WHITE PAPER

Introducing HMAX

The Digital Asset Management Solution from Hitachi Rail

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1. DIGITAL TRANSFORMATION

1.1. Context of the rail sector and the need for digitalisation

Digitalization is a transformative force that is fundamentally revolutionizing the rail industry, paving the way for unprecedented new challenges and opportunities. This transformation is no longer just a trend, but an essential necessity to ensure a sustainable and competitive future for the sector. The introduction of innovations in mobility, the emergence of new socio-economic trends and the adoption of "disruptive" technologies are redefining the railway landscape, requiring a timely and strategic response from operators in the sector.

It becomes clear that one of the main challenges facing the rail sector is the modernisation of its signalling systems. These systems, often characterized by closure and heterogeneity, reflect a long history of technological evolution, regulatory changes and uneven financial investments. This complexity presents a significant obstacle to the complete digitization of the industry, slowing down data integration and digital transformation.

Another critical aspect is the vast amount of data produced by the rail sector, which is often heterogeneous and fragmented. Currently, this data does not allow for informed decisions in terms of maintenance and asset management, partially due to processing limitations. The need for more in-depth and accessible diagnostic information is evident. However, the main constraint often lies in the availability and readability of the data itself.

Therefore, only through an integrated and well-structured Digital Asset Management strategy will it be possible to effectively address these challenges. This can be achieved by exploiting the wealth of data produced by the systems and leveraging new technologies that generate information from this data.

This evolution requires structured and priority interventions, which start from identifying the most critical elements.

HMAX (Hyper Mobility Asset Expert) is not only a means to evolve rail systems and efficiently integrate and manage the data they produce, but also a catalyst for optimizing operations and reducing costs.

1.2. Hitachi's Approach to Digital Asset Management

Asset management in a critical and heterogeneous system such as the railway system, characterized by the coexistence of overlapping technologies and the generation of a vast amount of heterogeneous data, requires an integrated approach to Digital Asset Management to optimize operational efficiency and effectively manage the transition to digitalization.

Furthermore, this requires the inclusion of tools that support operators/maintainers in managing this level of complexity by incorporating new elements of integration, synthesis, action support, decision support, and predictive information to enable intervention before failures occur.

The HMAX digital asset management solution starts from the core concept of digitalization: it is through the appropriate utilization of data that we can improve the knowledge and therefore the operation of systems.

The concrete meaning of this concept and how it can be applied in the railway world is Hitachi's starting point to respond to the needs of the market.

One of the key aspects involves addressing operators' needs, including:

- Providing a system that furnishes essential information on all critical assets.
- Offering necessary support for managing complex failure scenarios through troubleshooting procedures or schemes.
- Prioritizing actions effectively.
- Proactively addressing issues through targeted actions.
- Standardizing information from diverse assets or systems.
- Leveraging experience to enhance and enrich information.
- Archiving important information for measuring parameters related to system performance and overall lifecycle management.

Today, finding the above is challenging due to several factors:

- Each system manages specific assets with detailed diagnostic and/or monitoring tools.
- Diagnostic and monitoring systems necessitate specific detailed knowledge of the technology or system.
- The methods of displaying and managing diagnostic information and alarms vary from system to system.

In this context, the implementation of the Digital Asset Management solution manifests as the adoption of a Digital Journey process. This process transforms the current scenario into one of digital evolution, enabling the implementation of a Digital Asset Management system for extended diagnostics.

Extended diagnostics are made possible by detailed diagnostic data from running systems or through the application of additional sensors. This process includes:

- Identification of a set of Use Cases: Essential for identifying feasible cases of interest, primarily related to data availability and the concept of non-intrusive experimentation on operational systems. Use Cases are identified through a cost/benefit analysis
- Feasibility analysis of Use Cases: Selection of critical assets and assessment of the level of digitization (what data it produces, quality and frequency)
- Analysis of the impact on the maintenance process within the selected Use Cases.

- Enable data collection of interest: Identify an effective approach to enable the collection of all data necessary for the development of Use Cases. This is possible through the implementation of solutions that allow the analysis system to be fed safely and continuously.
- Algorithm creation: Identifying events/alarms to build monitoring/prediction logic, described in terms of "simple" or "complex" algorithms based on requirements.
- Algorithm testing: Checking the algorithm against historical data to conduct early tests before runtime execution, moving to validation if no updates are required.
- Algorithm validation: Field testing the algorithm for a specific period to observe real-world scenarios, aiming to validate the logic beyond historical data. Upon successful validation, the algorithm proceeds to approval.

