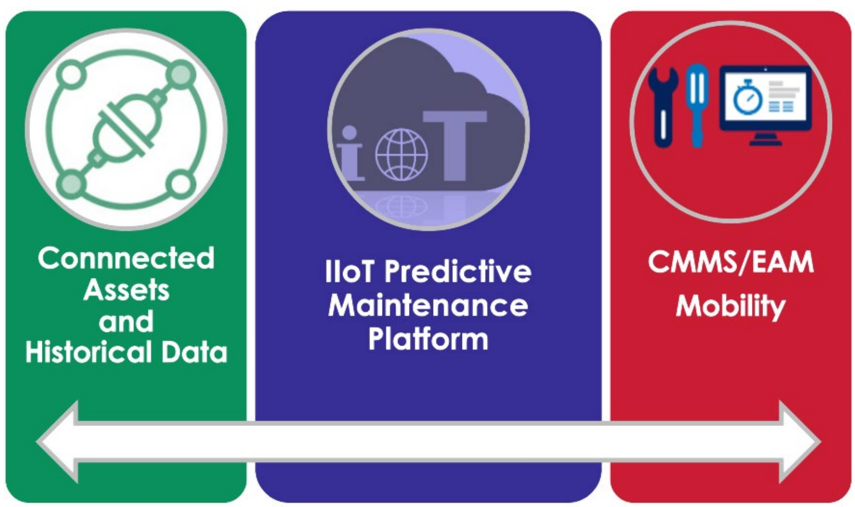

FIGURE 5: OVERVIEW OF UNIVERSAL IIOT DATA POWERED PREDICTIVE MAINTENANCE PLATFORM FUNCTIONAL ARCHITECTURE SHOWING THE THREE MAJOR ELEMENTS – CONNECTED ASSETS, PREDICTIVE MAINTENCE, AND MOBILITY

This design provides many core capabilities for industrial and railroad system applications, including edge analytics. This platform offers the ability to plug the IoT platform into a rail transportation system's existing technology stack, notably IoT and IIoT sensors, SCADA systems, and other management systems that provide asset's historical data. The Universal IIOT concept is described in further detail and illustrated in Figures 5, 6, and 7.

The connected assets in the cloud communicate with various connectors such as Lora, Sigfox, Specific, etc. (Figure 6).

