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Deliverable D5.3
Public summary with the strategy to measure and process data for Bogie & Drive components

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1. Executive Summary

This deliverable summarizes the activities covered in Work Package (WP) 5 as part of the Europe's Rail Joint Undertaking (ERJU) Flagship project 3 – IAM4RAIL. The aim of this WP has been to align, develop and to some extent test different strategies and technologies to collect and transfer data using on-board technology for rolling stock. In this work package, several different companies, including Alstom, CAF, Talgo, the Dutch Railways (NS), Faiveley and Knorr-Bremse have collaborated to create concepts that are feasible and target current pain points across the fleets. Some solutions are based on new sensing equipment implemented at key points of the subsystems, while others target a wider harnessing of variables available on the train in order to support large scale data analysis. Moving on from WP5, these concepts will be applied in the demonstrators planned throughout the project as part of WP6.

The use cases described pursue different technical approaches and cover different subsystems such as Bogie & Drive but also others including Traction, HVAC and Brakes. All have the common goal to enable the development of more advanced data analytics. This can in turn help operators and maintainers of the fleets to make more informed decisions, reduce costs, and improve the reliability of the systems. Implementing Condition Monitoring (CM), Condition based Maintenance (CBM) as well as predictive maintenance in the rail industry is a great undertaking facing several challenges such as harsh environmental demands, complex data integration, high costs, and regulatory requirements, all requiring improved data infrastructure, standardization, and stakeholder collaboration. Nevertheless, the transition will be crucial to keeping the industry competitive.

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
ATO	Automatic Train Operation
BLE	Bluetooth Low Energy
CBM	Condition Based Maintenance
CM	Condition Monitoring
ERJU	Europe's Rail Joint Undertaking
FP	Flagship project
GA	Grant Agreement
HVAC	Heating, Ventilation & Air Conditioning
LCC	Life Cycle Cost
ML	Machine Learning
MTB	Magnetic Track Brake
NS	Nederlandse Spoorwegen (Dutch Railways)
SNG	Sprinter New Generation
TCMS	Train Control and Monitoring System
TRL	Technical Readiness Level
WP	Work Package

3. Background

The present document constitutes the Deliverable D5.3, Public summary with the strategy to measure and process data for Bogie & Drive components, in the framework of the Flagship Project FP3 – IAM4RAIL as described in the EU-RAIL MAWP. This deliverable is the public summary of the two deliverables D5.1 & D5.2, which describe the work done in WP5 in more detail.

Some of the use cases in WP5 – “*Rolling Stock (on-board): Data acquisition and monitoring technologies*” are further developments of previous European projects such as PIVOT2 (GA ID: 881807) and PINTA2 (GA ID: 826054). This work package, which started in December 2022 runs until end of November 2024 can be seen as the foundation for WP6 – “*Rolling Stock (on-board): Data acquisition, monitoring technologies, asset prognosis and feedback into operational processes*”. In WP6, the developed technologies are demonstrated in practice and data is further analyzed and used for model and algorithm development.

The Figure 1 below shows WP5 transferring results into WP6 after its completion in month 24. As data was partially already available, WP6 also started in December 2022 as well and was running in parallel to WP5 to allow the partners to directly start with the planning of demonstration activities.