HMAX fully integrated approach is based on the following pillars:

- Asset Digitalization.
- Data Integration and Standardization.
- Implementation of services.

2. HMAX (HYPER MOBILITY ASSET EXPERT)

2.1. Introducing HMAX

Hitachi's response is a fully holistic railway ecosystem digital asset management solution called HMAX - Hyper Mobility Asset Expert.

HMAX is the solution designed for monitoring and managing a diverse array of railway assets, encompassing both wayside and on-board assets, including vehicles. HMAX addresses market demands by processing large volumes of data to optimize the utilization of railway systems and associated resources. Its objective is to support maintenance operations in transitioning from a preventive/corrective routine maintenance approach to an on-condition/predictive one.

From rolling stock and signalling to track infrastructure and passenger flows, railway systems generate enormous volumes of data every day.

HMAX enables you to use this data to predict problems, optimize your network, and transform customer's business.

Fully modular and customizable, HMAX lets rail operators select and connect the services they need the most – and scale at their own pace.

Designed to monitor and manage operational data across railway assets and infrastructure, HMAX offers a modular solution to optimize performance, seamlessly integrating all this data in a single platform.

Already installed in over 2000 trains around the world, and operational across thousands of kilometers of signalling infrastructure, HMAX is built to meet our customers where they are on their digital transformation journey.

With a full systems or modular approach, HMAX helps operational leaders achieve strategic goals for their organisations.

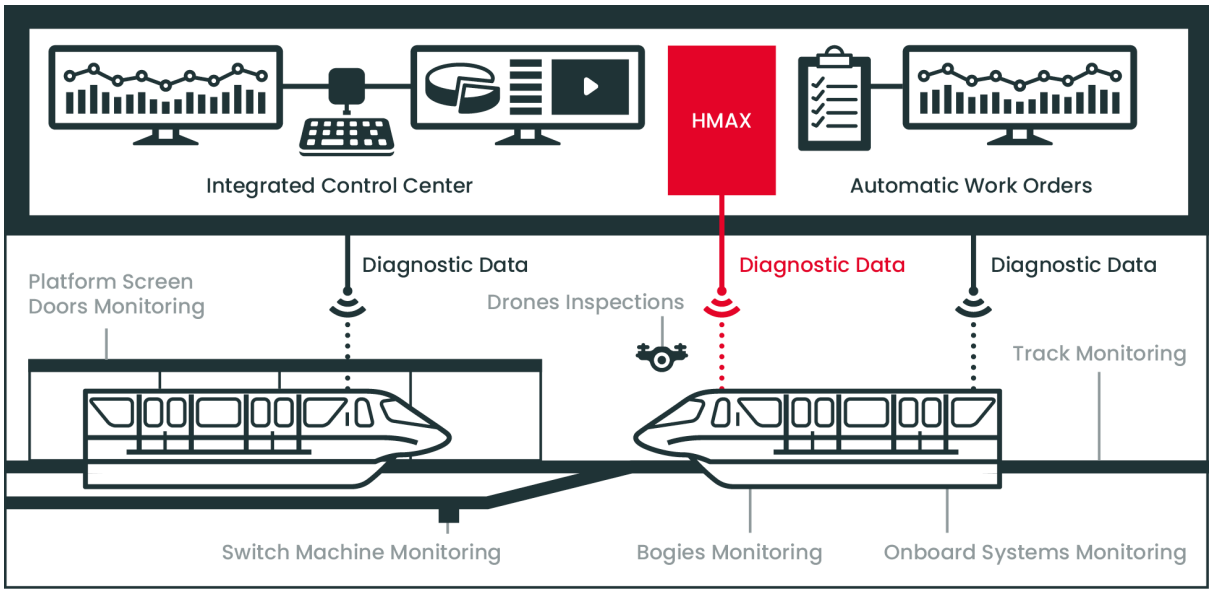

Figure 1: HMAX- application for the railway environment

HMAX provides a modular and customizable solution for easy and quick access to health and diagnostic information of the Railway Infrastructure System. This facilitates remote monitoring of asset conditions, enabling prompt responses to failures and paving the way for a digital transformation towards a preventive and prescriptive maintenance regime.

