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Contributions for Portuguese and European Projects to help increasing the Railway Sector

Project Report to fulfil the Master's degree in Engineering
and Management of Physical Assets

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RESUMO

O caminho-de-ferro português está fragmentado em comparação com os caminhos-de-ferro da União Europeia. Nos últimos anos não houve investimentos relevantes na infraestrutura ou na manutenção do material circulante, com o passar do tempo, degradaram-se e acabaram por ficar nas oficinas. A empresa Comboios de Portugal (CP) começou a fazer supressões por falta de material circulante e não satisfazer o serviço comercial de passageiros.

Atualmente, a CP está a recuperar muito material circulante que foi parando e degradando ao longo do tempo a fim de ter uma frota de substituição em caso de avaria. Contudo, a CP tem feito um esforço no sentido de não suprimir comboios comerciais.

No entanto, a ferrovia tem procurado melhorar a manutenção preventiva e assim poder implementar a manutenção preditiva de modo a reduzir a paragem das locomotivas e assegurar que as operações não tenham quaisquer problemas ao longo do percurso. Com a indústria 4.0, o material circulante está interligado e posteriormente será feita a recolha e a filtração da informação e depois mostra o estado atual do equipamento/componente. Com isto, a ferrovia aumenta a Fiabilidade, Disponibilidade e Manutenção e Segurança do seu equipamento, assegurando um melhor serviço comercial e de mercadorias.

O principal objetivo da manutenção preditiva é evitar avarias. Assim, a manutenção preditiva tem de assegurar uma manutenção de qualidade, a fim de prolongar a vida útil da infraestrutura e das locomotivas. No entanto, na área das ferrovias, é importante assegurar a qualidade e o estado de conservação das infraestruturas e da gestão de ativos.

Assim, a manutenção preditiva consiste em recolher dados dos sensores em tempo real para compreender o desempenho e a vida útil do componente em estudo. Além disso, existem operadores europeus que procuram soluções e inovações para os integrar no caminho-de-ferro que possam ter contribuições da I&D nacional.

Na União Europeia (UE), a ferrovia tem evoluído muito em termos de infraestrutura e manutenção, facilitando assim a mobilidade do material circulante entre países da União Europeia, a fim de ser mais confortável para os passageiros e, também no transporte de carga.

Contudo, um organismo da União Europeia, o Europe's Rail, tem como objetivo fornecer uma rede ferroviária integrada de alta capacidade, eliminando barreiras de interoperabilidade, a fim de fornecer soluções para uma integração total. Com estes projetos e inovações, será possível explorar a digitalização e automação para reduzir custos, aumentar a capacidade, e aumentar a flexibilidade e fiabilidade que deve ser partilhada pelo sector ferroviário. Com base nisto, será possível fazer uma transição

rápida, mais atrativa, de fácil utilização e eficiente, integrando-se assim num sistema de mobilidade mais amplo. O caminho-de-ferro europeu apoiará o desenvolvimento da ferrovia global mais competitiva a fim de contribuir para a realização do Espaço Europeu, com a normalização de todas as infraestruturas nos países membros, desde bitola, catenária, material circulante, etc.

Este projeto visa dar um contributo estratégico ao consórcio que envolve o Instituto Superior de Engenharia de Coimbra e o Centro de Competências Ferroviário (CCF) para a conceção de Projetos Portugueses e Europeus em projetos ferroviários com o objetivo de ajudar Portugal a atingir os mais altos níveis de desempenho na UE, de acordo com o estado da arte. O principal foco destes projetos é a inovação na frota de material circulante, fiabilidade, manutenção preditiva, manutenção remota e interoperabilidade de toda a informação.

Palavras-chave: Interoperabilidade; Manutenção Preditiva; Manutenção Remota; Indústria Ferroviária; Inovação ferroviária; RAMS; Fiabilidade

ABSTRACT

The Portuguese railway is fragmented in comparison with the European Union's railways. In recent years, there was no relevant investment in the infrastructure or in the maintenance of the rolling stock; as the time went by, they degraded and ended up staying in the workshops. The company Comboios de Portugal (CP) began to make suppressions for lack of rolling stock and unable to meet the commercial passenger service.

Currently, CP is recovering a lot of rolling stock that were stopped and degraded over time to have a replacement fleet in case of breakdown. However, CP has tried aiming to do not suppress of commercial trains.

However, the railway has been looking to improve preventive maintenance and thus be able to implement predictive maintenance to reduce locomotive downtime and ensure that operations do not have any problems along the way. With Industry 4.0, the rolling stock is interconnected and then information will be collected and filtered and then shows the status of the equipment/component. With this, the railway increases the reliability, availability and maintenance and safety of its equipment, ensuring better commercial and merchandise service.

The main objective of predictive maintenance is to prevent breakdowns. Thus, predictive maintenance must ensure quality maintenance to extend the service life of the infrastructure and locomotives. However, around railways, it is important to ensure the quality and state of conservation of infrastructure and asset management.

Thus, predictive maintenance is collecting data from sensors in real time to understand the performance and service life of the component under study.

Additionally, there are European operators that are looking for solutions and innovations to integrate them in the railway that may have contributions from the National I&D.

In the European Union (UE), the railway has evolved a lot in infrastructure and maintenance, thus facilitating the mobility of rolling stock between countries in the European Union to be more comfortable for passengers and, also in cargo transport.

Additionally, with climate change, the railway has been invested in because it is a cleaner means of transportation, thus reducing the use of air and road transportation.

However, a European Union body, the Europe's Rail, aims to provide an integrated high-capacity rail network, eliminating interoperability barriers to provide solutions for total integration. With these projects and innovations, it will be possible to exploit digitisation and automation to reduce costs, to increase capacity, and to increase the flexibility and reliability that must be shared by the railway sector. Based on this, it will be possible to make a fast, more attractive, user-friendly, efficient transition, thus integrating into a broader mobility system. Europe's Rail will support the development of the most competitive global railway to contribute to the

realisation of the European Space, with standardisation of all infrastructures in the member countries, from gauge, catenary, rolling stock, etc. This project aims to give a strategic contribute to the consortium that involves Instituto Superior de Engenharia de Coimbra and Centro de Competências Ferroviário (CCF) to design Portuguese and European Projects in railway projects with the goal of helping Portugal to reach the highest levels of performance in UE according to the state of art. The focus of these projects is the innovation in the rolling stock fleet, reliability, predictive maintenance, remote maintenance, and interoperability of all information.

Keywords: Interoperability; Predictive Maintenance; Remote Maintenance; Railway Industry; Railway innovation; RAMS; Reliability

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ACRONYMS AND ABBREVIATIONS

AAM	Augmented Asset Management
AIF/R	AI Factory for Railway
AI	Artificial Intelligence
ANNs	Artificial Neural Networks
APA	American Psychological Association
BCRE	Birmingham Centre for Railway Research & Education
CBM	Condition-Based Maintenance
CCF	Centro de Competências Ferroviário
COFUND	Programme co-fund action
CSA	Coordination and Support Action
CP	Comboios de Portugal
DL	Deep Learning
DOOR	Dynamic Object Oriented Requirements System
DTS	Dynamic Track Stabilisation
DTT	Divertor Tokamak Test
DUT	Device Under Test
EC	European Commission
EIT	European Institute of Innovation and Technology
ERDF	European Regional Development Fund
ERTMS	European Rail Traffic Management System
ESIFs	European Structural and Investment Funds
EU	European Union
FAHP	Fuzzy Analytic Hierarchy Process
FFMECA	Functional Failure Modes, Effects and Criticality Analysis
FMECA	Failure Mode Effects and Criticality Analysis
IA	Innovation Action
LCC	Life-Cycle Costing
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IIoT	Industrial Internet of Things
IRT	Institute of Railway Technology - Monash University
ISEC	Instituto Superior de Engenharia de Coimbra
LTU	Luleå University of Technology
ML	Machine Learning
ORCID	Open Researcher and Contributor ID
PdM	Predictive Maintenance
PIC	Participant Identification Code
JVTC	Luleå Railway Research Centre
LCP	Life Cycle Profit
PIC	Participant Identification Code
PNI	Programa Nacional de Investimentos

Contributions for Portuguese and European Projects to help increasing the Railway Sector

PPP	Public-Private Partnerships
PRR	Plano de Recuperação e Resiliência Português
RAMI	Reliability, Availability, Maintainability and Inspectability
RAM4S	Reliability, Availability, Maintainability and Safety
REFER	Rede Ferroviária Nacional, EP
RIA	Research and Innovation Action
RNN	Recurrent Neural Network
RTRI	Railway Technical Research Institute
RTSC	Railway and Transport Strategy Centre
RTU	Remote Terminal Unit
RUL	Remaining Useful Life
SPR	Syemmaint Platform Rail
TEN-T	Trans-European Transport Network
TRL	Technology Readiness Levels
TTCI	Transportation Technology Centre, Inc.
UIC	Union Internationale des Chermains de Fer
UK	United Kingdom
US	United States

1 INTRODUCTION

1.1 Framework

Portugal is a country that is in the extreme southwest of Europe, bordering only one country, Spain. However, Portugal has sought to develop several infrastructures that are not yet developed as the European Union would wish. So, Portugal, being a country that belongs to the European Union Member State, has been looking for support for its economic, infrastructure and cultural development. The European Union, together with the European Commission, provides various support to help other countries that have difficulties in fulfilling the goals set by the organisations. Some of these supports could be European Funds 2021-2027, European Regional Development Fund (ERDF), Portugal 2020-2030, Plano de Recuperação e Resiliência Português (PRR), European Structural and Investment Funds (ESIFs), etc.

In this way, besides these types of support, there are others which are improvement or transformation incentive projects. These projects are made available on an electronic platform for all organisations that wish to participate or collaborate. The interested organisations should formalise the application, fulfilling all the requested requirements.

Most of the support mentioned above can be financed directly or indirectly. The support financed directly from the European Fund is totally covered, by the available sum while the Co-Financed support is provided with part of the sum from the European Funds and the rest from the State. The purpose of these incentives is to help development on a national or regional level.

In recent years, Portugal has invested in the railway area, namely in the recuperation of the rolling stock that was damaged or stopped some years ago. So, the Portuguese State created a PRR providing funds for the recovery of passenger transport carriages, improving the comfort, and recovering locomotives that were stopped. In addition to these recoveries that are made by CP (Comboios de Portugal), CCF (Centro de Competências Ferroviário) together with ISEC (Instituto Superior de Engenharia de Coimbra) has been seeking new forms of predictive maintenance using Augmented Reality.

The purpose of Augmented Reality is to help in the recovery of most of the rolling stock to ensure that human failure does not occur and to prevent breakdowns.

1.2 The European Projects

The European project allows organisations to access research and development projects funded by the European Commission.

The Funding & tender opportunities platform is a portal where participants can access research projects whose funding is managed, notably by the European Commission.

This work involves a European project with the theme "Marker-less Augmented Reality to Support Equipment Repair with Self-Diagnosis".

1.3 Structure of the report

This work was motivated by a personal interest in the area of research, exploration and reflection to delve a little deeper into the subject of railroads in Portugal and Europe, as it is a recurring, diversified theme and seeks new solutions to be always up to date and at the same time be part of a dream of all those who have idealised, and now seek to design to make it a more effective reality.

Throughout this report, some revealing topics about the railway are covered, both at European and national level.

This topic required some research and dedication in maintenance, which is a great challenge with an enormous responsibility. With this new project, I'm highlighting and referencing themes that have been proposed to me to work on, giving great importance to what is revealing.

Throughout this work I have tried to do my best to help other people who may be interested in the same subject, considering the personal, European, social and academic context.

This project is structured into seven sequenced chapters, each dealing with a specific subject, but all related to the topic of railroad maintenance.

I will therefore present the following framework:

Chapter 1 - Introduction - takes a descriptive approach to Portugal's commitment to the European Union with the development of railway infrastructure supported by funds and programmes.

This is followed by an overview of the location and infrastructure challenges in Portugal, and then to the European Union's support for the Member States.

Finally, the structure of the report is presented, which reflects a great interest in railway maintenance, both at national and European level. It also highlights the importance of innovation, research, and cooperation to overcome some of the railway's challenges. In this chapter it is provided a detailed discussion of the

development, challenges, and innovations in the railway, setting it in the context of maintenance and innovation that are being carried out with significant support from the European Union.

Chapter 2 – Theoretical framework – In this chapter I begin by giving an overview of the development of the railway sector in Europe. After this, I will give an overview of the importance of remote maintenance and predictive maintenance in railway equipment. Due to the immense importance of maintenance mentioned above, I have highlighted railway maintenance and the types of predictive maintenance tools in a new topic.

Chapter 3 – Luleå University Research Centre – This is a research centre located in the Nordic country of Sweden. This research centre has been linked to the railway industry from the outset, from its development of railway operations and maintenance. However, this centre is more focused on the area of maintenance, highlighting RAMS (Reliability, Availability, Maintainability, Safety), LCC (Life Cycle Costing), risks, maintenance limits and the development of maintenance strategies. It has also been developing Railway 4.0 and finally getting involved in the projects co-funded by the consortia.

Chapter 4 – European Projects – provides a framework with a brief explanation of the financing of projects and programs with development objectives. Next, I'll focus on pathfinder projects, which fund research to develop a scientific base, while the Horizon project covers research up to the final project. Finally, I will explain how to use the Funding & Tender EU website, from searching for a specific topic, reading the application requirements, and then formalising the application.

In chapter 5 – The strategic importance of the railway in Portugal and in Europe – I explain the importance of using this means of transportation that respects the environmental principles of the railway both in Portugal and in Europe. Next, I will focus on European and Portuguese rail policy. Finally, I highlight the creation of a rail research enter in Portugal and Europe.

In chapter 6 – Development – I explain how to search for a topic on the Funding & Tender website. Then I explain how the choice of articles was made to develop this work with some quality. Finally, I explain how to fill in the two forms and submit them.

In chapter 7 – Conclusion

2 THEORETICAL FRAMEWORK

2.1 A Global approach about the Railway sector in Europe

Since 2013, Europe has been looking for ways to invest in the railway sector through support and incentives.