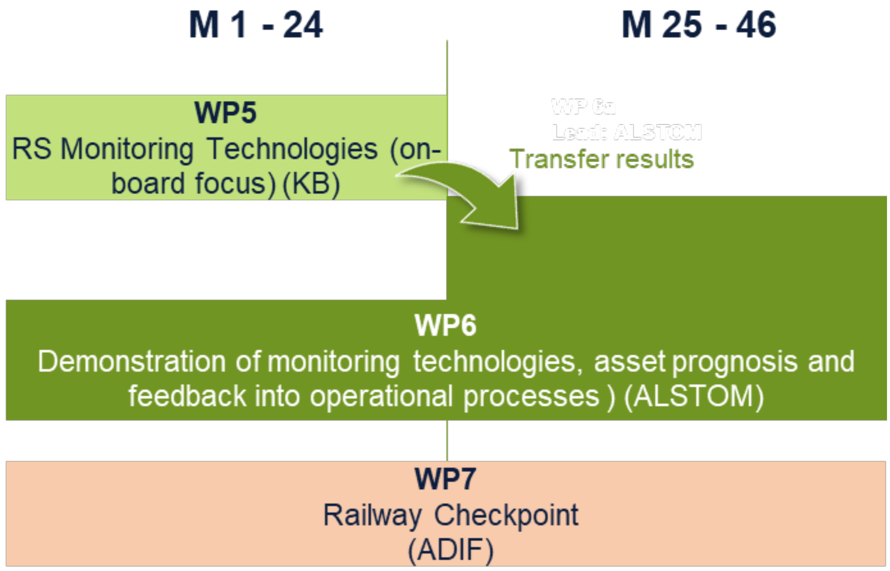

Figure 1 - Relation of WP5, WP6 & WP7

In contrast to WP7, which contains developments related to wayside technologies and railway checkpoints, WP5 and WP6 are exclusively linked to technologies mounted resp. data captured on-board of a vehicle.

4. Objective/Aim

This document has been prepared to provide a public summary of the work done in FP3-IAM4RAIL WP5. The objective is to provide information outside of the project about the strategies and solutions being targeted. In addition to bogie & drive components, it also covers additional subsystems analysed and targeted during the project, such as traction and HVAC among others.

Figure 2 shows the relation of this deliverable to the Tasks and other deliverables in WP5. Deliverables D5.1 and D5.2 contain more detailed information from the different Tasks.

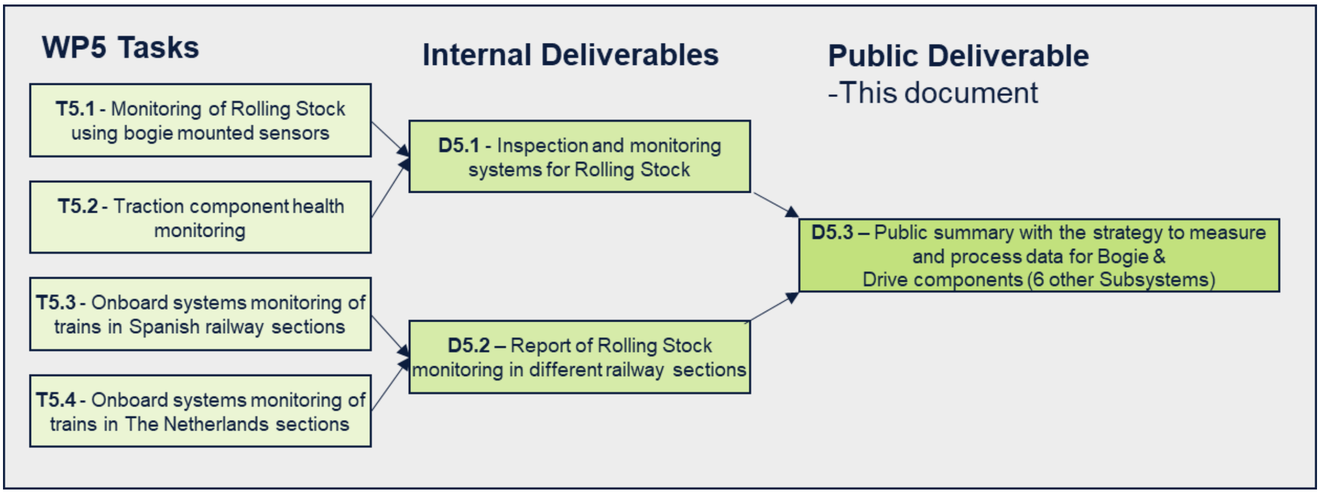

Figure 2 - Deliverable Structure WP5

5. Problem statement

WP5 of Flagship area 3 – IAM4RAIL serves railway maintainers, owners, and operators to obtain asset transparency by making additional Big Data available from rolling stock and its subsystems and other relevant data sources. Making those data workable in the appropriate structures, including cloud architectures. It reflects a trend of leveraging data, like seen in other industries such as automotive.