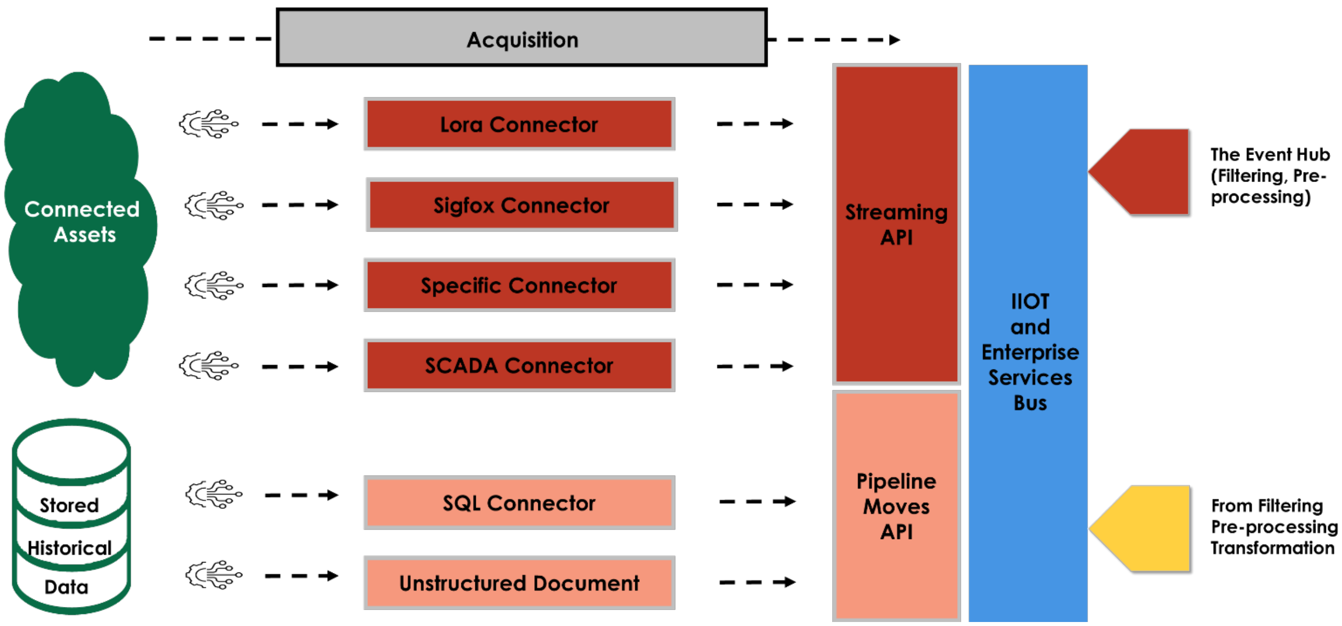

FIGURE 6: DETAIL OF THE CONNECTED ASSETS AND STORED HISTORICAL DATA ELEMENT FROM FIGURE 4

These connectors further interface with a streaming API and through IIoT service bus to an event hub. Via the same method data is received from pre-processing hub into Stored Historical Data. The major interface between the Connected Assets and Historical Data and the CMMS/EAM Mobility is the API management bus (Figure 6).

The data from this bus is stored in long term storage and this storage also has two-way data exchange with other elements of the system. For example, a requesting API may fetch or transmit data from/to storage. Other interfaces in this part of the system include streaming analytics and pipeline analytics which directly interface with fuzzy logic auto-classification. The fuzzy logic also has access to, and interface with, requesting API and storage (Figure 7).