Europe and its member states have been investing in railways because they continue to be the most environmentally friendly means of motorised passenger transport. Climate change is a global threat and thus has considerable consequences for infrastructure and public services worldwide. “The challenges posed by the mobility sector to the future sustainability of cities, regions and countries include fostering alternative modes of transport that can compete with cars and airplanes but producing less environmental impact.” (Cordera, *et al.*, 2021)

Europe has been strengthening rail transport because it is less polluting than other means of transport, such as sea, air, and land, and because it is also a means of transport with a lower carbon footprint “greater environmental sustainability and safety levels compared to road transport.” (Cordera, *et al.*, 2021)

In recent years, the European Commission and the European Union have provided incentives and funding to EU countries for the development of railway infrastructure. Due to high maintenance costs, many European countries have disinvestment in railways and even closed them down due to a lack of support and incentives. In order not to make the situation even worse, Europe began to create support and incentives to reverse the closure of railway infrastructure. The countries that agreed to receive support to rebuild and improve infrastructure were also challenged to create new corridors for high-speed trains with connections between countries. In addition, this aid also served to modernise existing lines by implementing more advanced technologies across the entire rail network.

Today, Europe is investing in new corridors for transnational high-speed trains, making it easier to transport goods and passengers and improving connections between member countries. Promoting the efficient use of infrastructure will help, “Re-thinking railway stations as “multi-modal and proximity services hubs” could allow us to sustainably move large numbers of people while boosting the compactness of the city by offering proximity.” (Lunardon, *et al.*, 2023)

According to Lunardon *et al.* (2023), “European railway stations see the potential of better using stations to improve urban transportation and related urban spaces, citizens’ daily life, and city’s resources optimisation.”

Since 2013, the EU's main objective has been to create a trans-European transport network (TEN-T). The EU wants to create a core network by 2030 and then a global network by 2050. Each member state is responsible for implementing projects to create a new railway network. The EU has a significant role to play in the development of the TEN-T, drawing up and accompanying and supporting the

project that will be in the common interest and thus being able to implement measures to ensure interoperability. The main network has nine corridors across Europe.

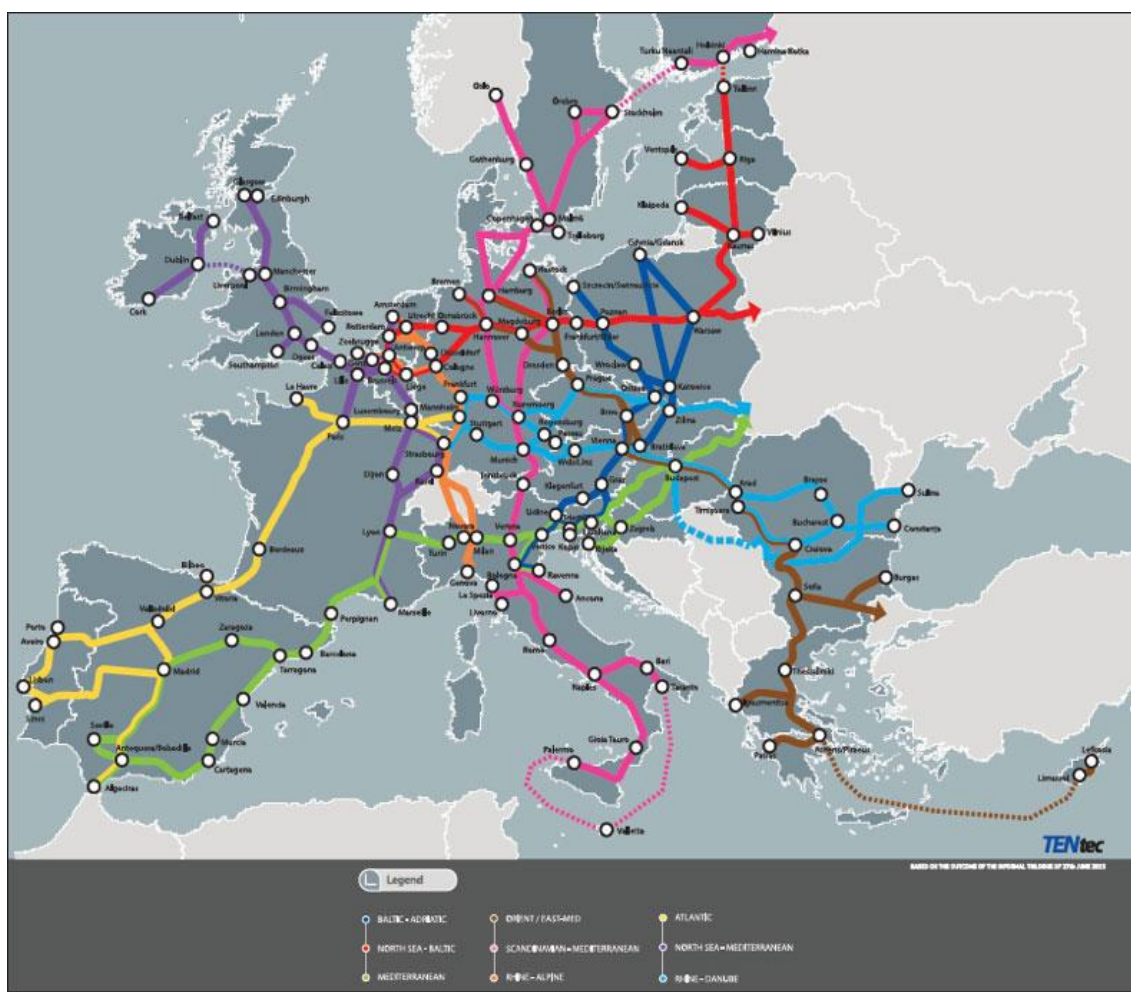


Figure 1 – The main train routes in Europe

Source: [<https://op.europa.eu/webpub/eca/special-reports/ertms-rail-13-2017/pt/>,
Accessed in 2023.11.01]

Figure 1 shows the main railway corridors on the map, according to Regulation (EU) N° 1315/2013:

- a) "Rail Baltic": Baltic-North Sea corridor - railway line linking Estonia, Latvia, Lithuania, Poland and to Finland;
- b) "Lyon-Turin link": Mediterranean Corridor - cross-border railway link between France and Italy;
- c) "Brenner Base Tunnel": Scandinavia-Mediterranean Corridor - railway link between Austria and Italy;
- d) "Fehmarn Strait Link": Scandinavia-Mediterranean corridor - railway link between Denmark and Germany;

- e) "Basque Y link to France": Atlantic Corridor - high-speed rail link between Vitoria (Spain) and Bordeaux (France);
- f) "Seine-Scheldt link": North Sea-Mediterranean and Atlantic Corridor - a link between the Seine and Scheldt rivers (France and Belgium);
- g) "A1 motorway": Rhine-Danube corridor - Romania;
- h) "E59 railway line": Baltic-Adriatic corridor - linking the Polish ports of Szczecin and Świnoujście.

Bearing in mind that not all member states have common interests, or, in other words, each country defends its own interests and most of the time the railway is not one of the priorities because it has a prohibitive cost in both infrastructure maintenance and locomotives.

As can be seen in Figure 1, Portugal is part of the Atlantic line corridor. This corridor connects Portugal and Spain to the rest of Europe, extending as far as France. This line will connect to other corridors and thus facilitate the transport of goods and passengers. In addition, Portugal has shown interest in investing in the railway. This corridor will bring both advantages and disadvantages. One of the advantages is sustainability, better connections, and an economic boost, while the disadvantages are high maintenance costs and regional inequality. This integration will bring many opportunities, but also challenges that require management to maximise the benefits and minimise the disadvantages that may arise.

Sweden, as one of the member states of the European Union, has been seeking to carbonise its transport system but “has failed to achieve momentum in its attempts to decarbonise transport”. (Haikola, & Anshelm, 2022)

According to Haikola & Anshelm (2022) there are three reasons why the country has not been able to carbonise “the issue of financing, the role of the state in scion-technical change, and fatalism”. In addition to these issues, there are others that will converge “deflationary” discourse coalition, characterised by ideas of sound finance and depoliticised governance, which reinforces material dependencies on existing transport infrastructure.” (Haikola & Anshelm, 2022)

Cordera *et al.* (2021) has conducted a study in which it presents two types of scenarios for the demand for public transport, namely rail transport. By 2030, there will be a significant increase in demand “if there is an increase in the costs of the private car that reduces its use by 10%”, while in 2050 demand will increase, but not as sharply as in 2030 “due to greater competition from autonomous bus modes over urban and middle distances and the electric bicycle in urban areas.” (Cordera *et al.*, 2021)

As the EU is a strong advocate of climate change, it has been looking for solutions and ways to minimise environmental impacts, using less land, air, and sea transport to use more and more rail transport for trade transactions between continents and passenger transport.

With the increase in trade between two major powers, namely China, the EU has an EU-China partnership which “have maintained a dialogue on climate change and biodiversity while clashing over other economic and political issues”. (Altun & Ergenc, 2023)

2.2 Remote Maintenance

Nowadays, technologies are more advanced and sophisticated due to technological advances. If maintenance does not keep up with this innovation, it starts to lose its ability to respond. The 4Th industrial revolution requires equipment to be connected to the Internet of Think (IoT) so, the maintenance department has made a huge effort to keep up with this evolution. What is already happening with maintenance is that increased sensors are electronic to alarm different malfunctions of components. With Remote Maintenance it will be another advance at the digital level, that is, the sensors will be connected to a central and the operator at a distance can see all the information that is emitted by the sensor and later be corrected at a distance. Sahal, Breslin & Ali refer that “all propose an approach based on Railway Industry 4.0” to introduce new examples of digital and autonomous control. However, these authors give immense importance to citing "Big data and IoT technologies are playing a key role in creating data-driven applications such as predictive maintenance." (Sahal, Breslin & Ali, 2020). The fourth revolution in the industry covers four key areas: "Advances in internet technology, internet of things, cloud computing, big data and artificial intelligence have had a profound impact on

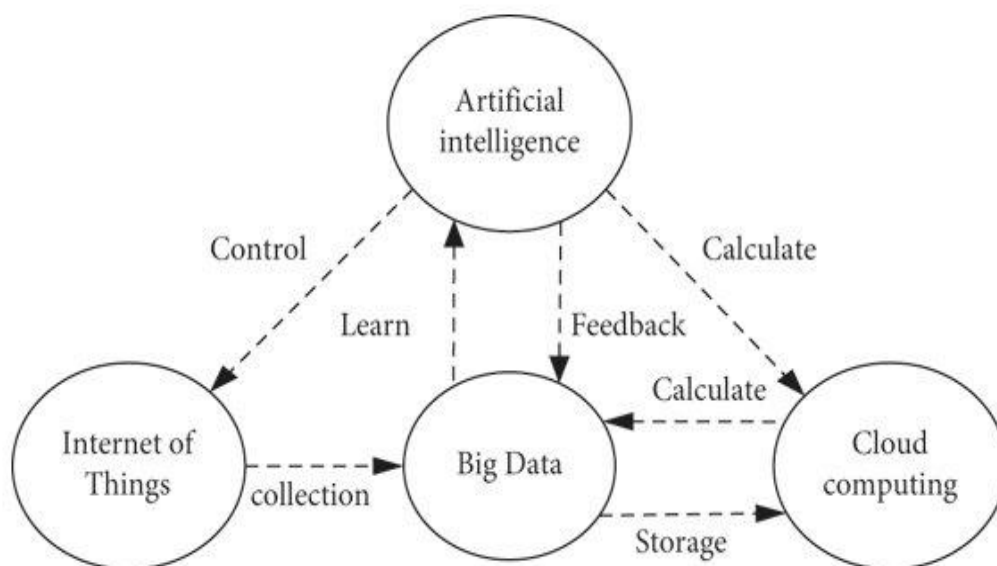


Figure 2 – The relationship between Big Data, Artificial intelligence, Internet of Things (IoT) and Cloud computing

(Wang & Wang, 2022)

production", (Figure 2). (Tao et al., 2018)

Industry 4.0 contains automation and connects with data in industrial technologies, which will involve "Internet of Things (IoT), wireless sensors, cloud computing, artificial intelligence (AI), machine learning and Big Data." (Valeukeep, 2022)

“At the same time, in the rapid development of the information age and the development of computer and network technology, artificial intelligence and other related high-tech are also developing rapidly.” (Wang & Wang, 2022)

Industry 4.0 requires a quick and efficient maintenance service to guarantee that companies implement an efficient production system. (Masoni et al., 2017)

With This revolution will allow maintenance to be simpler and make it easier to control and monitor operations. With this, the maintenance department will be able to collect data to maximise the useful life of the equipment components and thus avoid failure. Maintenance processes will evolve from preventive maintenance to predictive maintenance. With this, the maintenance department begins to focus not only on prevention, but also on prediction.

Big Data has come to facilitate us and is also our main ally to do more focused maintenance on the equipment. Big Data and Artificial Intelligence are great allies that can accurately predict the lifetime of components and thus anticipate the risk of failure and the impact that may arise on the system.

“Big data analysis is different in which it uses various technical means to screen and statistically classify a large number of huge and diverse data according to certain rules.” (Wang & Wang, 2022)

Big Data is a concept that describes a large volume of data, whether structured or unstructured. Big Data is useful for companies for decision making to improve various business strategies.

“Artificial intelligence technology is an emerging high-tech application in the computer field.” (Wang & Wang, 2022)

Artificial Intelligence: Lately, companies have invested in artificial intelligence mechanisms. In the maintenance area it can robots that help humans to perform jobs that are more time - consuming, difficult, or even heavy. Now, they are already investing in more cleaning robots, which is an immense help for the cleaning area. These mechanisms demonstrate that it is possible to create robots that can play a key role in maintenance.

Internet of Things (IoT) technology has been improving astronomically over the years. The equipment's connected to this technology is now identified on the network and exchanging information in real time will be easier.

Cloud Computing is a server where you can host and send all your information. This service can store data, databases, and software over the internet. Cloud computing can deliver services quickly with flexible resources.

Industry 4.0 use cases are categorised into the following three areas, namely, (I) intelligent products, (ii) intelligent processes, and (iii) intelligent machines. (Sahal, Breslin & Ali, 2020)

The intelligent product aims to collect all the necessary information through sensors in a particular component, the process aims to manage the information received from the sensor. to allow the intelligent machine to be trained to be able to make failure predictions, detection of quality problems to allow preventive maintenance.