A standout feature of HMAX is its innovative approach to digital asset management, allowing for the collection, processing, and correlation of data from various sources – both wayside and on-board, including signalling systems, rolling stock, and automation applications. Its modular design enables the seamless integration of new assets and functionalities, extending and adapting the system to specific needs.

The collected, normalized, and analyzed data are accessible to users through the integrated diagnostics and maintenance station, providing transparent access to all information via a single user interface.

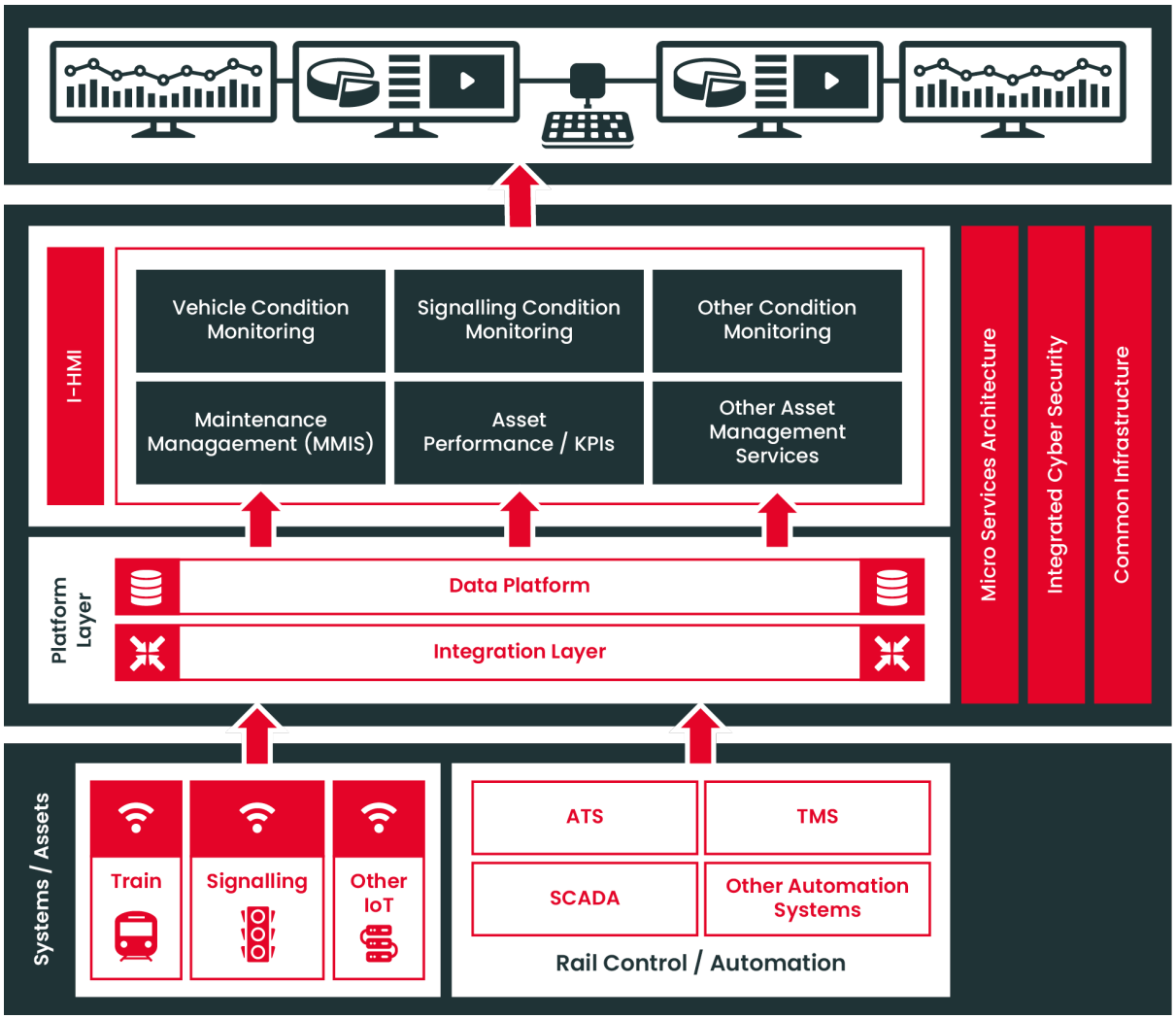

Figure 2: HMAX Architecture

The HMAX architecture, illustrated in Figure 2, provides integrated rail operations by enabling standardized communication between systems and information sharing through a common data model. This facilitates automation and the connection of rail systems and data.