As an extension of WP5, the objective of WP6 is to design, develop, validate, and deploy at Technology Readiness Level (TRL) 6 Condition-Based Maintenance (CBM) based on Machine Learning (ML), predictive algorithms and digital process aids capable of supporting the railway maintainers, owners, and operators in the decision-making process. These solutions target Rolling Stock operating on different types of lines and under different climate conditions across Europe.

While the idea of data driven asset management is not new, its implementation is inherently slow due to several challenges. Harsh operating environments with extreme temperatures, vibrations, dust, and humidity affect sensor reliability and data accuracy. The complexity of modern rolling stock, which includes numerous systems and components, requires a comprehensive monitoring approach stretching a large number of interfaces. In addition, high costs and resource constraints hinder the holistic adoption of advanced monitoring technologies. Lack of standardized protocols across manufacturers poses interoperability challenges and limited effectiveness of solutions. Regulatory compliance adds another layer of complexity, especially for solutions looking to support paradigm shifts in maintenance planning. Data availability issues arise from fragmented data sources, legacy systems, data quality concerns, ownership, and privacy issues, limited historical data, and connectivity challenges are additional significant factors. Addressing these challenges requires investments in data infrastructure, standardization, and collaboration among stakeholders to improve data access and optimize maintenance practices.

6. Solutions & Use cases

6.1. Bogie & Drive

The objective of Rolling Stock Condition Monitoring Systems is to monitor the condition of railway vehicles in real-time to enhance safety, efficiency, and availability. These systems collect, analyze, and interpret data on various Bogie components allowing for early identification of potential issues. By enabling predictive maintenance, Rolling Stock Condition Monitoring helps minimize unexpected failures and optimize maintenance intervals.

This summary provides an overview of the bench tests conducted as part of the Bogie & Drive project. In this context, the bench tests play a central role, as they are crucial for confirming functionality and reliability in practice while also laying the groundwork for future implementations in on-track testing. Additionally, the effectiveness and feasibility of monitoring through the sensors have been assessed, with the goal of developing the most economical solution and, if possible, keeping the number of additional sensors to a minimum. In the initial phase, the bench tests specifically aim to evaluate a wide range of sensors, most of which are standard solutions. Furthermore, innovative acoustic-based sensors are also included. These sensors are essential for the precise collection of operational data needed for monitoring bogie conditions. The use of these advanced technologies has the potential to identify possible damages early and enable proactive maintenance.

During the bench tests, the following types of sensors were tested:

- Accelerometers
- Motor Current Sensors
- Acoustic Sensors
- Temperature Sensors
- Oil Sensors

These sensors were used to evaluate the following bogie components:

- Motor
- Gearbox
- Axle Box

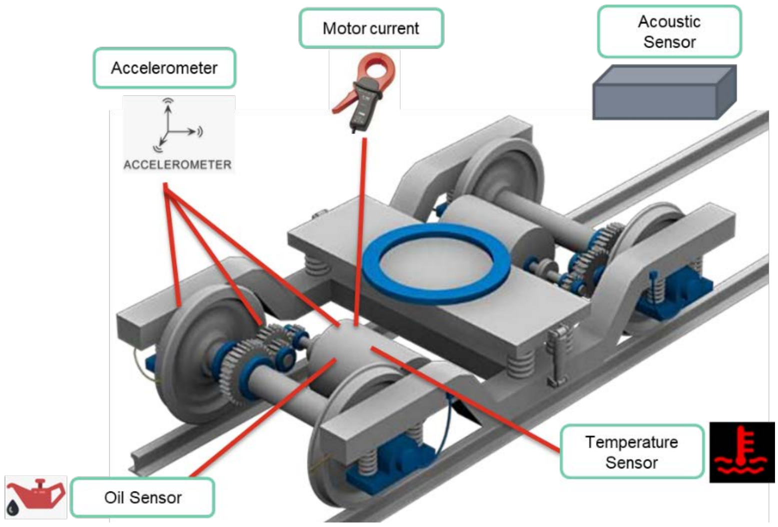

Figure 3 - Overview of Bogie sensor technology

The insights gained from the bench tests will not only contribute directly to the development of more effective and efficient condition monitoring systems for bogies but also serve as a valuable data source for identifying improvement opportunities in existing systems. The testing is an integral part of the development of the bogie monitoring system, aimed at increasing the Technology Readiness Level (TRL) for the new system. Partially, these sensors also provide data that can be reused for parallel infrastructure monitoring, which is included in several topics within WP9 and therefore not further detailed in this deliverable.