With the evolution of the Internet of Things (IoT) there are advantages and disadvantages. In advantages, there is greater mobility, analyse the rail network, easier route planning and scheduling. “Opportunities abound to expand smart sleeper deployment for condition monitoring and real-time management of track assets, to decrease the life cycle cost (LCC) of track components and increase infrastructure availability enabling increasing track capacity.” (Jing et al., 2021) and “...the development of innovative technological solutions, providing responses to the industrial needs of reducing costs and contributing to improving the competitiveness of railway transport.” (Sainz-Aja *et al.*, 2023) The disadvantages are having a system that can receive all the information that is sent by the sensors and be able to make the data transaction and processing, greater likelihood of targets for cyberattacks and theft of confidential information. Today, many industries are concerned about preparing their assets for a new era of digitisation so that they can manage big data from various sources. have developed smart factories which are based on the powerful capacity of handling big data from various sources, e.g., instruments, sensors, Internet transactions, CAD models, and digital records to enable the real-time control of multiple elements within the production process. (Tiwari *et al.*, 2018)

“The IoT technology has been heavily used in railway applications, including railway operations, management, maintenance, video surveillance systems, and train control systems.” (Singh *et al.*, 2022)

The predictive maintenance “IoT are enablers of the following services: condition information on railway equipment; freight delivery information systems; train control systems, “Smart Infrastructure” (infrastructure and equipment embedded with sensor technology that enables them to interact with each other and communicate real time data to infrastructure owners on the structural health of assets); and Predictive maintenance.” (Global Infrastructure Hub, 2020). The new IoT solutions initially must receive historical data to "learn" and predict future failures, make diagnoses, and then trigger maintenance flows based on the data that was entered. “The results are then used to train and validate a series of predictive models based on Machine Learning algorithms.” (Sainz-Aja *et al.*, 2023). And in that way, it possible to make more assertive diagnoses. However, “The historical data should be possible to easily restore and retrieve from big data storage.” (Sahal, Breslin & Ali, 2020)

Nowadays, locomotives already have alarm sensors / warning lights. On the railway they already use technology to be able to do real-time communication, locomotive localisation, and management of the lines' points.

The transportation sector, especially railways, has adopted Industry 4.0 to improve the quality of services, new savings, and enhance resource utilisation. (Sahal, Breslin & Ali, 2020).

“Furthermore, real-time information informs more intelligent and safer resource allocations and operations, thus improving the productivity of railway maintenance.”. (Global Infrastructure Hub, 2020). And so, it is possible to monitor all railway equipment, for example locomotives, wagons and signalling equipment.

“For example, the multiplicity of sensor data will generate very large flows and volume of data in real-time such as the location of trains, speed, passengers on board, door status.” (Sahal, Breslin & Ali, 2020) and there may be other types of sensors that may also already be linked to Big Data technology to prevent the locomotive from breaking down and thus be able to do predictive maintenance. “Besides the online analysis of railway data, offline analysis could be performed to predict future failures using past failures information extracted from historical data.” (Sahal, Breslin & Ali, 2020). This kind of information is essential to prevent future failures.

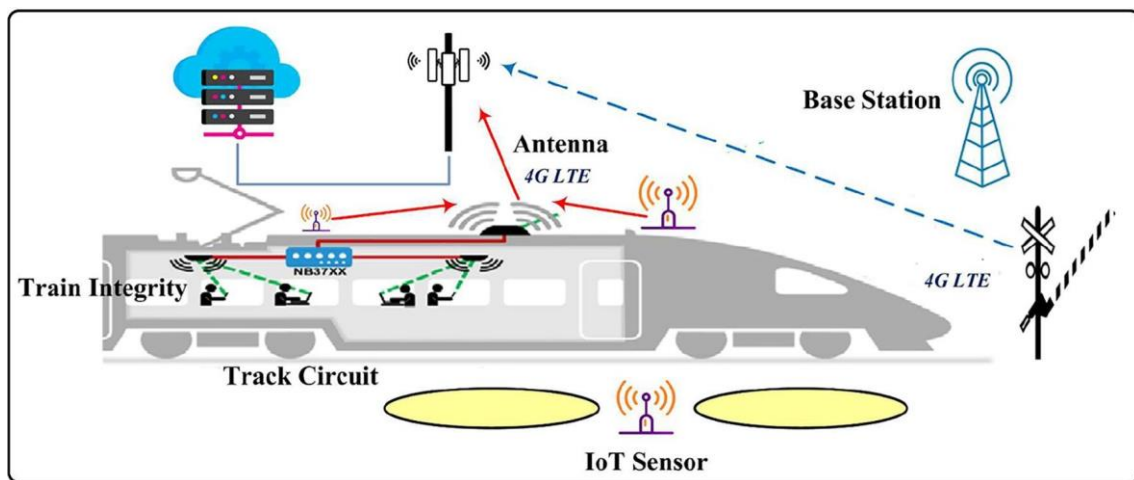


Figure 3 – Level crossing monitoring using the IoT.

[Source: (Singh *et al.*, 2022)]

In Figure 3, we can see the architecture of the train with the implementation of Industry 4.0. In 2020, the French railway presented one project "Télédiag" with the aim of improving predictive maintenance. This program will introduce Industry 4.0 in the railway area, involving the Internet of Things (IIoT), edge computing, big data, analytic, and cloud computing. The "Télédiag" program will also enable maintenance agents to gather status information about on-board equipment in real time, providing at the same time innovative approaches to create flexible production, preventive, and predictive maintenance, and rolling stock remote quality control

(SNCF, 2020). The IoT-based applications can be used to remotely monitor irregular activities at level crossings and send the appropriate notifications to the train driver and network control enter. (Singh *et al.*, 2022).

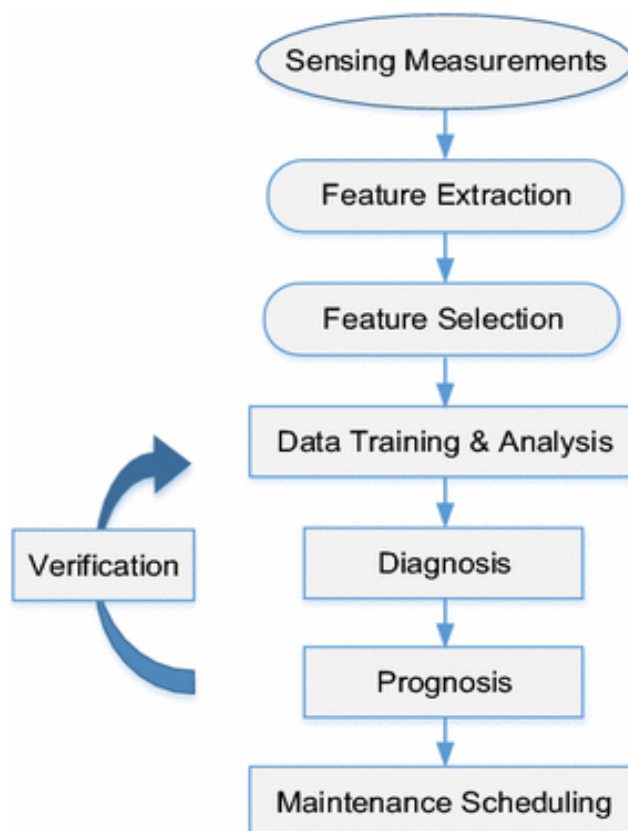


Figure 4 – Analytical framework for predictive maintenance

[Source: (Wang *et al.*, 2015)]

In Figure 4, we can see an analysis of the Analytical framework for predictive maintenance. “The aim of predictive maintenance is to provide decision support for maintenance scheduling by diagnosing the defects and predicting the remaining service life of motors.” (Wang *et al.*, 2015). The monitored data is available in real time on a server. The data will go through several phases. The first phase of the data will be analysis of the information received, and then it will move on to the data processing phase, where information is filtered and, in the future, made available for consultation. With “Such new approach could highly reduce the amount of data transmission, thus improving the system efficiency.” (Wang *et al.*, 2015).

“The expected results are, among others, increased maintenance competences in the industry, and the improvements of the different maintenance services following a predictive, condition-based maintenance strategy.” (Kans, Campos & Håkansson, 2020)

DEMO remote maintenance is a project that aims to push forward with some technologies available on the market. Although the components are still at an immature stage, maintenance is creating a development strategy so that they can consider maintenance requirements. Seeing that, “the remote maintenance concept design process to identify the immature technologies that have the greatest threat to the feasibility of the concepts.” (Crofts *et al.*, 2016) Considering that in the engineering field, remote maintenance is a great innovation because “that integrates with the plant and component systems engineering processes, to analyse the functions, gather requirements and consider failure modes and reliability.” (Crofts *et al.*, 2016)

The characteristics of the new components can fully meet the requirements of remote maintenance and are intended to collect and send information to a “requirements management database DOORS (Dynamic Object Oriented Requirements System) in which it could be linked to parent plant level requirements above and, as the subsystem requirements are developed, to child requirements below to ensure the remote maintenance subsystems deliver the required maintenance functions.” (Crofts *et al.*, 2016)

After processing all the data, the most revealing information is filtered, and a document is created with “remote maintenance system requirements”. (Crofts *et al.*, 2016)

Considering that this kind of project is an ongoing process that aims to collect data and, in the future, develop it to make it more complex and complete.

The RAMI system (Reliability, Availability, Maintainability and Inspectability) “then became the measure of the effectiveness of a system through its availability by combining reliability, maintainability, and inspectability.” (Van Houtte, 2019). RAMI technology is aimed at “guarantee the specified functionality of a system over its complete life cycle and to keep the operation and maintenance costs at a reasonable level.” (Van Houtte, 2019)

To “Minimizing the criticality of failure modes is essential to ensure that the remote maintenance system can achieve plant availability and safety requirements.” (Crofts *et al.*, 2016)

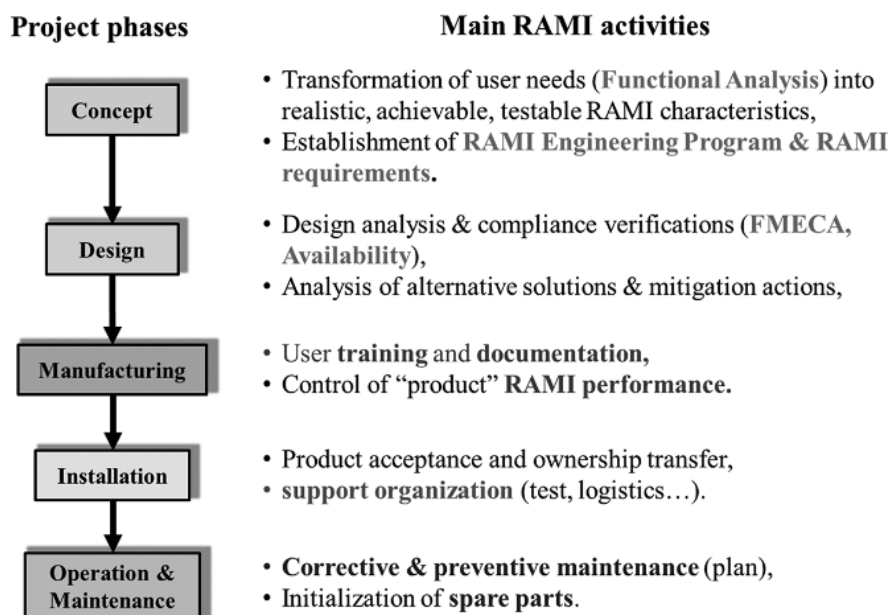


Figure 5 – Main RAMI activities during project phases

[Source: (Van Houtte, 2019)]

Figure 5 shows several phases of the project actively involving the RAMI system. However, in the RAMI System “there are two types of availability: the inherent availability of a system and its operational availability. Inherent availability corresponds to the percentage of time that a system is available when no delays due to preventive maintenance are taken into account.” (Van Houtte, 2019)

RAMI has as its main goal “A Functional Failure Modes, Effects and Criticality Analysis (FFMECA) has been undertaken for each of the nine remote maintenance subsystems and they are updated as the subsystem designs evolve.” (Crofts *et al.*, 2016)

Bearing in mind that “The FMECAs are now being used to develop the top-level Reliability, Availability, Maintainability and Inspectability (RAMI) analysis.” (Crofts *et al.*, 2016)

Figure 6 shows that FMECA analyses risk to act and provides an opportunity to reduce the possibility of error.

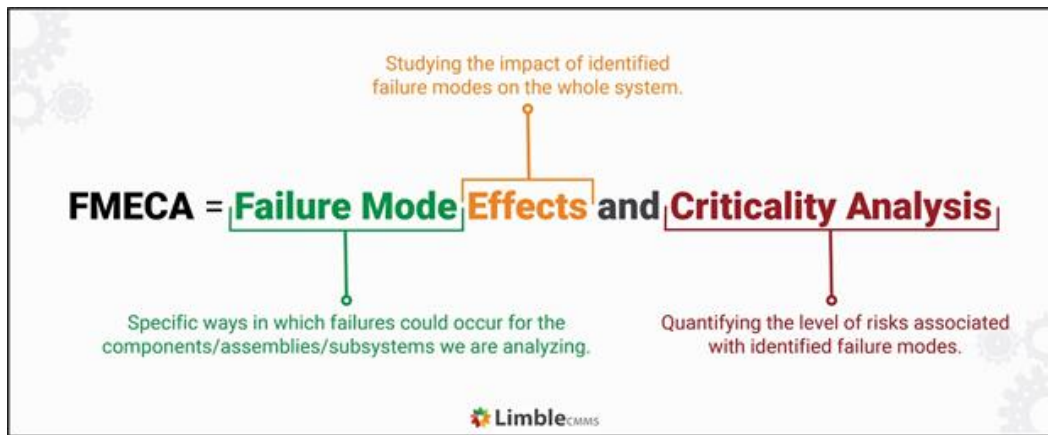


Figure 6 – FMECA System Legend

[Source: (Christiansen, 2020)]

“Basic FMEA is qualitative and only explores “what-if” scenarios. When we add the criticality analysis from FMECA, you get a number that will allow you to rank your failure modes. This makes it easier to prioritise your work and (hopefully) keep problems from happening in the first place.” (Christiansen, 2020)

The remote maintenance strategy is that “Wherever possible, remote handling equipment will be designed to self-recover from failures. Inevitably, however, there will be failure scenarios that are un-recoverable. These scenarios must be highly unlikely to minimise the duration of maintenance interventions and preserve plant availability.” (Crofts et al., 2016)

Today, remote maintenance is more focused “on the application and limits of immature technologies that are the greatest threat to the viability of the strategy” (Crofts et al., 2016)

Remote maintenance is recognised as Augmented Reality, being one of the main “leading technologies in the 4th industrial revolution, the so-called Industry 4.0.” (Masoni et al., 2017). Augmented reality has come to help companies improve their maintenance services, but for this to be possible there will be an investment on their part.