The HMAX system was designed with the primary goal of ensuring maximum flexibility while respecting the life cycle of existing systems. This flexibility is achieved through a set of "core" services, to which customized services can be added based on customer needs and priorities.

2.2. HMAX for Trains

For over a decade, Hitachi Rail has been monitoring over 2,000 train cars and 200,000 systems, processing more than 60 million signals from +1000 type of sensors and analyzed +1,000 TB of data.

Hitachi Rail supplies a variety of fleets, including High-Speed trains, Regional trains, and Metros, to numerous global rail customers. These customers are striving to enhance the reliability and availability of their fleets. Hitachi Rail is focused on optimizing the costs associated with maintenance and services.

Hitachi Rail solutions include Condition-based maintenance, Predictive Maintenance, Maintenance Automatic Work Orders generation, Data Analysis utilizing real-time and batch data.

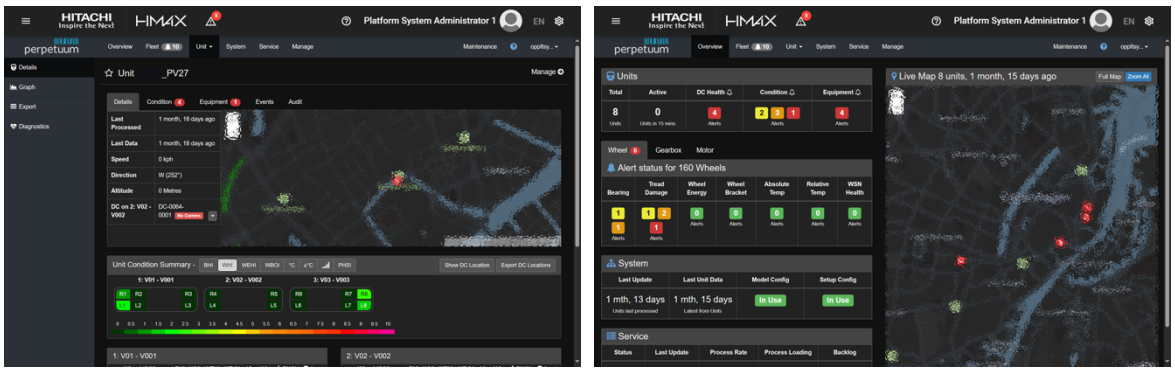

Figure 3: HMAX for trains – Perpetuum VMS

HMAX assures improvements in service reliability and availability of trains and the wider rail infrastructure. Outcomes include:

- **Reliability improvements** reflected by up to **20% reduction in service delays** (HMAX can reduce service delays by improving reliability through e.g. reducing No Fault Found (NFF) incidents. Reduced overhauls up to 50%, and Overhaul costs reduced by up to 6%).
- **Up to 15% reduction in train maintenance costs** and broader maintenance costs reduced: For example, corrective maintenance driven by Automatic Work Orders, can reduce corrective maintenance costs by approximately and conservatively 10% by decreasing NFF occurrences. Roughly calculated, a 10% cost reduction can translate into a 10% increase in repair speed, resulting in a 10% reduction in service delays.
- **Up to 30% reduction in overhauls** and lifecycle of critical assets including bogies, pantographs, door cylinders, doors, GU, Couplers, etc.
- **Energy consumption reduced** with up to **40% reduction in idling fuel costs** at depots

The main existing HMAX applications for trains are currently covering:

- Wheel Imbalance & Load Impact Monitoring
- Automatic Video Inspection
- Fleet Monitoring including subsystems & critical assets:
  - Vibration Monitoring (bearings, axels)
  - HVAC Health
  - Engine Coolant Temperature
  - Compressor Health
  - Battery Degradation
  - Fuel / Energy Consumption
  - Bogies
  - Pantographs
  - Door cylinders
  - Doors
  - GU
  - Couplers
  - Wheel Imbalance & Load Impact Monitoring
  - Automatic Video Inspection
  - Train gauge and weight/unbalances monitoring

2.3. HMAX for Signalling

Hitachi Rail's extensive experience in delivering signalling systems for over 26,000 km of mainline and 4,600 km of urban railways has given it unparralled understanding of how to monitor and predict the status of critical assets vital for the safe performance of railways around the world.