A key focus of WP5 is to evaluate the developed solution from an economical perspective. It is clear – it is rather a question of financial, rather than technical feasibility to monitor the main components. WP5 will select the most suitable technologies for WP6, where the sensors are to be tested and validated under real operating conditions. This transition from laboratory-based testing to practical application is crucial for verifying the functionality of the sensors and their applicability under varying conditions. The goal is to ensure seamless transition from research to application, confirming that the developed technologies function effectively in real-world scenarios. Another significant aspect of the bench tests is verifying the sensors' functionality, particularly in conjunction with damaged and previously used components.

Additionally, the tests focus on specific failure analyses aimed at systematically identifying common defects in various components. These analyses are vital to understanding the root causes of failures and developing appropriate solutions.

This comprehensive approach to effective maintenance interval management has the potential to extend the lifespan of the trains and significantly reduce operating costs. Tests have been conducted under different temperatures, varying speeds, and diverse loading conditions. This thorough validation ensures that the sensors can operate effectively under realistic conditions, which is crucial for the overall operational efficiency of the rail transport system.

6.2. Traction

In railway traction drive application, to ensure rolling stock performance and availability, some components like the power converter, cooling system and bearings are subject to maintenance, and others, like the switchgear, to replacement. To limit their associated costs to the customer, developing maintenance cost reduction solutions is an important need. This study focuses on finding a way to reduce maintenance costs generated by cooling system installed on rolling stock (for example for main transformer or power converters) and to evaluate the feasibility to predict potential failure of switchgear or main circuit breakers.

The clogging of a powertrain heat exchanger is one of the feared events affecting its performance and availability. Heat exchanger clogging is generally due to dust, insects, fine particle pollution, dead leaves, snow, pollen… If the heat exchanger cannot dissipate power converter and/or passive component power losses, the concerned powertrain must be power limited or disabled. As a result, the train may find itself in a situation where it isn't able to achieve its mission anymore because of a lack of motoring/braking power – due to limitation of one of its powertrains. Concretely, this entails delays or even worse: passenger evacuation if the train is completely out of order. This kind of breakdown has a huge impact for the customer costs and image. From this point of view, the cleaning of the heat exchanger must be done as often as possible. But this means increasing the number of maintenance operations significantly and thereby the maintenance cost. To maximize rolling stock availability, minimize maintenance operation costs and limit the use of train depot capacity, it is therefore imperative to carry out maintenance steps (cleaning of the exchanger) at optimum times. For this reason, a technical solution is studied based on the estimation of the thermal resistance and the error between the temperature measurement from the cooling system (air plate, oil) and the prediction of this temperature throughout a thermal model fed by real-time losses estimation. This approach demonstrates that under certain conditions it is possible to estimate probable clogging of the cooling system.

Regarding switchgear components, mechanical and electrical endurance tests have been performed on one line contactor, one preload contactor and one main circuit breaker. Several mechanical and electrical characteristics have been monitored in order to identify which parameters could provide a health indicator. The performed study shows that evolution of contact resistance is the most reliable health indicator for preload and line contactor even if it is difficult to evaluate it in line.

6.3. Brake Air Supply

A further system targeted as part of this project is the air supply. Pressured air is critical for the operation of the brake system and vehicle suspension; therefore, the air supply unit is a crucial part of rail vehicles. In the classical air supply units, monitoring is not available, meaning that failures could not be predicted or detected. As part of the ERJU Flagship project 3 - WP6, the one Vehicle of the Renfe operated high speed Talgo S106 fleet shall be equipped with a Knorr-Bremse sensor kit. The kit provides information about air pressure, temperature, oil level and dew point enabling advanced condition monitoring. The data can be used to prevent and predict failures in the equipment.