Due to “technological limitations have prevented AR from becoming an effective industrial tool in the past”. (Masoni *et al.*, 2017)

Industries have difficulties implementing Augmented Reality (AR) because “o the low performance/cost ratio of both the software and hardware technologies available on the market”. (Masoni *et al.*, 2017)

Augmented Reality is a fundamental pillar for the maintenance area that can bring several benefits, such as “AR can help to reduce time and errors of maintenance tasks”. (Fiorentino *et al.*, 2014)

There are several types of maintenance “as long as machine failure can be predicted with accuracy, predictive maintenance allows the maintenance frequency to be as

low as possible to prevent unplanned reactive maintenance, without incurring costs associated with doing too much preventative maintenance, ideally”. (Masoni *et al.*, 2017)

Many times, it is not possible to make the planned repair because it is so complex that a specialised technician must be called in to solve the malfunction. This repair will be a prohibitive cost for the company to request a specialised technician. With remote maintenance we can have several advantages, having access to equipment documentation in digital format and avoiding the specialised technician's need to travel to the site. In other words, the non-specialised operator can consult the equipment's documentation and solve a malfunction or, as a last resort, can resort to a specialised technician remotely and thus instruct another operator by exchanging information and sharing images and thus repairing the malfunction. The “AR has been recognised as being an interesting support in the industry for maintenance applications, assembly, and repair of machinery”. (Masoni *et al.*, 2017)

In Figure 7, non-specialised operators can send pictures to a specialised person, and subsequently receive instructions by text, schematics, or pictures with symbols.

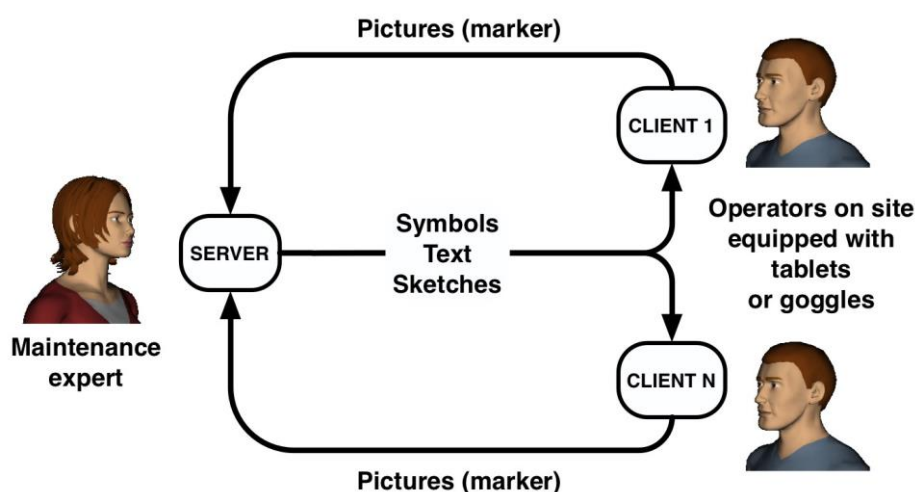


Figure 7 – System architecture: the expert and the operators can communicate thanks to a server/client system.

[Source: (Masoni *et al.*, 2017)]

This architecture is one application. As quoted by the authors, “The architecture of the application is of the Client-Server, which well supports the connection of a skilled operator with an unskilled one, or with several unskilled operators working on the same machine, remotely located. The application works in the following way: the unskilled operator/operators (client) take some pictures of the real environments and sends them to the skilled one (server) automatically through the application. These pictures are used by the client as a marker to visualise the instructions on the real environment, and for the server to indicate the maintenance tasks to perform.” (Masoni *et al.*, 2017)

Railway maintenance is fundamental to ensure infrastructure safety to manage all assets. However, with the rapid evolution of robotics and autonomous systems, there has been a need for railway maintenance to develop intelligent strategies to manage assets for digitisation and manage railways for Industry 4.0.

One of the main focuses in the Railway 4.0 industry is “Precise and real-time rail vehicle localisation is essential to robotic command and control, task execution, safety and efficiency.” (Rahimi *et al.*, 2022)

Maintenance has several requirements that are fundamental and that must be met, from corrective maintenance to preventive maintenance. This maintenance is fundamental to your “Ineffective job execution or failure in preventive maintenance can lead to railway service disruption and unsafe operations” (Rahimi *et al.*, 2022). They bet a lot on “regular maintenance to ensure safe operating conditions” (Rahimi *et al.*, 2022) because they can save a lot of money. Seeing that, “preserving or improving the safety, reliability, and quality of the whole railway system is a key challenge, and is paramount for passengers, employees, and the entire rail network. Without reliable rail track maintenance, the safety of the rail network will be at risk, and delays will occur regularly.” (Rahimi *et al.*, 2022). With the revolution of the industry came the possibility of creating “innovative maintenance solutions for railway systems, as well as the integration of maintenance into operations, are constantly studied and developed to ensure a better management of the railway network.” (Rahimi *et al.*, 2022). The sectors of industry “benefit from automation, which has led to the development of a number of robotic solutions to maintain and repair applications in the industry.” (Rahimi *et al.*, 2022). Several robots with different projections were created for “to do various railway track maintenance tasks; however, most of them are limited to specific scenarios, uses, or applications”. (Rahimi *et al.*, 2022). “Autonomous systems will be one element involved in solving the trade-off between the transport capacity challenge and the maintenance cost and time reduction.” (Rahimi *et al.*, 2022) Worldwide, the railway is engaged in developing various systems that allow automated inspection to detect irregularities, missing fasteners, and track failures. “These systems can improve the ability to detect defects and minimise inspection time, allowing for more frequent railway network maintenance.” (Rahimi *et al.*, 2022). Considering that one of the maintenance strategies is to be monitored. With the incorporation of Artificial Intelligence “and with cognitive analytic tools can make the whole process dynamic and autonomous” (Galar & Kumar, 2021).

Railway maintenance incorporates some techniques to inspect, repair the rails to ensure that the rolling stock prolongs the life of the components.

The main purposes for which rail maintenance is done:

- With the speed of the rolling stock and heavy loads, the structure is stressed, and the track starts to get damaged.
- The track being exposed to the environment will also degrade over time. Rolling stock and rails have a shorter life cycle.

- As the track has many curves, it must support the speeds and loads that pass over it, and maintenance must be done at points and crossings.

This is one of the main factors that require maintenance to be done on a regular basis. These types of maintenance are expensive when preventive maintenance becomes impossible and profound consequences result. We are using robotics and autonomous systems to conduct this maintenance with greater precision and reliability.

“The cost-effectiveness of robotics automation in railway track maintenance and related tasks has been already proven.” (Vithanage *et al.*, 2018).

To maintain the track, it is often necessary to use machines that are highly specialised in doing certain functions “including replacement, track stabilisation, ballast injection (stone blowing), sleeper replacement, tamping the ballast, excavation, spiking rail, tightening bolts, and aligning the track is achieved through the utilisation of highly specialised machines” (Rahimi *et al.*, 2022).

During the maintenance period, the most critical components in the railway industry will be serviced. However, it should be noted that 8 evaluation criteria can be adopted that have been selected from the requirements of remote maintenance. A Divertor Tokamak Test (DTT) team (Figure 8) developed these criteria.

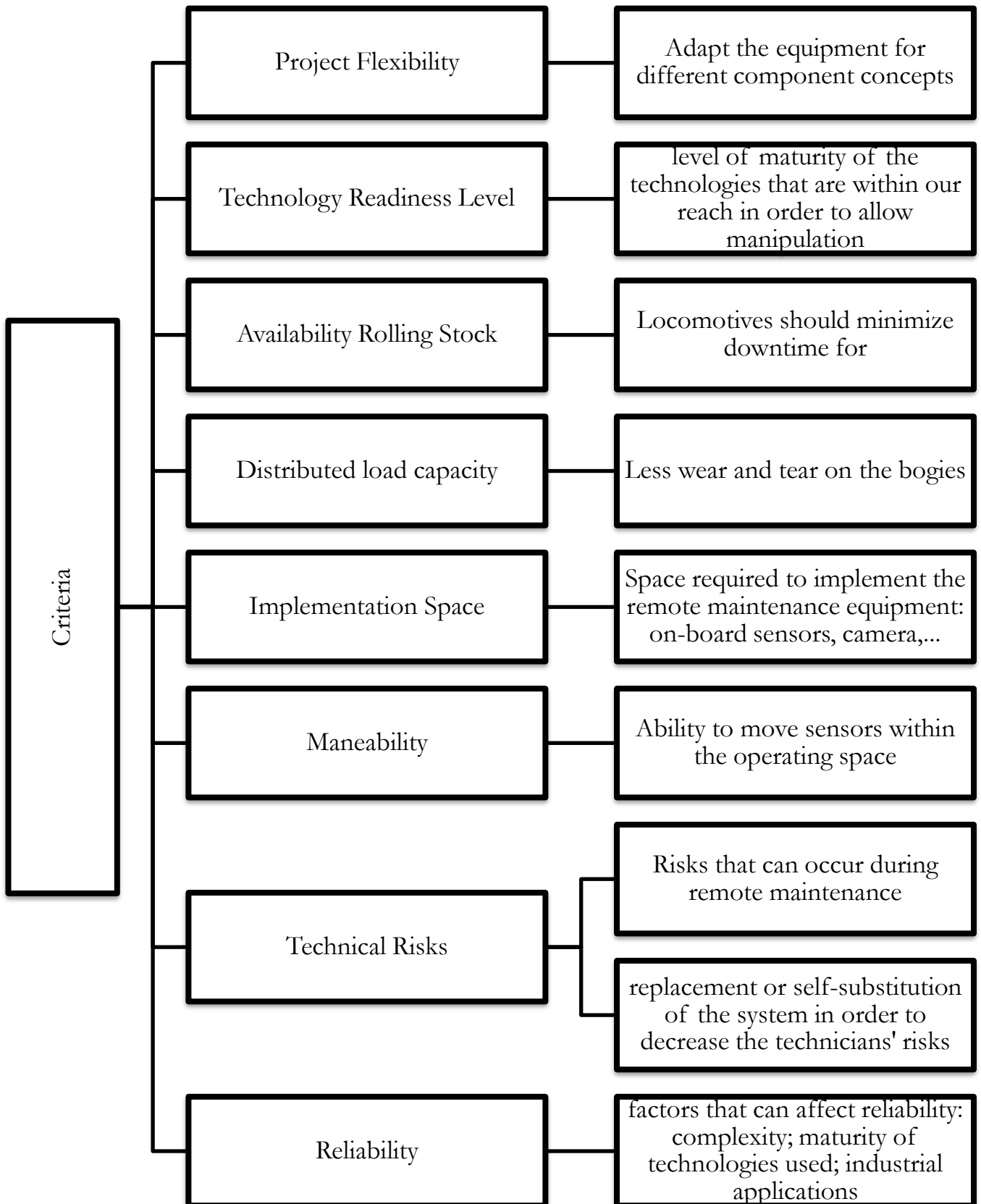


Figure 8 – Criteria were developed by a Divertor Tokamak Test (DTT) team

Source: [(Gironimo & Grazioso, 2022)]

These criteria were adapted from the article (Gironimo & Grazioso, 2022).

National Rail has defined two types of maintenance to be able to keep the rails as functional as possible: corrective maintenance and preventive maintenance. This maintenance has a significant amount in resources, equipment, and specialised personnel. Preventive maintenance is fundamental for railway maintenance so that it does not reach the state of degradation of the track. On the railway, preventive maintenance aims “are to extend the useful life of capital equipment, reduce critical equipment breakdowns, improve the planning and scheduling of needed maintenance works, reduce production losses due to equipment failures, promote the health and safety of maintenance personnel, and provide maximum system reliability and safety with the least amount of maintenance resources” (Rahimi *et al.*, 2022)

In preventive maintenance there are several key elements to be checked, as can be seen in Figure 9:

- Inspection - has its main objective in the evaluation of the track condition and materials;
- Maintenance - preservation of the track condition;
- Calibration - compares standard values with the values that are taken;
- Testing - aims at checking maintenance and looking for mechanical/electrical wear;
- Alignment - rail alignment;
- Adjustment - of specific materials to improve rolling stock performance;
- Installation - replacement of parts that have a very limited life span and will degrade over time.

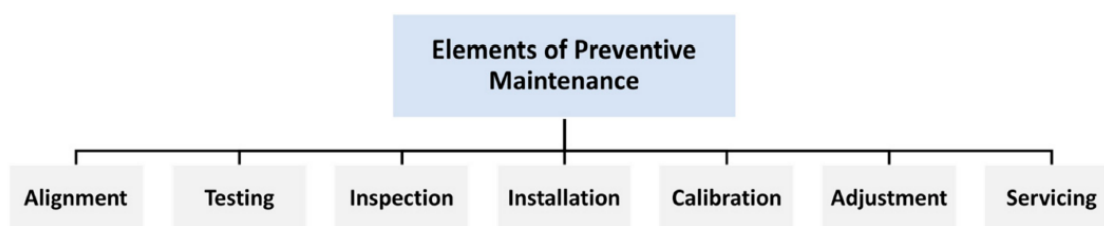


Figure 9 – Elements of preventive maintenance.

[Source: (Rahimi *et al.*, 2022)]

“Preventive maintenance for these operations takes place at specified intervals” (Rahimi *et al.*, 2022) because not all types of maintenance have the same life cycle. There are components that have more wear than others.

When this maintenance is not done in a preventive way, some malfunctions can occur, from the poor state of the track not being aligned, and even derailment can occur. The objective of daily maintenance is a general inspection until the final check,

that is, to keep the track clean and operational so that the trains can run without causing disturbances. To this end, there are machines that already perform this operation. “stoneblowers, tampers, and Dynamic Track Stabilisation (DTS) machines” (Rahimi *et al.*, 2022).

Corrective maintenance aims at “locating, isolating, and resolving a fault so that failed equipment can be substituted or restored to an operational condition within the tolerances or limits set for in-service operations” (Rahimi *et al.*, 2022).

This maintenance plays a key role in the efficiency of maintenance.