By bringing all signalling operational data into Hitachi Rail's new Intelligent Operating Control Centre (iOCC), rail operators now have access to all critical operational data through a combined web-based HMI – allowing them to focus on what matters most.

By using HMAX for Signalling, rail operators can benefit from improved reliability and availability of their railway infrastructure, with the potential for reduced operating costs and improved performance.

Figure 4: HMAX for signalling

The main existing HMAX applications for signalling are currently covering:

- Wayside Signalling
  - Track Circuits
  - Switch Machine Monitoring
  - Balises
- Central Signalling systems (ACC, RBC)
- On Board Signalling Systems - SCMT, ERTMS/ETCS
- Traffic Management System
- all the related wayside equipment and furthermore other automation systems covering at 360 degrees all the assets.

2.4. HMAX for Infrastructure

The cost of maintaining the railways has never been higher nor more critical.

Today, many operators rely on visual inspections and service trains to find out what's compromising the network.

But there must be a more efficient way to manage and maintain thousands of kilometres of track and overhead lines.

HMAX from Hitachi Rail uses sensors fitted on existing fleets of passenger and freight trains to perform the maintenance job, bringing data about track health, ride quality, overhead lines and vegetation into a single platform.

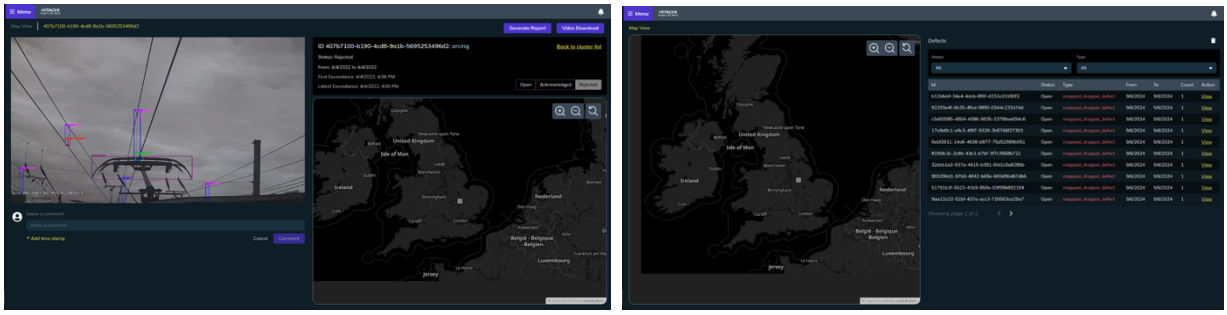

Figure 5: HMAX for infrastructure - Catenary

By using machine learning and AI to monitor and capture potential problems, operators can now achieve lower operating costs while increasing the reliability of the railway ecosystem.

The main existing HMAX applications for infrastructure are currently covering:

- Track health
- Ride quality
- Overhead line health
- Vegetation Management

3. ASSET MANAGEMENT SERVICES

3.1. Asset Data Integration, Normalization, and Historicization

3.1.1. Data Acquisition Interfaces

Data must be collected from various selected assets through pre-installed systems or sensors. The HMAX solution provides this capability, offering flexibility to create interfaces with any system using standard APIs or developing custom solutions if necessary. This feature also normalizes the data, ensuring it conforms to a single standard before being published to the integration layer. This step aligns the data to a unified standard, enabling efficient archiving and analysis.

3.1.2. Integration Layer

The Integration Layer acts as the communication hub between various systems and sensors that provide data and the different services and functions of HMAX. It functions as a distributed data processing bus, managing communication, data validation, and data sharing. Its primary goal is to ensure interoperability between new software and legacy systems, creating an integrated solution for data management and processing. The data follows a standardized format, Hitachi's railway data model, allowing applications connected to the Integration Layer to interpret the exchanged data payload. Communication can be direct or indirect, depending on the functionality of the integration layer used.

3.1.3. Historical Data Collection

Data storage components are fundamental for both analysis and reporting. This archive is flexible in terms of data volume and dispatching, ensuring that all analysis modules have quick access to the stored data. The historicization process involves:

- **Data Archiving:** Storing data in a structured manner to support long-term retention and retrieval. This ensures that historical data is available for future reference and analysis.
- **Data Indexing:** Creating indexes to facilitate quick search and retrieval of specific data points. This improves the efficiency of data access and analysis.
- **Data Backup:** Implementing regular backup procedures to protect data against loss or corruption. This ensures data integrity and availability.
- **Data Lifecycle Management:** Managing the lifecycle of data from creation to deletion, ensuring that data is retained for the required period and disposed of securely when no longer needed.