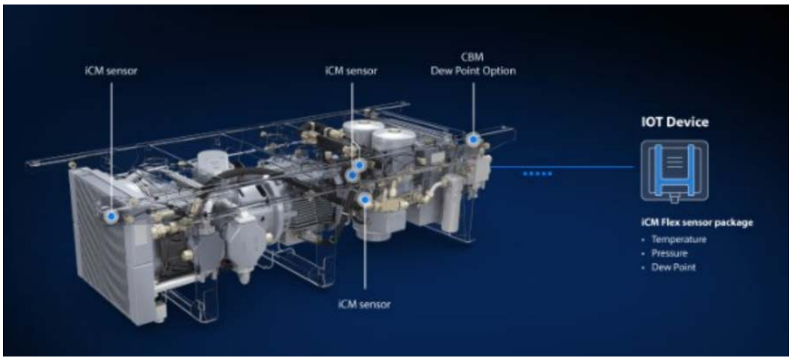

Figure 4 - IoT concept for Air Supply

The work in WP5 has focused on developing a suitable solution for the selected fleet and aligning on use cases and mechanical and electrical interfaces to allow for the implementation and the following demonstrations. The pain points and possible improvements were identified in the maintenance plan together with Talgo, reviewing possible solutions. The aim of the use case is to both reduce time consuming and labour-intensive manual maintenance steps (such as oil level checks), detect unfavourable operating conditions that might lead to a reduction of the lifetime and to detect malfunctions of the subcomponents before they lead to consequential issues in the system.

6.4. HVAC

A railway Heating, Ventilation and Air-Conditioning (HVAC) unit is a specialized system designed for the climate control of train interiors. Combining heating, ventilation, and air conditioning functionalities, it ensures passenger comfort throughout the journey. Developing and implementing condition monitoring and predictive maintenance for HVAC units has several system specific benefits. First, it plays a critical role in maintaining passenger comfort, as service failures—especially during extreme climatic conditions—can immediately impact service continuity. Secondly, well-functioning HVAC units help optimize energy consumption. Climate control is energy-intensive, and malfunctioning units quickly lead to excessive energy use. Additionally, HVAC units are often mounted on train roofs, so unplanned or extensive maintenance demands high labour resources and specific depot locations with roof access. Train availability could be therefore affected depending on where a critical failure takes place. Effective CBM, combined with predictive maintenance strategies, can minimize such risks, and maintain reliable train operations.

As part of the ERJU FP3 project – WP6, two fleets are to be equipped with Knorr-Bremse developed sensor kits for the HVACs - the Sprinter New Generation (SNG) fleet of NS in the Netherlands, and the high speed S106 fleet of Renfe/Talgo in Spain. For each fleet, the intention is to mount the sensor kits on two separate saloon units. As part of the project, the partners aligned to target functions and failure modes that provide potential value for operation, which was the base of the kit layout. HVAC unit sensors, which are part of the original equipment, as well as KB sensors (developed outside of ERJU project) are used to collect the data.

The selected sensors cover several different use cases, including monitoring of the filter clogging status, the refrigerant charge level, and the compressor’s health by measuring variables such as temperature, pressure, and current at various points in the system. The aim is to monitor the functionality of the unit and detect any malfunctions. With time, the goal is to use the data to accurately predict upcoming failures and reduce the need of manual maintenance procedures and checks for the HVACs, as well as extend the useful life of specific components such as the filters, by replacing them only when their condition requires it.

In preparation of the installations, several bench tests were carried out, preparing data baselines and HVAC unit characterization. Standard and modified HVAC unit type tests (such as air flow measurement and cooling capacity under different conditions) were performed. This will allow for more accurate validation of the data received from the field. The tests were carried out in the KB-Merak facilities in Spain, where a climatic chamber and specific equipment for simulating air flows in the units are available.

Figure 5 - Bench tests for HVAC use cases

6.5. Magnetic track Brake

On the Dutch sprinter fleet, also the Magnetic track brake is being targeted as part of the project by installing a specialized monitoring device (device developed outside ERJU). The main goal of the MTB monitoring system is to make operation of the train easier, while keeping high safety standards. The designed monitoring system supports the development of ATO, by real-time monitoring of the brakes, allowing to gather all necessary information for operation.