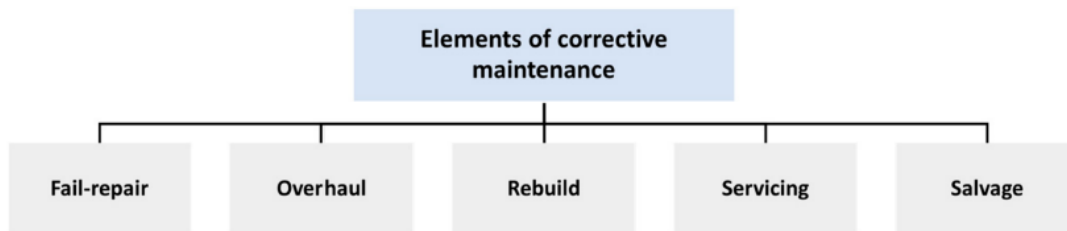


Figure 10 – Elements of corrective maintenance

[Source: (Rahimi *et al.*, 2022)]

Corrective maintenance is very expensive because it requires deep repair / maintenance, requiring the replacement of parts that are degraded and the use of specific machines designed to perform this task. This process involves a lot of specific machinery and people with expertise. “The activities for larger maintenance are almost entirely automated.” (Rahimi *et al.*, 2022)

In Figure 10, several corrective elements of maintenance, the main ones being failure repair and reconstruction. This maintenance in the railway industry is very critical, but at the same time it ensures safety. The tracking system is critical to ensure the safety of the rail system. “Rail vehicles are confined to travel along the railway and an error in train location might result in a dangerous overestimation of braking distance.” (Rahimi *et al.*, 2022)

To be able to do good management in the railway system, it is necessary to have an accurate and reliable estimate of the location of the rolling stock.

There are sensors that have already been applied to the rolling stock to be able to locate them. The sensors that have been applied are divided into two classes: “Elements in the railway environment (infrastructure-based) (Rahimi *et al.*, 2022) are used to locate rolling stock on the track, considering the disadvantages of this sensor the installation and maintenance are very high; “On-board sensors (infrastructure-less)” (Rahimi *et al.*, 2022) “(tachometers, inertial sensors, satellite-based positioning systems, etc.) and infrastructure equipment (balises, track circuits, etc.)” (Otegui *et al.*, 2017)

After several studies that have been done, it is difficult to have an accurate location system due to some scenarios such as mountainous areas, tunnels, and places where it is difficult to catch the transmission network.

There are several types of positioning sensors, which include on-board sensors and Elements in the railway environment (infrastructure-based) that are applied in the railway industry.

In the article, Rahimi *et al.*, 2022, in Table 2, we can see what sensors exist and what the advantages and disadvantages of using the sensors available to the railway industry are.

The sensors allow a lot of information to be collected, and once extracted they must be learned by a Recurrent neural network (RNN) method. This method will allow “RNN, improve sequential localisation of data. Learning algorithms may in the future provide an end-to-end deep learning localisation and mapping system” The combination of sensors should be chosen in a way which optimises coverage of multiple aspects, including availability, reliability, speed of response, cost, and accuracy of the system, besides providing a better on-board measurement system” (Rahimi *et al.*, 2022)

There are also other Fuzzy Analytic (FAHP) methods. This method will “compare the relative importance of the given evaluation criteria and the relative preference of one alternative over another, for each evaluation criteria.” (Gironimo & Grazioso, 2022) Being that “the most adopted approaches for group decision making problems involving a discrete set of alternatives to be compared with respect to different, and often conflicting, evaluation criteria.” (Gironimo & Grazioso, 2022).

Preventive maintenance is critical to the rail industry to ensure that the rolling stock fleet is safely and reliably maintained and managed for degradation and ageing.

2.3 Predictive Maintenance

Predictive maintenance aims to reduce costs to increase the competitiveness of companies. Most of the time, predictive maintenance uses collected data to be able to optimise maintenance interventions and with the help of “decision support tools able to use the data from the field in order to optimise the use of resources, reducing assets’ life cycle costs (LCC)” (Consilvio, *et al.*, 2020). This maintenance will require the cooperation of several assets involving knowledge and skills in several areas involved. This maintenance will require the cooperation of several assets involving knowledge and skills in several areas involved. Predictive maintenance addressed a “topic with two main scopes: diagnostic and prognostic.” (Jimenez *et al.*, 2020)

“The purpose of diagnostics is to detect, isolate and identify a fault which has occurred.” (Xu *et al.*, 2019) and “prognostics can predict a fault before it occurs and estimate the Remaining Useful Life (RUL) of equipment.” (Xu *et al.*, 2019)

Predictive maintenance will allow us to detect anomalies from the detention that can be used to improve, in the prognostic’s methods, address models to predict the condition of the equipment and in the architecture that will allow us to implement methods of detection and prognostics of anomalies in real time “services are coded in mobile agents including fault diagnosis, prognosis, and maintenance planning.” (Wang *et al.*, 2015) Now, there is a huge need to collect, send and process data in large quantities and in real time to be able to schedule maintenance. “In predictive maintenance, all condition measurements are usually collected and transmitted to a centralised server, and then the measurements are processed in a centralised server based on models and algorithms for fault diagnosis, prognosis and maintenance scheduling” (Wang *et al.*, 2015). In Figure 11, we can see how the data will be collected and processed, and later, with the help of artificial intelligence, the planning will be done.

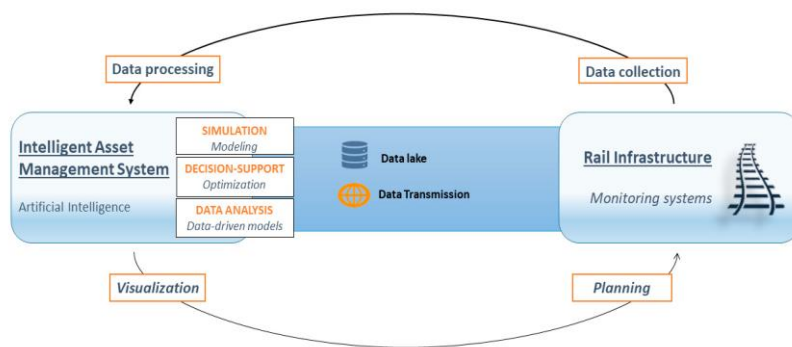


Figure 11 – Decision Support System (DSS) elements and interactions.

[Source: (Consilvio *et al.*, 2015)]

In Figure 12, “these modules elaborate real-time data about track conditions and the conditions of each asset, providing their current and future states on determined degradation”. (Consilvio *et al.*, 2015)

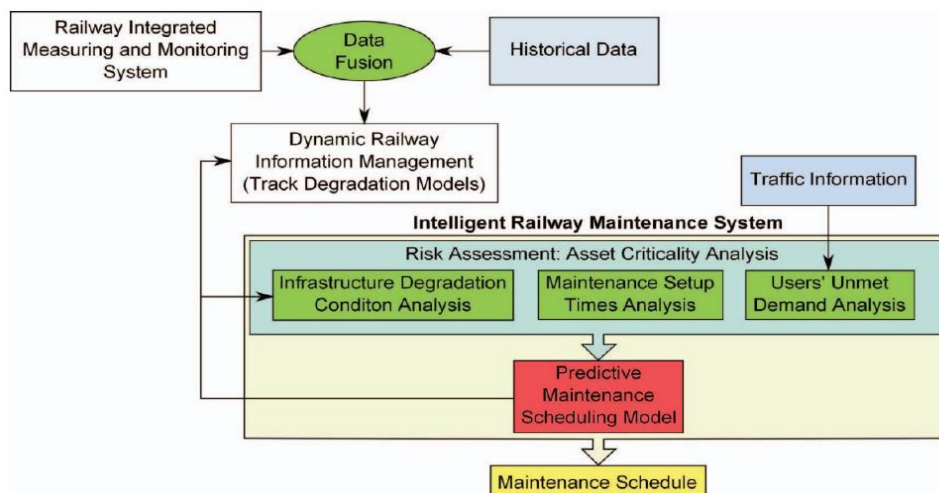


Figure 12 – Modular model architecture

[Source: (Consilvio *et al.*, 2015)]

2.3.1 Railway maintenance

Railway maintenance is typically a large and complex system. Therefore, these tasks need to be scheduled in an active way to improve safety, reduce downtimes, eliminate corrective maintenance jobs, optimise asset/equipment life cycle, and reduce costs (Vithanage *et al.*, 2019).

As technologies evolve, the rail industry is looking to automate the most critical components to monitor data and then evaluate their life cycle. This will allow maintenance to have rolling stock available so as not to affect the service of passengers and goods. In this work, predictive maintenance is addressed and what will be its great importance and its development over the last years.

In recent years, predictive maintenance has been gaining momentum as a key to satisfactorily improving rail services.

In the railway sector, there are already robots implemented but they are limited in performing monitoring or inspection tasks because they still need human intervention. However, there are some examples “are automatic laser scanning of wheels, automated brake shoe monitoring system, automated wayside inspection, teleoperated robots in power lines maintenance and ACEMRail project.” (Vithanage *et al.*, 2018)

Maintenance has mostly resorted to Remaining Useful Life (RUL) of the equipment to be able to develop a real-value, reliable condition monitoring maintenance architecture “use of Artificial Intelligence, Neural Networks, Machine & Deep Learning techniques capable of handling large amounts of data.” (Nappi *et al.*, 2020).

“Predictive maintenance focuses on proactive methods to reduce cost and increase machine uptime.” (van Dinter *et al.*, 2022). Predictive maintenance predicts the life

cycle of the component until it becomes damaged. The life cycle estimate is based on a component's efficiency indicator.

However, maintenance scheduling must be sustainable because all available resources are used in a way that does not damage other assets. Predictive maintenance is often replaced by proactive and intelligent (van Dinter *et al.*, 2022). This method is more difficult to implement. Rolling stock is important to ensure smooth operation of transport, “any failure detains the achievement of their strategic goals of safety, passengers’ and goods’ safety, reliability and velocity of the transportation task provided” (Kalathas *et al.*, 2021).

The railway materials are separated by wagons and by locomotives. The most critical material that must undergo predictive maintenance more often is the locomotive because it is where the engines that have the function of pulling the wagons are located. However, railway transportation must be done with some precautions considering the “including technological features related to the use of mobile devices, more comfort, safe and accurate timetable, creating new challenges to the constructors” (Silva & Mendes, 2020)

In the railway industry, the maintenance of rolling stock is scheduled in various ways by “mileage, by time or by conditioning monitoring. Of these three methods, condition monitoring is the most recent.” (Connor & Piers, 2019) to keep up with the digitisation of the railway.

Maintenance of locomotives must be systematic because parts along the way can deteriorate. The parts that have the most wear should be inspected and, if necessary, replaced in time before causing failure that can “affecting the services it provides” (Oliveira *et al.*, 2019)

The maintenance of the rolling stock is fundamental to guaranteeing “preservation and reliability of the trainsets for the smooth functioning, keeping the principles of the safety of the staff and environmental protection” (Kalathas *et al.*, 2021)

The goal of rolling stock maintenance is to extend the life cycle of components for a long period of time without incurring astronomical repair costs. Therefore, the railway industry has invested in predictive maintenance to protect the rolling stock by complying with maintenance procedures that have become increasingly efficient and thus limit costs and improve passenger and freight service.

Rolling stock is one of the most durable fleets. The railway main strategy “focus tends to be on keeping them in service for as long as possible, to get value out of the considerable initial investment.” (Stoddart, 2018) The new technologies allow predictive maintenance to be done, to reduce operating costs and extend the useful life of the fleet / components. With the data collected in the black box, it was possible to “build up a powerful predictive maintenance program that reduced maintenance costs and extended the life of its fleet by over a decade.” (Stoddart, 2018)

Locomotives that run passenger service cannot run freight service at the same time because this can jeopardise the safety of passengers. SPR being embedded in rolling stock sensors allows “detect anomalous dynamical behaviours that in turn activate pre-specified maintenance countermeasures on the vehicle of interest.” (Nappi *et al.*, 2020)

This tool transmits the most relevant data to a checkpoint “the class of the detected anomaly and the vehicle geopositioning.” (Nappi *et al.*, 2020)

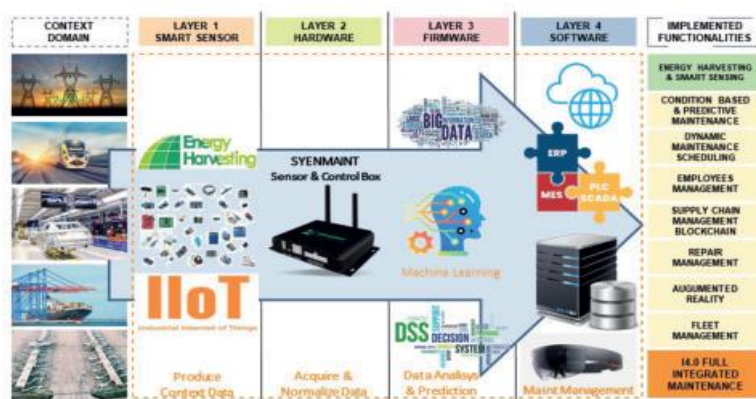


Figure 13 – The Syenmaint Platform Rail architecture

[Source: (Nappi *et al.*, 2020)]

As can be seen in the figure (Figure 13) above, it is distributed over four layers. The innovative tool consists of four distinct layers. In the first layer there will be the collection of data by a set of sensors; in the second layer the Firmware will process the data through exploration and machine learning and artificial intelligence algorithms to estimate Remaining Useful Life (RUL) in the third layer “of the Device Under Test (DUT)” (Nappi *et al.*, 2020). In the last layer, the estimated result of the RUL value is sent to the software where the maintenance process is managed.

With the evolution of technology, there are tools that help collect, store, and analyse all the data received by the sensors that the rolling stock may have available.

Syenmaint Platform Rail (SPR) is an innovative tool that consists of multi-layers and has as its main objective managing predictive maintenance processes of railway systems (Figure13).

2.3.2 Predictive Maintenance Tools

“In the last few years, many works have addressed Predictive Maintenance (PdM) by the use of Machine Learning (ML) and Deep Learning (DL)” (Davari *et al.*, 2021) Now, there is software that receives data that is entered and can predict when a malfunction will occur. To make this possible, you can use open-source software where you can work with it and then build an algorithm that can receive the data and information and make predictions based on the data that has been entered.