By implementing these historicization processes, the system ensures that data is not only stored securely but also remains accessible and usable for analysis and reporting purposes.

3.2. Built-in alarm management

The objective is to present alarms and events through the user interface, prioritizing recent and high-priority ones. The alarm view enables operators to easily supervise and monitor all alarms and events in real-time. Filtering, sorting, and highlighting items based on their priority ensures a hierarchical approach to alarm management. Additionally, users can access associated help pages (i.e., Wiki) to view detailed resolution procedures for individual alarms.

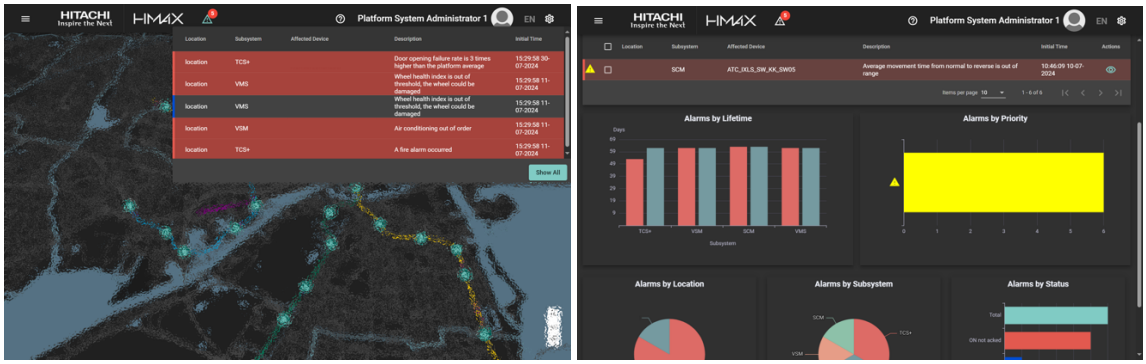

Figure 6: Integrated Alarms and Events View and Associated Help Procedure

Furthermore, the operator will have access to a decision support system designed to assist in managing procedures associated with particularly critical alarms.

Clicking on each task provides further details on the required action, including a textual description and buttons for accessing subsystem pages or related links.
Moreover, clicking on the Decision Support System (DSS) icon in the top bar grants the operator access to all critical alarms managed by the system, categorized as 'open' (i.e., unresolved) or 'closed' (i.e., resolved).

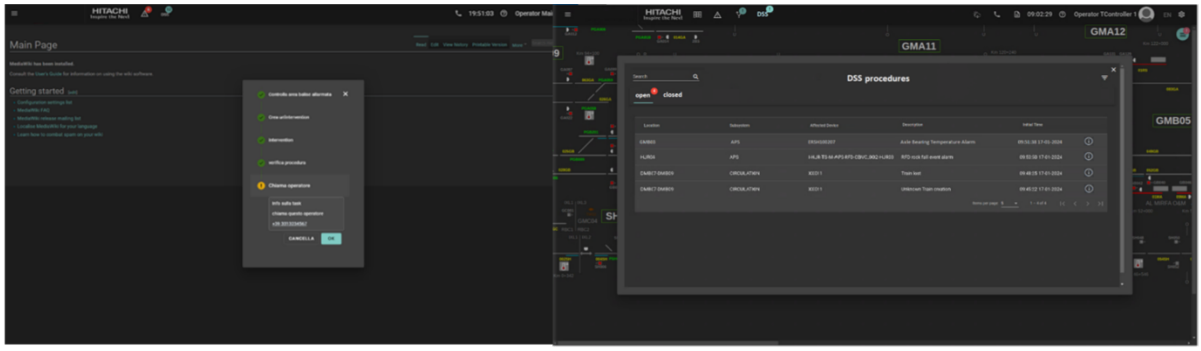

Figure 7: Decision Support System

3.3. Condition Monitoring and Condition-based Maintenance

The acquisition, management, and analysis of diagnostic data are fundamental pillars of HMAX, facilitating the transition from a preventive/corrective routine maintenance approach to an on-condition/predictive one.