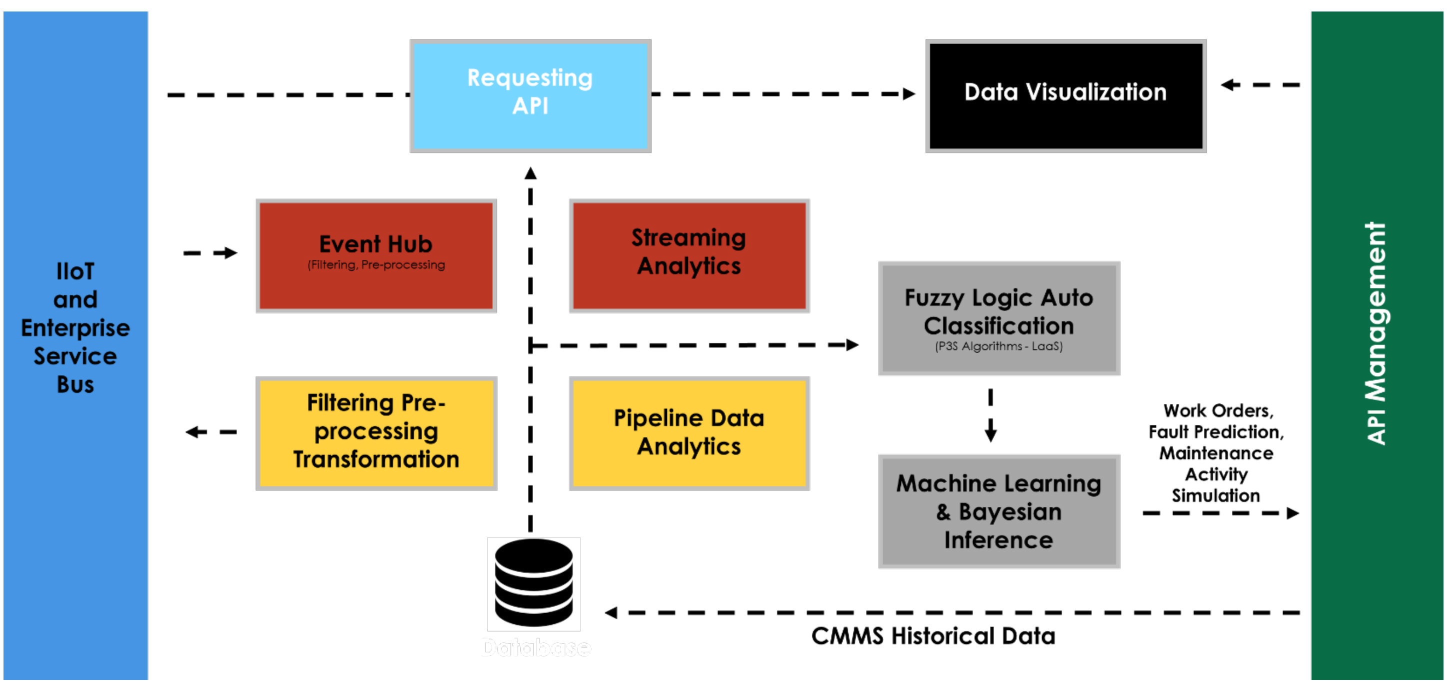

FIGURE 7: DETAIL OF IIOT PREDICTIVE MAINTENANCE PLATFORM FROM FIGURE 4, API MANAGEMENT BUS

In many asset-intensive infrastructures, particularly rail infrastructure, there are critical assets which are difficult to physically access easily due to location or extensive user (i.e. underground assets, tunnels, high area, track, electrical and signal assets, etc.). These "dark assets" are critical to operations and need to be remotely monitored. However, deployment of an IoT infrastructure, considering the network coverage of these assets, can be complex[15]. LP-Wan type technologies, such as Lora WAN networks, are suitable to provide network coverage and reliable communication with the dark assets; particularly by having a private network with a low deployment cost in underground infrastructures and using long-range capacity of the network. This allows signals to easily cross walls and ground to access signals from such assets.

Once connected, am IIoT predictive platform can automatically model assets, trigger maintenance work orders & inspections, and generate analysis of an asset's recommended future service life.

As illustrated in Figure 8, using this advanced detection capability minimizes the integration period required to initially configure the system. The interoperability between the EAM and the IIoT Platform dedicated to predictive maintenance provides new functionalities to the EAM system such as:

- Real-time maintenance monitoring in EAM and mobile tools (visualization of dashboards, alarms, events)
- Establishing links between connected objects and measurement points managed in the EAM
- Triggering maintenance or work requests
- Predictive Maintenance: Establish Links between maintenance facilities and connected objects or connected assets