“The monitoring and logging of industrial equipment events, like temporal behaviour and fault events anomaly detection in time-series can be obtained from records generated by sensors installed in different parts of an industrial plant.” (Davari *et al.*, 2021)

There are controllers that help monitor the efficiency of the rail infrastructure.

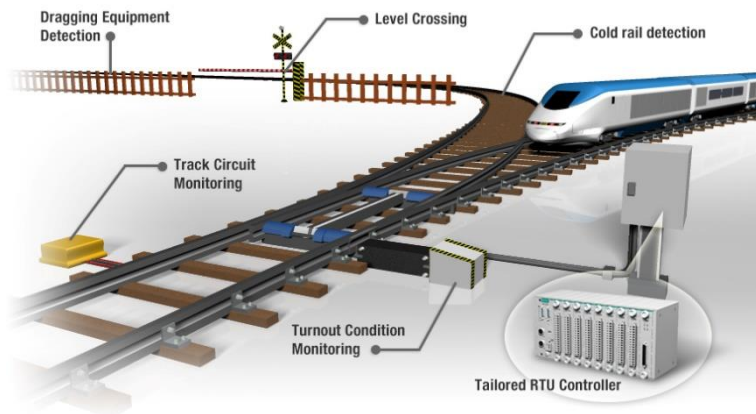


Figure 14 – Conditioning Monitoring

[Source: (SPHINX, 2022)]

In Figure 14, it is possible a system can receive data by “sensors, transducers, and remote terminal units running on different platforms and closed communication protocols, which can make maintenance more challenging and costly.” (SPHINX, 2022)

RTU controllers are already adapted for railway asset monitoring “and offer system integrators a more accurate, open platform field solution to collect large amounts of real-time condition monitoring data” (SPHINX, 2022)

Sensors are implemented to help decrease failures and thus allow the reliability of the system to increase.

In the maintenance area, this type is in great demand because it helps predict the failure of a particular component. This results in a better “optimisation of all processes of a business, in as short a time as possible by making the best decisions.” (Kalathas *et al.*, 2021), as is demonstrated in Figure 15.

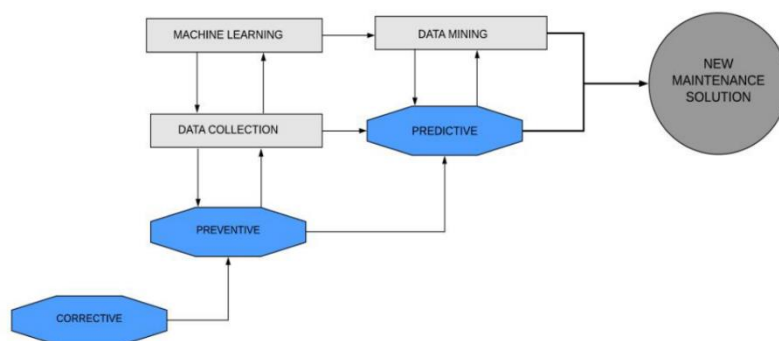


Figure 15 – Integrated maintenance system

[Source: (Katathas *et al.*, 2021)]

With the evolution of technologies, it is possible to have information to be able to make quick and right decisions, guaranteeing the safety of passenger and goods transportation.

In 2004, a team of engineers developed the open-source software KNIME at the Konstanz University of Germany with the goal of “analyse data, with the permission of GNU (General Public License)” (Katathas *et al.*, 2021)

This software allows the user to quickly analyse many tasks such “the processing, conversion, analysis, and the visual presentation of data.” (Katathas *et al.*, 2021)

“Rolling stock maintenance has a considerable impact on train operations, availability, reliability, punctuality and costs.” (Artificial intelligence, 2021)

Rolling stock manufacturers is the replacement of components with higher wear and tear and this requires them to be purchased. So, the rolling stock manufacturers already see a big competitive advantage.

“The punctuality and the safety of trains depend in particular on the availability and reliability of infrastructure (tracks, tunnels, bridges, embankments and cuttings, etc.), which makes predictive maintenance on infrastructure an important issue.” (Artificial intelligence, 2021)

The implementation of “Replacing patrols and periodic manual inspections with more frequent, automated, and standardised inspections is a major objective. This could increase availability, reliability, and safety” (Artificial intelligence, 2021)

Predictive maintenance has increased due to “With growing service demands, rapid deterioration due to extensive usage, and limited maintenance due to budget cuts, the railway infrastructure is in a critical state and requires continuous maintenance.” (Bukhsh *et al.*, 2019)

Then the responsible entities must make decisions to improve the rolling stock and “spend optimal cost and keep the network available” (Bukhsh *et al.*, 2019)

“Maintenance corresponds to the process that deals with equipment or system components to ensure their normal functioning” (Davari *et al.*, 2021).

Railway companies are looking for open-source programs and decision models to make decisions more efficient and effective so as not to hinder rolling stock downtime.

Lately, the area of railway maintenance has turned to “the machine learning techniques to estimate the performance state of an asset, predict the maintenance possible failure modes, and such similar aspects in advance.” (Bukhsh *et al.*, 2019)

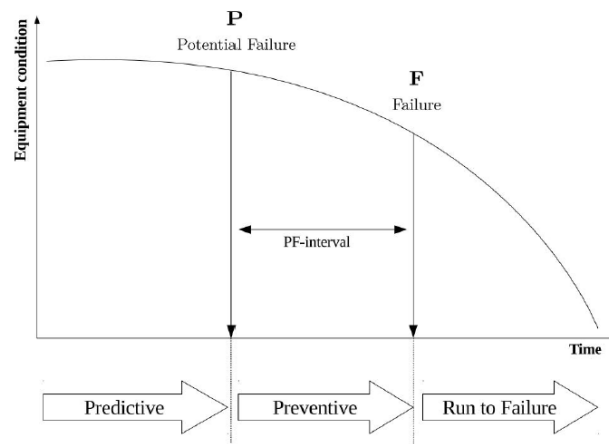


Figure 16 – PF curve

[Source: (Davari *et al.*, 2021)]

Considering that a failure of a component can happen at any time due to several factors. In Figure 16, we can see that predictive maintenance can have a potential failure and be necessary to perform rapid maintenance to “problem before a functional failure occurs.” (Davari *et al.*, 2021)

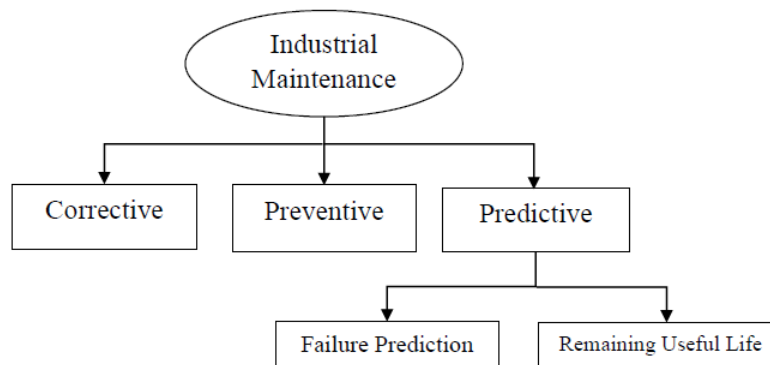


Figure 17 – Maintenance classification

[Source: (Davari *et al.*, 2021)]

Table In Figure 17, industrial maintenance has three types of maintenance. However, predictive maintenance has two fundamental aspects, one that is failure prediction and the other remains useful life (RUL).

Fault prediction aims at “predict the approximate moment where some failure could occur.” (Davari *et al.*, 2021)

That is, this situation will allow no serious damage, “based on the operational history of different components, this strategy can be used to predict failures over time, minimising costs and extending the useful life of the components.” (Davari *et al.*, 2021)

While in the remaining service life, maintenance can use the "use of anomaly detection, diagnostics, and prognostics” (Davari *et al.*, 2021). RUL lets you know how many days are left to repair and replace the component. This prognostic is linked to estimation and “the likelihood of system failure occurrence” (Davari *et al.*, 2021)

There are several methods that help to make component predictions.

The Machine Learning method, Figure 18, was used to predict failures and RUL, its performance is good, but on smaller amounts of data. While the Deep Learning method already allows us to get more data than the previous method, it is more dedicated to the advances in detection technologies and IoT (Internet of Things) technology.

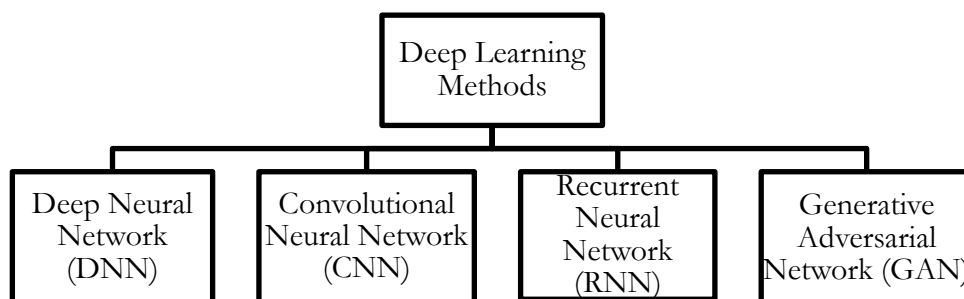


Figure 18 – Types of Deep Learning Methods

[Source: (Davari *et al.*, 2021)]

“A DNN is an ANN with multiple layers (more than two hidden layers) between the input and output layers without looping back, and the flow of the network goes through the layers, calculating the probability of each output.” (Davari *et al.*, 2021)

“A CNN is a DNN that is trained with the backpropagation algorithm and is common in image processing tasks and is widely used for PdM practices.” (Davari *et al.*, 2021)

“In, a method based on LSTM RNN, is proposed to assess bearing performance degradation.” (Davari *et al.*, 2021)

“GAN is an approach to generative modelling using DL, where two NNs compete with each other.” (Davari *et al.*, 2021). The network GAN “offers an alternative approach to maximum estimation techniques” (Alom *et al.*, 2019) “PdM strategy is distinctive and application-dependent, supported by the environment, available data, hardware, among others.” (Davari *et al.*, 2021) “As one of its main features, the proposed strategy allows to predict the RUL specification by resorting to model based arguments.” (Nappi *et al.*, 2020)

Table 1 presents the synthesis of all references used in this report.

Table 1 – References used in this report

Journal	Doi	Quartile	H-Index
Urban Mobility	10.1016/j.urbmob.2023.100047	Q1	103
Environmental Policy & Planning	10.1080/1523908X.2022.2038104	Q1	61
Sustainable Transportation	10.1080/15568318.2021.1999540	Q1	51
Manufacturing Systems	10.1016/j.jmsy.2018.01.006	Q1	80
Manufacturing Systems	10.1016/j.jmsy.2019.11.004	Q1	80
Computers & Industrial Engineering	10.1016/j.cie.2017.11.017	Q1	136
Construction and Building Materials	10.1016/j.conbuildmat.2020.121533	Q1	198
Advances in Engineering Software	10.1016/j.advensoft.2022.103357	Q1	86
Cleaner Logistics and Supply Chain	10.1016/j.clscn.2022.100065	Q1	10
Intelligent Manufacturing	10.1007/s10845-015-1066-0	Q1	85
Computers in Industry	10.1016/j.compind.2013.11.004	Q1	108
Sensors	10.3390/s22114185	Q1	196
IEEE Sensors Journal	10.1109/jsen.2017.2747137	Q1	132
Information and Software Technology	10.1016/j.infsof.2022.107008	Q1	107
Sensors	10.3390/s21175739	Q1	196
Artificial intelligence	https://uic.org/IMG/pdf/artificial_intelligence_case_of_the_railway_sector_state_of	Q1	155

	_play_and_perspectives.pdf		
Sustainability	10.3390/su12062544	Q1	109
Manufacturing Systems	10.1016/j.jmsy.2020.07.008	Q1	80
Transportation Research Part C: Emerging Technologies	10.1016/j.trc.2019.02.001	Q1	147
Intelligent Manufacturing	10.1007/s10845-015-1066-0	Q1	85
Transport Policy	10.1016/j.tranpol.2019.09.002	Q1	113
Research in Transportation Economics	10.1016/j.retrec.2012.03.014	Q1	58
Rail Transport Planning & Management	10.1016/j.jrtpm.2013.10.004	Q1	30
Research in Transportation Economics	10.1016/j.retrec.2012.11.011	Q1	58
Cleaner Production	10.1016/j.jclepro.2020.120926	Q1	268
Case Studies on Transport Policy	10.1016/j.cstp.2022.01.016	Q1	31
Future transportation	10.3390/futuretransp1030028	Q1	136
Utilities Policy	10.1016/j.jup.2009.12.001	Q1	59
Mathematical Problems in Engineering	10.1155/2022/6219489	Q2	68
Asia Europe	10.1007/s10308-023-00664-y	Q2	22
Computers	10.3390/computers8030056	Q2	24
Fusion Engineering and Design	10.1016/j.fusengdes.2022.113161	Q2	84
ITER Framework for RAMI Engineering	10.1080/15361055.2019.1658042	Q2	54
Fusion Engineering and Design	10.1016/j.fusengdes.2015.12.013	Q2	84

Contributions for Portuguese and European Projects to help increasing the Railway Sector

Electronics	10.3390/electronics8030292	Q2	49
The Annals of Regional Science	10.1007/s001680050037	Q2	71
The Annals of Regional Science	10.1007/s001680050037	Q2	30
IFAC-PapersOnLine	10.1016/j.ifacol.2020.11.016	Q3	76
Applied Sciences	10.4236/ojapps.2021.111a003	Q3	35
Procedia Manufacturing	10.1016/j.promfg.2017.07.257	Q2	69
2018 International Conference on Computing, Electronics & Communications Engineering (iCCECE)	10.1109/iccecome.2018.8658788	>Q4	9
2020 25th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)	10.1109/etfa46521.2020.9212183	>Q4	46
2019 IEEE 15th International Conference on Automation Science and Engineering (CASE)	10.1109/coase.2019.8843068	>Q4	30
2019 18th IEEE International Conference On Machine Learning And Applications (ICMLA)	10.1109/icmla.2019.00172	>Q4	--
KnE Engineering	10.18502/keg.v5i6.7039	>Q4	--

2018 International Conference on Computing, Electronics & Communications Engineering (iCCECE)	10.1109/iccecome.2018.8658788	>Q4	8
2015 International Conference on Models and Technologies for Intelligent Transportation Systems (MT- ITS)	10.1109/mtits.2015.7223290	>Q4	11
IFAC- PapersOnLine	10.1016/j.ifacol.2016.11.037	>Q4	86
Transportation Research Procedia	10.1016/j.trpro.2020.02.038	>Q4	59
Transportation Research Procedia	10.1016/j.trpro.2016.05.199	>Q4	59

3 THE STRATEGIC IMPORTANCE OF THE RAILWAY IN PORTUGAL AND IN EUROPE

The railway plays a great role with high strategic importance for both Portugal and Europe. This means of transport is an essential element for the strategic development in several areas, namely in the transport of goods or passengers, regional connections, regional development and tourism, environmental sustainability, and European integration.