Collecting diagnostic data from various railway assets plays a crucial role in enhancing the efficiency and safety of railway operations. This practice aims to prevent breakdowns and accidents, optimize maintenance, and maximize asset availability.

The HMAX platform efficiently gathers this information from a diverse range of data sources, either by leveraging third-party monitoring systems or by implementing collection processes directly on the systems and entities involved.

This capability enables the early detection of anomalies or signs of degradation, facilitating timely and targeted preventive maintenance interventions. By anticipating breakdowns and allowing for optimal planning of maintenance activities, HMAX contributes to the seamless operation of railway systems.

3.3.1. On-condition maintenance

An on-condition maintenance approach aims to optimize resource utilization and ensure an optimal level of safety and reliability for assets.

This approach is founded on the principle of intervening only when necessary, responding to actual degradation or potential imminent failure as indicated by monitoring data. Rather than adhering to a predefined schedule, maintenance interventions are scheduled in response to specific signals detected by sensors and monitoring systems.

One of the primary benefits of this approach is the reduction of operating costs, achieved by eliminating the need for unnecessary preventive maintenance and optimizing the allocation of financial and human resources. Additionally, on-condition maintenance enhances rail vehicle availability by minimizing downtime resulting from unplanned interventions.

Consequently, this approach leads to an overall increase in operational efficiency and passenger satisfaction, representing a significant advancement in optimizing rail asset management. It enables the maintenance of high levels of performance and reliability with minimal impact on costs and operations.

3.3.2. Predictive maintenance

Predictive maintenance represents a further step in the evolution of railway asset management compared to on-condition maintenance.

While the latter is based on responding to degradation indicators detected by sensors, predictive maintenance goes beyond, leveraging machine learning algorithms and artificial intelligence to analyze historical data and accurately forecast when failures or anomalies might occur.

This proactive approach enables anticipation and prevention of problems before they arise, thereby minimizing the risk of unplanned outages and further optimizing operational efficiency.

Compared to on-condition maintenance, predictive maintenance offers enhanced planning and control capabilities, empowering railway companies to schedule maintenance at strategic times, thereby minimizing disruptions to operations. Furthermore, by identifying predictive signs of failure, this approach enables the extension of asset lifespan and maximization of rail equipment availability.

3.4. Performance Monitoring

The Performance Monitoring function is implemented by a dedicated module that provides all the functionality to calculate and report on KPIs related to system performance. The module provides the functionality to view the configured KPIs based on the data available on the Data Platform and to track the performance of the system. The module also provides a support function for FRACAS (Failure Reporting And Corrective Action System) analysis through a dedicated page allowing the aggregation of faults with the aim of highlighting systematic problems.

3.4.1. KPI monitoring and calculation

KPIs are calculated from maintenance data and events/alarms generated by the system and stored in the module.

The module enables users to enter, update, and delete data pertaining to corrective and preventive maintenance work orders. For corrective maintenance, users can manually enter new faults and their interventions through dedicated pages. Additionally, if a repair has been conducted, users can add it to the system by referencing the associated intervention. Similarly, for preventive maintenance work orders, the module allows users to input information regarding the preventive intervention.

The module offers the users in charge the possibility to verify the correctness of the fault information and to carry out its evaluation and validation.

Based on the validated faults, the module automatically calculates KPIs, thus ensuring the ability to keep track of the real progress of the system. If the KPIs require the use of additional information contained in events and/or alarms coming from the system, the module is able to process this data and use it for calculation purposes. Finally, the module allows you to calculate custom KPIs by providing the possibility to program the calculation or perform it manually.

3.4.2. FRACAS Analysis Support

Through a dedicated page, the module enables users to analyze multiple faults simultaneously, providing the option to create "Problems." Within the context of the performance monitoring module, a Problem is defined as a grouping of faults with similar characteristics. The purpose of utilizing Problems is to support FRACAS analysis by aggregating systematic faults.

In more detail, the page presents users with a tabular view of all created issues. Each record corresponds to a specific issue, and users can manually add, edit, and delete each one. The page offers various filtering operations, allowing users to manage and observe issues from different perspectives.

Problem management consists of several phases, starting from creation to closure.