On the train side, this solution utilises a Magnet Control monitoring system, consisting of the PowerSwitch and BrainUnit. The PowerSwitch is responsible for activating the magnetic track brake, while the BrainUnit reads the sensors connected to the PowerSwitch and calculates the results of safety critical functions in real time based on the information. The generic system is also capable of sharing safety critical information directly with the train system, to inform the driver about the actual status. This comprehensive solution offers an efficient method for monitoring and maintaining magnetic track brake systems, leading to improved operational performance and safety.

The strategy developed in WP5 for this system is to systematically gather, collect and interpret data to develop predictive algorithms for MTB maintenance on train level. The MTB monitoring system to be installed in WP6 continuously monitors the status of the magnetic track brakes in real time. It uses sensors to gather data on parameters like current and operational parameters such as actual speed and usage. This real-time data helps to understand how the brakes are performing and eliminates the need for manual brake tests, saving valuable time and effort. One of the standout features in development of this system is its predictive maintenance capability. By analysing the collected data with advanced algorithms, the system can predict when the brakes will develop weldings or wear out. This means it is possible to plan maintenance activities better in advance, ensuring that the necessary materials are available when needed. This not only reduces downtime but also keeps the operations running smoothly.

Specific safety measures are in place to make sure that the brakes are always in optimal condition, which increases the availability of the machinery and improves overall performance.

The data collected by the MTB system is transmitted to the Knorr-Bremse cloud through an independent Gateway using GSM (LTE) functionality, where it is processed and analysed. A cloud-to-cloud data transfer allows for seamless integration with the system of partners, providing valuable insights that help improve the overall performance of the system. Since also security is a top priority, the system includes robust features, and the intended design has undergone cybersecurity threat modelling to ensure protection against potential threats.

As part of the Project, one of the end cars of the Dutch Sprinter trains is planned to be equipped with the described solution, observing the main functions over time.

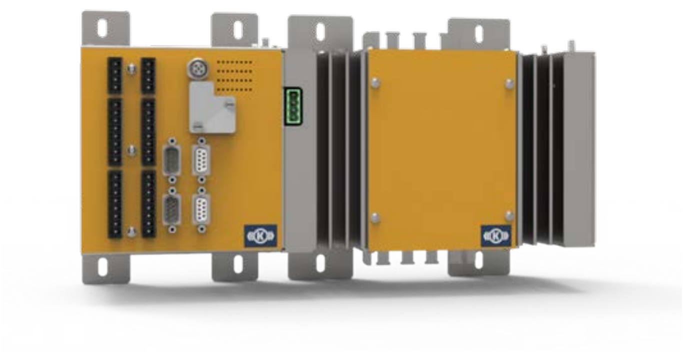

Figure 6 - Magnet control unit for MTB

6.6. Sanitary System

For the sanitary system, two vehicles in the Netherlands are planned to be equipped with an enhanced condition monitoring solution. The developed strategy entails a pressure sensor which can monitor the pressure vacuum curve of the vacuum toilet, and hereby identify early malfunctions, as well as give an accurate prediction of the aging of the equipment. The aim is to enable more accurate maintenance interventions, as well as extending the useful lifetime of the unit by basing overhaul on the actual condition instead of fixed intervals. A further goal is to prevent service failures. For vehicles such as the Dutch Sprinter, where each vehicle only has one toilet, a failure of the sanitary system has an immediate effect on operations, and preventing upcoming issues ahead of time has direct benefits for the operator.

The work done in WP5 has focused on aligning the use case needs with the partners and defining the mechanical, electrical and digital interfaces for the solution. In addition, SW adaptations to the control unit were needed to enable the transmission of operational data. Since the interface to the train system is purely based on discrete relays, the sanitary system is not providing operational data to the train system.

For this use case, the developed strategy is to perform the data transmission using BLE (Bluetooth Low Energy) , which connects the sensor equipment wirelessly with an independent gateway for further connectivity to the assigned cloud. A wireless application can be a useful option for retrofits and applications with limited space, where options for wiring is limited. As part of WP5, field tests were carried out on the Sprinter fleet in the Netherlands, validating the transmission range and data quality across different sensor positions.