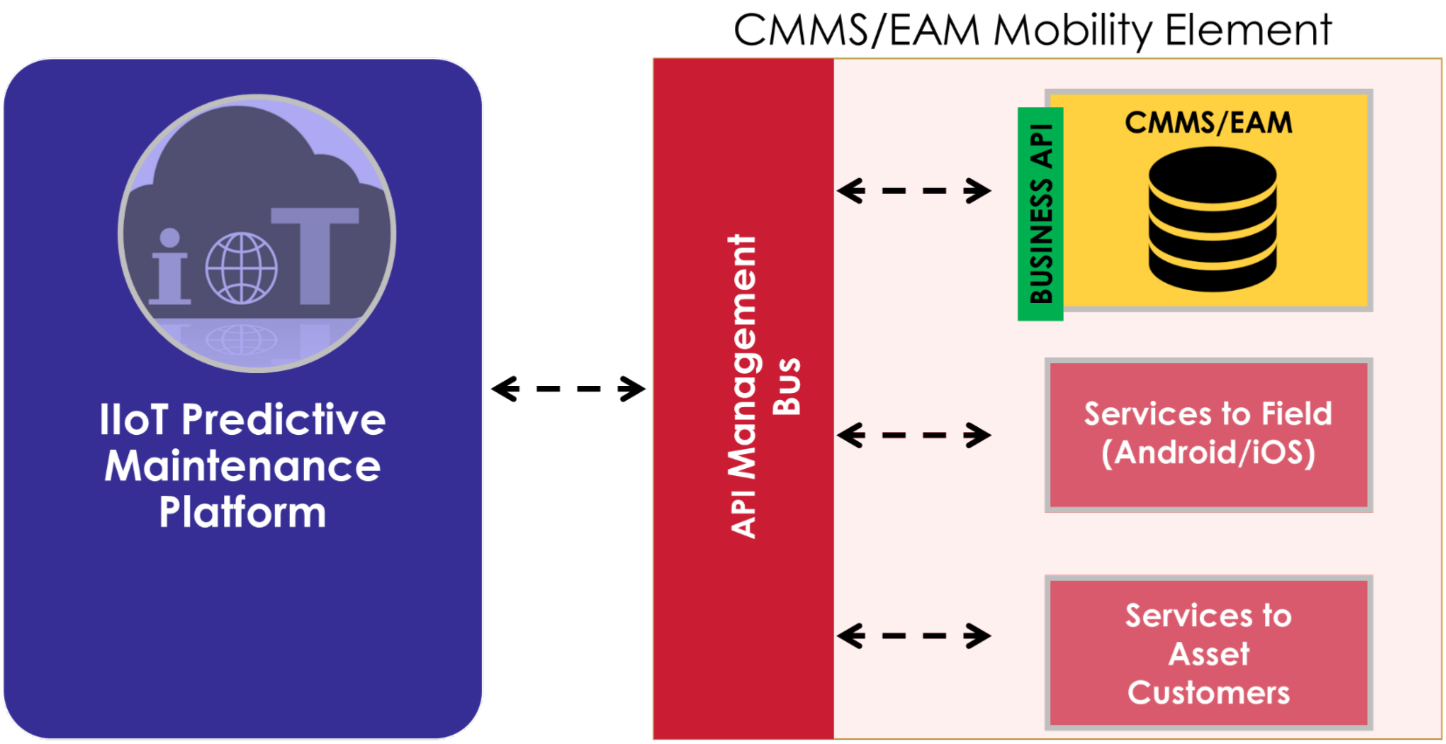

FIGURE 8: DETAIL OF CMMS/EAM MOBILITY ELEMENT FROM FIGURE 4

Focusing on the core of the architecture we observe that the predictive layer (Figure 7) categorizes data into the abstract class which represents technical asset's behavior; the auto-classification of different types of data are extremely beneficial (discrete and quantitative data, time series, and qualitative data) and it is a reliable and reproducible approach. The Fuzzy Logic auto-classification allows:

- Auto-selection of the most relevant variables and anomaly detection (sensors)
- Self-Learning and self-discovering: Automatic learning ("clustering"), supervised learning (predefined classes), and class evolution (active learning)
- Fewer adjustments, easy integration and deployment for different systems
- Recursive, simple, and fast execution algorithms for online identification

3.3 EAM Innovation: Augmented Reality[16][17][18][19]

The authors have identified several key observations of EAM/CMMS development. These are:

- Complete and accurate field technician reports enable more reliable and in-depth analyses, and better forecasts on future breakdowns, root cause, and cost control

- Approx. 80% of maintenance work order records are incomplete and present too little information to help improve the performance of an organization's maintenance department. EAM improves this
- Contextual information that helps the field technicians work efficiently and safely is often missing. Augmented Reality helps to resolve this
- Summary findings of customers, including shop technicians, produced the following wish list: Easily create maintenance work orders' report to improve data quality
- Access data (IoT, documentation, 3D models) in the physical world and the field to increase knowledge, efficiency, and safety and provide 3D asset visualization.
- Share what a technician sees with a subject matter expert (via teleassistance) or a colleague to quickly identify root cause and remedy to reduce time to repair and increase asset's uptime

To address user's needs researchers are investigating an AR solution connected to EAM software supported by the IIoT Platform (Figure 9).

Role	Needs	EAM Response	KPI
Director of maintenance	Responsible for the planning of maintenance activities, with the aim of minimizing failure within budget constraints and the least impact on the transportation system and traffic.	• Simulation maintenance activity planning and of the impact of maintenance activity on the transportation system and traffic. • Recommendation on the best operating range, the best spare parts supplier, the optimal time for replenishment	• **Reduce failure by 50%** • **Reduce maintenance cost by 30%** • **Optimize spare parts stock**
Director of exploitation	Responsible for the elaboration of the exploitation plan. He has little investment for minimizing failures	• Simulation maintenance activity planning and of the impact of maintenance activity on the transportation system and traffic. • Simulation of the impact of preventive and conditional maintenance on the energetic consumption (energy optimization)	• **Reduce transportation stops by 70%** • **Reduce energetic consumption by 20%**
Maintenance operator	Receive a coherent planning on mobile tools. Receive recommendations for field maintenance : technical documentation, root cause analysis.	• Planning prediction and optimization based on technician skills and technician role. • Fault prediction. • A connected EAM to the predictive platform provides field recommendations.	• **Reduce Time To Repair (MTTR) by 30%** • **Improve maintenance knowledge**
General Manager	Responsible for defining operation strategy and transportation system policy as well as support policy (maintenance, general services, IT).	• Simulation dashboard with business parameters	• **Increase flexibility** • **Reduce global cost of exploitation (maintenance cost and production stops)**

FIGURE 9: SURVEY RESULTS ON HOW AN EAM PLATFORM WOULD RESPOND TO USERS NEEDS AND KPIS

The AR solution is being prototyped and combines two available applications:

- An EAM & Mobile Application
- An AR Maintenance Application

This combined augmented reality concept (Figure 10) is currently a prototype to address significant technical and scientific challenges such as:

- Digital overlay on the physical world: Acceptable solution for physical-virtual synchronization and visual fatigue.
- Physical interaction with virtual objects: Natural interaction with virtual objects in the real world (mid-air interface, eye tracking, voice interface)
- Transition between smartphone and augmented reality: Ensure continuity between the management process and field operations