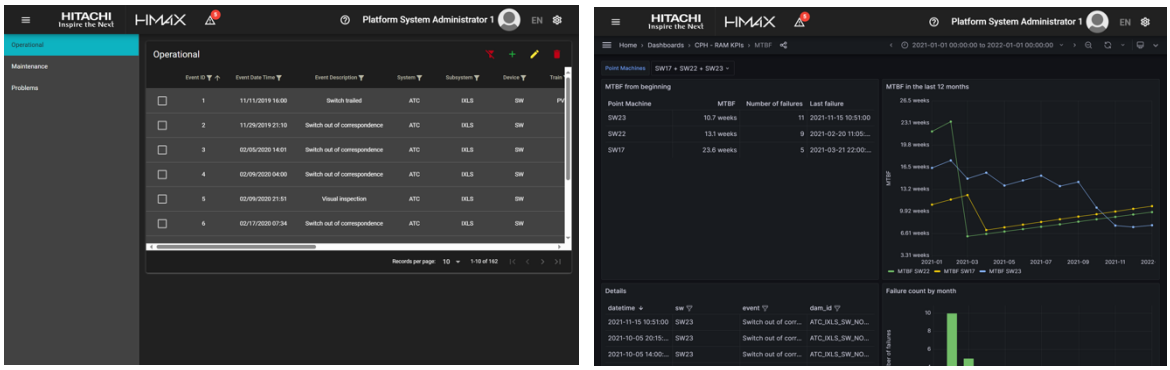

Figure 8: FRACAS analysis support

3.4.3. Analysis and reporting of failure events and maintenance times

The end user can interact with the form through a web user interface, which allows access to and display of data in tabular format. Additionally, dashboards are provided to present aggregated visual information regarding KPIs and stored events. The KPI dashboard can be configured to adjust the level of detail of displayed KPIs, either for inclusion in monthly reports or as required for reporting. Reports are managed and configured through the same user interface.

The performance monitoring module can highlight any deviations from normal performance and display weekly, monthly, and yearly performance trends for all KPIs. Moreover, the calculation and updating of custom KPI displays can be configured and modified according to the user's specific needs.

Figure 9: Viewing custom KPIs

3.5. Maintenance Management Information System MMIS

The Maintenance Management Information System provided by HMAX is a complete suite of functions for maintenance operators

The MMIS system suitably configured with the list of assets, locations, maintenance procedures and maintenance organization allows operators to perform maintenance on all devices/assets (on trains, signaling and infrastructure systems)

The main features of the MMIS are:

- Asset digitalization with a unified and standardized data collection and asset register approach
- Preventive and predictive maintenance.
- Condition based maintenance.
- Corrective maintenance.
- Spare parts warehouse management and repair management.
- Contact and Procurement Management.
- Interfacing with external applications.
- An automation subsystem (Adapter) that allows interfacing with the main automation systems for alarm acquisition and the automatic and configurable generation of Work Orders or Service Requests in the MMIS Platform so that OEM operators can immediately execute the corrective maintenance.
- A configuration subsystem (MDC – Maintenance Data Configurator) that allows to populate the MMIS Platform, Labeling and Mobile device, with all the data necessary to perform maintenance.
- A Labeling subsystem that allows to label all devices and materials with labels and coding that will be defined during the project phases.
- Definition of procedures for warehouse management (Storeroom) and material repair.
- Configuration of mobile devices, such as Barcode readers and Laptops, which allow easier management of warehouses and maintenance.
- An integration subsystem for data exchange from MMIS Platform and other external systems.
- A Documentation subsystem for the storing and presentation of all maintenance documents.

3.6. Integrated HMI

The interface of the integrated diagnostics and maintenance workstation serves as the primary point of contact between the operator and HMAX, playing a crucial role in accessing all information managed by HMAX. Ultimately, all data and information are presented to the user through interfaces at the appropriate times to enhance operations and provide support for exceptional cases that the system cannot handle automatically.

Users can access all information through a single, dedicated HMI, utilizing Single Sign-On to ensure secure and personalized access to their responsibilities and duties. This means that system administrators, station and train supervisors, maintenance technicians, etc., can only access the parts of the system relevant to their assigned roles and tasks.

Figure 10: I-HMI Look and Feel Example

4. CONCLUSION

HMAX enables operators across the rail industry to predict problems, optimize their assets and networks, and transform operations to provide better outcomes for their customers – whether passenger or freight. Hitachi Rail's commitment to implementing proven HMAX solutions – as well as co-creating new solutions with its customers and partners – means that HMAX users benefit from a modular platform that can meet them where they are today, and scale seamlessly in the future.