6.7. Health Monitoring based on available data

In contrast to the other use cases in WP5 where additional sensors are used, two use cases focus on using data that is already available on the train. Mounting additional HW can provide new insights but also involves higher costs. By using available data in a more effective way, additional benefits can be reached. For example, available data from the pressure of the HVAC system, the external and saloon temperatures and working hours can be combined to get an indicator of the health of the HVAC system. The situation is analogue with other systems, internal signals that give information of the working conditions are combined, providing a final health indicator.

In this project, various fleets, in particular the SNG Sprinter in the Netherlands and a Euskotren fleet in Spain were targeted and the various variables available on the train control and monitoring system (TCMS) were analysed between the operators, car builder and system provider to agree on data sharing principles and potential benefits.

For the Sprinter fleet, a fleetwide transmission system adaptation was needed to enable the transmission of sufficient data to the wayside. This was carried out throughout the project and allows for additional variables to be analysed and used for predictive algorithm development in WP6. The data collected covers a wide range of subsystems such as doors, brakes, HVAC and traction and is done through Leadmind, a readily available solution from CAF. Leadmind is the data platform proprietary of CAF, already a commercial product and developed outside of the scope of this project.

For the other fleets, data sharing agreements allow for mutual analysis of the different subsystems, allowing for the know-how of the component manufacturer Faiveley and the maintenance experience of the car builder, CAF, to be used in conjunction to provide better analytics for the selected systems.

The work done in WP5 and the gathering of large amounts of data will allow predicting the behaviour of the subsystems in response to different recorded events. Additionally, these models will help optimize maintenance strategies, ensuring greater operational availability and efficiency of the railway vehicles. With this predictive capability, potential failures can be anticipated, and maintenance interventions can be scheduled more accurately, reducing costs and improving overall system reliability. This work will continue in WP6.

7. Conclusions

WP5 is a part of the Europe's Rail Joint Undertaking (ERJU) Flagship project 3, focusing on aligning, developing, and bench-testing different solutions and strategies to collect and transfer data using on-board technology for rolling stock. This deliverable summarizes the results prior to the transfer of work to WP6.

The problem addressed in this work is the need for improved data acquisition and monitoring technologies for rolling stock to enhance asset transparency and support large-scale data analysis. The objective of WP5 was to provide new sources of data for various subsystems such as bogies, traction, HVAC and doors, in order to enable more advanced condition monitoring. WP6 then aims to develop improved analytics and algorithms to save costs and improve efficiency and reliability of railway fleets. Despite a promising market potential, these technologies are slow and time-consuming to implement. The main limitations to successful roll out of industry wide CBM include harsh operating environments, complex and non-standardized data integration structures, high costs and strict regulatory requirements.

The methodology involved joint analysis between operators, car-builders and component manufacturers to identify pain points and use cases that could be viable from a commercial perspective. It also included different bench tests to evaluate a wide range of sensors and transmission technology and their applicability under varying conditions. These tests focused on specific failure analyses, systematic identification of common defects, and the development of preventive and predictive maintenance strategies. With the conclusion of WP5, these technologies are suitable and ready for installation and physical demonstration on the selected fleets for further validation under real conditions.

WP5 focuses on technologies that have not yet reached a necessary maturity level and to extend the application of existing technologies to further components. As the life cycle costs (LCC) is one of the main drivers for the implementation of CBM it is always to be seen in context of the acquisition cost of the technologies. WP6 will further investigate the cost benefit aspects of the developed solutions. Although most use cases in this project are carried out as proof of concept on a limited scale, the results of WP5 are not limited to a specific market segment or climate environment and are intended to generate results applicable for a wider market.

The work done will continue in WP6, focusing on generating models to determine the health status of the subsystems and predict their future behaviour, using the sensor technology and fleet wide data gathering of the solutions from WP5. This information will be crucial in making informed changes to maintenance strategies, ensuring that tasks are optimized for maximum efficiency and effectiveness. Providing successful proof of concepts for the different strategies and technologies will provide an important step forward for CBM using on board solutions.