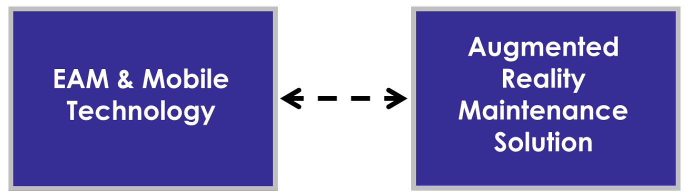

FIGURE 10: AUGMENTED REALITY EAM PROTOTYPE

4. CONCLUSION

An integrated and comprehensive EAM implementation using leading-edge software and similar tools can help the rail industry improve its maintenance and operations practices at an optimized cost. By leveraging Industry 4.0 and the IIoT, agency's maintenance processes can be automated to receive real-time data from the field and help streamline maintenance tasks. Tools such as EAM with add-on capabilities such as IoT interfaces, VR, and ML can help deliver accurate reports, generate automated work orders, and extend the life cycle of equipment without the need for labor-intensive field assessment.

5. REFERENCES

[1] D. Rocks, "3 ways for public transit systems to get the most out of EAM systems," DCX.Technology, 2020. [Online]. Available: https://blogs.dxc.technology/2020/02/13/3-ways-for-public-transit-systems-to-get-the-most-out-of-eam-systems/.

[2] T. Selig, "Prioritized Rail Corridor Asset Management," Bentley, 2006. [Online]. Available: https://www.iqpc.com/media/1000274/26982.pdf.

[3] American Public Transportation Association, "Transit Asset Management," 2019.

[4] International Standards Organization., Asset management – Overview Principles and terminology, ISO 55000:2014(E), 2014.

[5] ISO, International Standards Organizations. Asset management – Management Systems - Requirements, ISO 55001:2014(E), 2014.

[6] ISO, International Standards Organization. Asset management – Management Systems – Guidelines for the application of ISO 55001 ISO 55002:2014(E), 2014.

[7] Y. Miloudi, "The European research project (H2020 program)," CARL Software, Limonest, France, 2020

[8] The Institute of Asset Management, Guidance on using the 2012 IAM Competences Framework Version 3.0, 2014.

[9] i-scoop, "Industry 4.0: the fourth industrial revolution – guide to Industrie 4.0," 2019. [Online]. Available: https://www.i-scoop.eu/industry-4-0/.

[10] R. Ralph, "What is Enterprise Asset Management – EAM," ARC Advisory Group, 2017. [Online]. Available: https://www.arcweb.com/blog/what-enterprise-asset-management-eam.

[11] I. Ackermann, "Futurize Your Asset Management," 2018.

[12] Gruppo Torinese Trasporti S.p.A., Project feedback from the implementation of Berger-Levrault's CARL CMMS/EAM at Turin Metro, 2015.

[13] S. U. Amm, "Modeling and simulation of complex manufacturing phenomena using sensor signals from the perspective of Industry 4.0," Advanced Engineering Informatics, vol. 39, pp. 1-13, 2019.

[14] "Inter-IoT project / scientific dissemination," 2018. [Online]. Available: https://inter-iot.eu/scientific-dissemination-interiot-project.

[15] Dryver Huston, Tian Xia."Mapping, Assessing and Monitoring Urban Underground Infrastructure". 11th International Workshop on Structural Health Monitoring (). Country unknown/Code not available. https://par.nsf.gov/biblio/10029273. 2017

[16] A. Toni and al., "Enablers and Barriers of Smart Data-Based Asset Management Services in Industrial Business Networks," in Proceedings of the 12th World Congress on Engineering Asset Management and the 13th International Conference on Vibration Engineering and Technology of Machinery, Queensland, Australia, 2018.

[17] K. Ducharlet and al., "A Multi-phase Iterative Approach for Anomaly Detection and Its Agnostic Evaluation," in *International Conference on Industrial, Engineering and Other Applications of Applied Intelligent Systems*, 2020.

[18] The Institute of Asset Management, The IAM Competences Framework Part 1 Version 3.0, 2014.

[19] J. Bokrants and al., "Maintenance in digitalized manufacturing: Delphi-based scenarios for 2030," International Journal of Production Economics, no. 191, 2017.

[20] L. Monostori and al., "Cyber-physical systems in manufacturing," CIRP Annals - Manufacturing Technology, vol. 65, pp. 621-641, 2016.