In December 1994, the Essen European Council agreed to extend certain points of view, namely, to reaffirm the great importance of trans-European high-speed rail projects.

Vickerman (1997) analyses several progresses of the high-speed railway network, discussing “three main issues in their evaluation: competitiveness, network effects and corridor development.”. According to the author, the Community of European Railways in some countries tried to adopt and improve the existing lines so that the locomotives could reach the speed of over 200km/h. However, these lines were always limited in connections, accessibility of the regions and could not always reach the desired speeds because there were sections with some special conditions. In the meantime, it concluded that “where some new investment was needed and a completely new alignment appeared the most cost-effective solution; this was essentially the rationale for the first French line, the TGV Sud Est” (Vickerman, 1997)

Some European countries, namely Spain and Italy, started by investing in new high-speed lines between the major cities. Due to a large affluence, there was a need to expand to other cities. The TGV entered testing phases in 1981 to 1983 on the French railway, resulting successfully. Countries like Germany, Italy and Spain tried to adopt the same model as France but were not successful due to lack of infrastructure such as bridges and tunnels. The countries mentioned above “are those involving major new construction to enable very high speed (250 km/h or over) operation” (Vickerman, 1997)

The railway plays a fundamental role in the transportation of goods and passengers because it is an efficient means of transportation. This transport allows heavy, bulky loads to be carried quickly and safely, contributing to the competitiveness of the economy. The European network is integrated by the main freight transport corridors with connections to ports, industries, and distribution enters.

Regional connections allow greater integration between rural and urban areas. In other words, it allows easier mobility for people, reduces dependence on road transport, and, in this way, will contribute to territorial cohesion.

The expansion and modernisation of the railway network in Portugal and in Europe will boost regional development, encouraging investment in infrastructure and job creation. Considering that the railway is a means of transportation that attracts more

and more tourists because it allows them to enjoy panoramic landscapes that are not easily reached by other means.

There are several advantages to using the railway, like a decrease in greenhouse gas emissions, greater safety, and sustainability. Railway transportation contributes to a decrease in air pollution, noise, and congestion on the roads. Europe has been investing more and more in electric locomotives and thus being less dependent on fossil fuel.

The European Union is increasingly betting on the European High Speed Rail Network. The EU's goal is to connect the main European cities and thus allow greater mobility and ease of travel between countries, thus helping the promotion of economic cooperation, tourism, and exchange between countries.

The railway is an extremely important means of transportation for contributing to economic development, regional and environmental sustainability. However, continuous investment in the expansion and modernisation of the railway network is needed to ensure an efficient and sustainable system in the future.

We can conclude that high speed rail has been increasing the concentration of economic activity in large urban areas in Europe and the development will be positive for regions affected by new rail developments.

Vickerman (1997) identified some problems associated with the study on the impact of high-speed rail development. Namely, casualty refers to improvements in accessibility and reduction in transport costs and improvements in competitiveness, investments source of growth, efficiency in infrastructure improve local infrastructure and access to international and inter-regional network.

3.1 Railway Policy in Europe

Rail policies vary from country to country and are often influenced by EU policy and regulations. In recent years, the EU together with the member states, has contributed to creating an integrated rail network in a more efficient way and with the aim of promoting sustainability, mobility, and interoperability.

Bearing in mind that there are several fundamental aspects to a good rail policy in Europe.

In 2002, the European Commission launched its policy to liberalise the railways. From that year onwards, some European countries began to free up the rail market to introduce several operators and, at the same time, encourage competition. This has resulted in greater efficiency and more variety for passengers. In the “European railways: Liberalisation and productive efficiency” the authors Lerida-Navarro, Nombela & Tranchez-Martin (2019) carried out a case study where they were able to draw some conclusions. One of the conclusions of the case study is the liberalisation of the railway, I.e. the market is still somewhat limited. The authors

also refer to the interests of governments in this area. “Our findings indicate that, globally, there is a weak positive link between EU rail liberalisation and higher efficiency, and that effective competition is the most relevant factor to achieve efficiency gains”; in another article, “The conclusions are that the actual level of market opening is still limited and, only in some cases, is the liberalisation improving. Entry into the industry has not yet developed its full potential. An issue emerging in this research is the opposing attitude of incumbent railways against liberalisation and the role of governments in backing this behaviour”. (Beria, P., et al., 2012)

The separation of infrastructure management and railway operations “sets new challenges to infrastructure managers: infrastructure performance becomes more and more visible as it often constitutes a metric for penalties/incentives included in contracts binding infrastructure managers to train operators.” (Putallaz & Rivier, 2004)

The high-speed rail network is a major issue that has been discussed since the end of the 20th century. Some European countries, such as France, Germany, Spain, and Italy have invested significantly in high-speed rail. The aim of high-speed rail is to provide faster and more environmentally friendly alternatives to local travel on certain routes. However, Vickerman (1997) “identifies the lack of genuine network development which has taken place, criticises the failure to provide a more integrated framework between modes and questions the assumptions of improved regional development and cohesion which are claimed for the policy. Instead, there is evidence of increasing concentration in the main metropolitan centres served by the emerging network.”.

Interoperability is one of the biggest challenges for Europe due to the huge diversity of railway systems and standards in the member states. As “Europe is driven by the need to service a market that is open within and across industrial sectors and national boundaries” (Smith *et al.*, 2012).

European countries must adopt a single ERTMS system (European Rail Traffic Management System) to make travel easier and cross-border between member states. However, the EU has established common safety standards and regulations to ensure maximum safety for passengers “railway systems facilitate not only interoperability but also enhancement of safety, capacity and efficiency” (Smith *et al.*, 2012) of the rail network.

The article “Rail vehicles, environment, safety and security” (Matsika *et al.*, 2013) addresses some issues that are important and fundamental to our daily lives “on safety and security of rail vehicles, standards for safety and measures against terrorist attacks”. (Matsika *et al.*, 2013)

In the area of railway, investments are extremely high, which is why European countries have the possibility to resort to financing. The EU allocates funds for the development and maintenance of rail infrastructure. These investments aim to modernise existing rail networks, build new sidings, and improve passenger comfort. Now, the railways are seeking sustainability by prioritising the reduction of carbon

emissions. Hence the electrification of railway lines, using renewable energy sources and promoting greener transportation compared to rail or air travel.

According to Dedík *et al.* (2020), “therefore the main long-term goal of EU transport policy in passenger transport is to eliminate individual car transport and to adopt measures for public passenger transport development and to achieve railway transport becoming a key mode”; but, these authors suggest that “should improve railway transport planning and organising and finally to increase efficiency, attractiveness, better image of public the travelling.” (Dedík *et al.*, 2020).

We should also bear in mind that there are Public-Private Partnerships (PPPs) that aim to finance, contribute to the construction and implementation of rail projects. These partnerships often help leverage private sector expertise and funding for infrastructure development.

With the evolution of technology, digitisation is becoming easier and easier. According to Noussan & Tagliapietra (2020), “Digital technologies have the potential to make the transport system more connected, intelligent, efficient, reliable and sustainable.”

Digitisation will help the railway improve operations, safety, and passenger comfort. Digitisation has also helped to implement advanced systems from signalling to (online) ticketing and real-time passenger information. The author points to two scenarios for “responsible” digitisation, in the direction of sustainable mobility, against a “selfish” digitisation, where the final users maximise their utility.” (Noussan & Tagliapietra, 2020)

The EU has also been obliged to implement various regulations on passenger rights and accessibility to protect the end consumer. In general, these regulations address issues related to delays (compensation) and assistance for passengers with reduced mobility “interest is also visible in The European Union transport policy, aiming at securing rights of passengers with reduced mobility.” (Zajac, 2016)

3.2 Railway Policy in Portugal

In recent years, CP and REFER have focused on modernising and improving infrastructure, and have sought ways to increase the efficiency, reliability, and sustainability of the railway system. To make this possible, there were two plans to contribute to these interventions: Infrastructures de Portugal "Ferrovia 2020", 2016 and the Portuguese Republic's National Investment Program 2030. These “interventions are also intended to contribute to the improvement of the rail infrastructure integration in the surrounding territory, thus enhancing positive externalities and mitigating negative ones, as well as improving mobility conditions (travel times). Bridges, tunnels, viaducts and buildings rehabilitation, slope stabilisation, rehabilitation of railway tracks and the improvement of

telecommunication systems are some examples of proximity interventions.” (Gonçalves *et al.*, 2022)

CP has been making new investments, particularly in infrastructure and locomotive maintenance, to increase train speeds. Investments could include modernising the line, electronic signalling, improving international connections and increasing the competitiveness of rail transport.

Portugal has plans to develop a new high-speed line to shorten travel times and connect the main cities. There is now a project under study about the possibility of creating a Lisbon - Porto high-speed rail line, which is included in the Programa Nacional de Investimentos 2030 (PNI 2030).

In Portugal, there are some intermodal interconnections for both freight and passenger transport. In freight transport there are some infrastructures that can provide " services such as temporary storage or intermediate buffer, and even pre-delivery inspection or enhancement work on the goods being transported" (Delgado *et al.*, 2021). In the case of intermodal passenger connections, they are unable to meet the needs of the population. However, there is a need to simplify the purchase of tickets by making them interoperable so that they can take advantage of other means of public transport, namely buses and the metro. The aim is to have a single ticket that can be used on various forms of public transport from departure to destination. By this way, passengers don't have to worry about buying tickets to travel.

In recent years, the Portuguese government has been encouraging people to use more public transport, particularly rail. CP and REFER have been working hard to restore locomotives and carriages, so that they can respond to the shortage of rolling stock that was already being felt. IP and CP are constantly seeking sustainability to guarantee passengers that they are travelling on an environmentally friendly means of transport. According to Santos *et al.* (2010), “rail transport can play an important role, both in suburban and long-distance transport, at high speed. Besides, it is a high-capacity transport mode which produces lower emissions when compared with other means of transport.”

The lines and locomotives allow Portugal to be part of the international rail network with its neighbour, Spain, and in this way, it is allowed to make international journeys.

Now, CP has been recovering old locomotives and carriages since the end of the 20th century to promote tourism. These trips allow visitors to enjoy the old locomotives and can explore the country's natural landscapes and cultural heritage. Trips can be made on the Historic Train in a 0186 steam locomotive built in 1925 on the Douro Line and a historic Alstom 9004 Diesel locomotive, both of which are 20th century locomotives.

3.3 Railway Research Centre

A railway research entrance is an organisation that focuses on advancing knowledge, technology, and innovation. The aim of the enters is to carry out research and develop new technologies to collaborate with industry, universities, and the government to meet the challenges and opportunities that arise over the years. Research enters focus on various areas of research, which can include infrastructure, operations, security, stability and monitoring the evolution of new technologies. Worldwide, there are several well-known research enters.

In the UK¹, they have railway research enter that provides support to professionals and commercial services in research and education activities. In this way, they have a partnership with industry, universities, and the government. This application focuses on training and technology. As stated on the institution's website, they welcome any person or company interested in railway research, education, or innovation. Birmingham Centre for Rail Research and Education (BCRE) is one of the largest rail research projects developed on the European continent.

In Japan, there is also research enter, the Railway Technical Research Institute (RTRI)², which aims to carry out research and development in technology and occupational science, investigate technologies, prepare draft technology standards, collect statistical documents in the field of railways, diagnose technologies and draw up plans and standardise railway standards. All these activities are financed by contributions from companies and government subsidies and contractual income from private company.

In the USA, Transportation Technology Centre, Inc. (TTCI)³, provides research and development, testing, engineering, inspections, technical support and, in this way, increases safety, reliability and efficiency in the rail industry. This research centre tests components to optimise rail vehicles, simulates bearing fatigue, uses Phased array ultrasonic testing technology for inspecting rails, supports the industry's shift to remote control systems, Web-based training for railway employees, consulting services for passenger rail, railcar testing, and detection systems for defective wheel bearings. This centre is aimed at all freight and passenger railways.

At the heart of Europe there is an organisation that has an innovation and research department to promote the development of research projects. The research entrance

¹ University Of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom, <https://www.birmingham.ac.uk/research/railway/about-us/about-us.aspx> (Consulted in 03/09/2023)

² Railway Technical Research Institute - <https://www.rtri.or.jp/eng/rtri/overview.html> (Consulted in 09/09/2023)

³ Transportation Technology Center, Inc., <https://www.railway-technology.com/contractors/training/transportation-technology-centre-inc/> (Consulted in 03/09/2023)

is in France's Union Internationale des Chemins de Fer (UIC). This enter also promotes cooperation between railways around the world.

In Australia there are two research enters. The Institute of Railway Technology (IRT)⁴ is research enter within Monash University. And the Rail and Transport Strategy Centre (RTSC) is more focused on developing strategies to increase efficiency, safety, and sustainability. Meanwhile, the research centre (IRT) conducts research together with industry with the aim of increasing technologies and operations in the railway area.

In Sweden, there is research enter that focuses on the development of operation and maintenance. The Lulea Railway Research Centre (JVTC)⁵ is located in Lulea, Sweden.

This enter aims to research and develop cutting-edge technology and innovation. Its development covers areas such as advanced railway technology, infrastructure, sustainability, railway safety, railway connections and the development of railway equipment.

Advances in technology have made it possible to create more efficient systems, such as energy management systems. It has also carried out studies to improve maintenance in the railroad sector, focusing on RAMS4 (Reliability, Availability, Maintainability, Sustainability, Safety, Security and Supportability), LCC (Life Cycle Cost), risk, maintenance limits, eMaintenance and the development of maintenance strategies. Considering the modernisation of infrastructure such as stations and signalling systems. In sustainability, it contributes to the development of lighter and more resistant materials to reduce carbon emissions. The research enter has been looking for ways to integrate rail systems with existing systems, such as land, air and sea transport.

By maintaining a continuous effort, Sweden will improve and expand the railway system, making it more efficient and sustainable. All research plays a key role in innovation and development in the field of rail.

In general, all companies collaborate with universities and industry to guarantee research, develop technologies, and contribute to the development of the railway sector.

Portugal has already created railway research enter (CCF), which is located in Porto and aims to develop research, infrastructure improvements, research and development in technology, research to ensure sustainable efficiency, study to invest in a high-speed line, apply and integrate new technologies in Railway 4.0, investigate safety and security and study political structures and planning.

⁴ University Monash – Monash Institute Of Railway Technology <https://www.monash.edu/irt/about> (Consulted in 03/09/2023)

⁵ <https://www.ltu.se/centres/jvtc?l=en> (Consulted in 05/09/2023)

4 THE LULEÅ UNIVERSITY RESEARCH IN RAILWAY SECTOR

The research centre at the University of Luleå is particularly focused on the railway sector. It is essential to highlight how a research centre can contribute to the advancement and implementation of technology. Luleå University is known for its excellence in research and innovation in the areas of engineering and technology, which can bring enormous development with advanced maintenance resources.

The railway sector faces many significant challenges related to the maintenance of rolling stock. Remote and predictive maintenance has emerged as a solution that predicts failures before they occur, and this makes it possible to improve the safety and reliability of services. Luleå University's research centre plays a key role in researching and developing technologies for this maintenance. The research centre collaborates with other railway companies, which will make it possible to successfully implement maintenance systems. These partnerships facilitate the exchange of knowledge, and the development of technologies and testing in real scenarios. As Luleå University is an expert in technology and engineering, it can lead the way in transforming railway maintenance and thus promote a safer, more efficient, and sustainable means of transport.

Every year the Luleå University Railway Research Centre releases its annual report on research and innovation development in the railway sector.

Throughout this report, important topics in the field of railways are covered, starting with research, the development of innovation activities and strategic research programmes. Subjects in Condition-Based Maintenance (CBM) and planning are also highlighted. In addition, the research centre already has projects underway on asset management in the railway and the development of Artificial Intelligence for the railway, thus creating the ePilot project.

In addition, the Luleå Railway Research Centre (JVTC) centre has already taken part in numerous research projects at both European and international level, not forgetting the publications made by researchers together with partners and sponsors.

In 1998, the Järnvägstekniskt centrum (JVTC) was built as a research and innovation centre taking a distinctive approach to tackling the challenges facing railway operations and maintenance engineers. The main aim of the research centre is to involve researchers in industries that are interested or have the same interests in maintenance operations, to create a more robust and reliable railway system. The research centre's deputy director, Verónica Jägare, mentions several strategies, including the development of methods, models, methodologies, and technologies to make rail transport more competitive and more sustainable.

Researchers at the JVTC have formed circles with other researchers who have the same interests in the area. However, this centre has been looking for innovative solutions to increase the effectiveness and efficiency of operations and maintenance of railway systems.

In addition, the research centre, JVTC, has sought to develop other competences more focused on the areas of reliability, availability, maintenance, and safety (RAMS), as well as condition-based maintenance (CBM). Over the years, the research centre has managed to secure funding to develop and establish projects such as AI Factory and ePilot.

In 2022, the research centre had 16 full members who are represented in different segments in the railway field and funded by the railway industry.

Figure 19 shows the working areas of the research centre set up by Luleå University of Technology (LTU) in different research areas. All the researchers are connected to a network where they exchange information about the railway and develop projects that are of the same interest to the researchers.

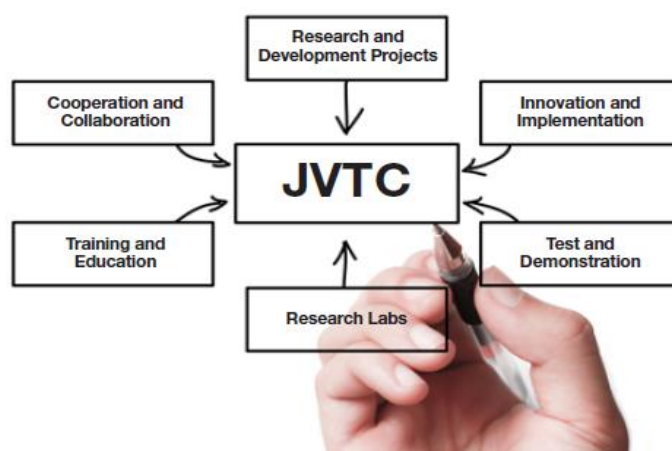


Figure 19 – The research centre

Source: JVTC annual report 2022

Over the last 25 years of research and innovation, it can be concluded that this research centre has made good progress. The JVTC began researching heavy transport in cold climates in the 1990s, and in the next stage dedicated itself to researching sustainable infrastructure, with the aim of being able to increase the load and speed of locomotives on railway bridges.

After carrying out this research, the research centre concluded that they needed to improve existing methods of classification, measuring the state of infrastructure, and repair operations.

Based on the developments mentioned above, the JVTC centre needed to create a research station with equipment to simulate the movement of trains. The research centre therefore acquired measuring equipment, namely an accelerate. The purpose of this equipment is to measure the vibration of the rails when a locomotive pass. This data is then collected by an eMaintenance LAB laboratory that was created and developed by the university itself.

From 2013 to 2022, the JVTC was obliged to increase its laboratory capacity due to the high number of research projects and innovations. The research centre and its

partner Trafikverket share common interests in the field of railways. As a result, a pilot project "ePilot" was developed and collaborated on in partnership.

According to the annual magazine, the focus of the Strategic Research and Innovation Programmes is to "ensure the availability, capacity, safety and sustainability of the rail network and rolling stock through effective operations and maintenance" to build optimised technologies and solutions for carrying out maintenance.

The research centre has created a synthesised and parameterised table to help researchers solve the next challenges in the railway industry. In Table 2 we can analyse the main themes that are addressed throughout this annual magazine.

Table 2 – Strategic research and innovation programs

Source: JVTC annual report 2022

Strategic research and innovation programs:

Condition monitoring and CBM	RAM4S	Asset management, Risk and Human Factors	Industrial AI / eMaintenance
<ul style="list-style-type: none"> ■ Context based diagnostics and prognostics ■ Modeling of track geometry ■ Wear and friction control ■ Grinding optimization ■ Sensor technologies ■ Demonstrator for testing on rail ■ On-board condition monitoring ■ Prognostics and health management 	<ul style="list-style-type: none"> ■ Dependability ■ LCC ■ Risk analysis and modeling ■ Maintenance optimization and modeling ■ Design for reliability and maintainability ■ Remaining useful life ■ RAMS/LCC Risk optimization 	<ul style="list-style-type: none"> ■ Asset maintenance organization and strategy ■ Asset Performance Measurements and management ■ Maintenance contracts ■ Models for evaluating and implementing new knowledge ■ Human, Technology and Organization (HTO) ■ Human Factors /Ergonomics for risk management ■ Life extension of assets 	<ul style="list-style-type: none"> ■ Big Data analytics ■ Cloud-computing and data mining ■ Information logistics ■ Data integration, fusion and processing ■ Data visualization ■ Context adaptation ■ AI Factory ■ Digital twin ■ Cyber security ■ Augmented and virtual reality

JVTC has already defined a research and innovation framework based on the new era of Digitisation or Railway 4.0.

RAM4S is characterised by (Reliability, Availability, Maintenance and Safety, including Carrying Capacity, Safety and Sustainability). However, the results of RAM4S could become critical to the competitiveness and economic viability of the railway system. The research centre, JVTC, is one of the main players in the analysis of RAMS in the railway system.

4.1 Asset Management, Risks and Human Factors Research Programme

Asset management of railway infrastructures is increasingly gaining acceptance around the world as an environmentally friendly and sustainable means of transport. However, there are several factors we must consider, such as increasing the capacity, reliability, and availability of railway infrastructure. The aim is to guarantee tools, devices, equipment, machines, and the environment that directly or indirectly promote human safety, well-being, and performance.

The Luleå research centre has been developing an Industrial AI / eMaintenance Research Programme (eMRP) that does not prevent the railway industry from achieving operational excellence, through several key factors such as: conducting multidisciplinary applied research in maintenance analysis; developing and providing an appropriate educational platform in eMaintenance; establishing an innovation process that supports the implementation of research results in real-world applications.

However, we cannot forget some important topics for the railway, such as Industrial Artificial Intelligence, Machine Learning and service-oriented approaches, digitisation, IoT and IIoT, Big Data Analytic, cloud computing, distributed computing, crowd-sourcing, information logistics, data integration, data fusion, data processing, data visualisation and context adaptation. We can see the schema in Figure 20.

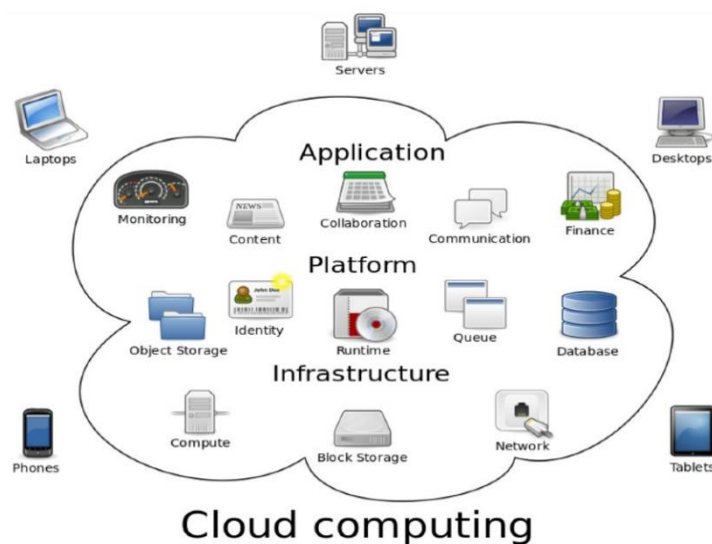


Figure 20 – Cloud Computing

Source: [<https://www.mdpi.com/2224-2708/11/4/84>,
Accessed in 2023.10.26]

According to the head of the area of excellence, Uday Kumar, "Operation and maintenance" must implement research, maintenance, and innovation to strengthen the railway and rolling stock infrastructures.

Reliability is one of the basic needs for sustainability, robustness, punctuality, and capacity in the railway system. The railway system consists of functional safety, maintenance, and maintenance safety. Research into operation and maintenance technology focuses on optimising the reliability of a system during its lifetime.

4.2 Railway 4.0

With the evolution of new technologies, the railway system can make good use of the most advanced technologies available on the market, and thus aim to innovate and implement and then present the results gathered on a day-to-day basis.

The JVTC and the Operation and Maintenance Engineering Division of the Luleå University of Technology have developed a structure dedicated to "Railway 4.0" with a "Testbed Railway" database, as can be seen in Figure 21.

Testbed Railway aims to establish digitised railway infrastructures and enable better decision-making through Big Data analysis. These tools offer the ability to collect condition data, failure data and reliability data relating to assets.

Railway 4.0 aims to offer the industry opportunities to collaborate, cooperate, test, and implement results and then develop in the railway areas in a digitised and eMaintenance way. In this way, it contributes to greater robustness and capacity in rail transport systems, as well as greater efficiency in operating and maintenance costs. The Railway Testbed is a platform more geared towards transparent and replicable testing of scientific theories, computational tools (Big Data) and new technologies. The aim is to strengthen the adaptability and competitiveness of the railway industry, to develop and provide data for a database, resulting in research and innovation in the railway industry both nationally and internationally.

This technology will enable integration for measuring, monitoring, and armouring data. JVTC researchers are focused on developing models, tools, and maintenance methodologies to facilitate future decisions. These decisions are made in a correct and timely manner, thus guaranteeing effective and efficient solutions. The monitored data is used for maintenance diagnostics, maintenance prognostics and maintenance prescriptive.

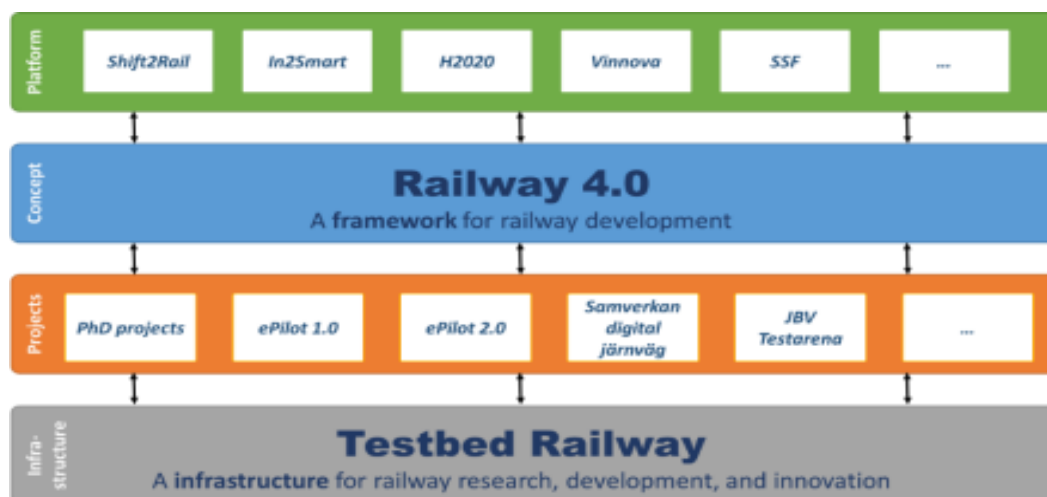


Figure 21 – Railway 4.0

Source: [<https://www.ltu.se/centres/jvtc/Swedish-Railway-Research-and-Demonstration-Corridor/Testbadd-Jarnvag-och-Jarnvag-4-0-1.155497?l=en>, Accessed in 2023.10.26]

The research centre has an eMaintenance LAB, a research and education platform for making better maintenance decisions through digitisation. This lab aims to offer various services, for example Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS). These types of services can be easily adapted to different contexts, industries, and applications. Now, eMaintenance offers technologies, methodologies, and approaches such as Artificial Intelligence, Machine Learning, Big Data, Cloud computing, Edge computing and cyber security. Bearing in mind that this laboratory has already supported some research projects and continues to do so. This makes it possible to continue with new innovations in the fields of aviation, mining, railways, energy, and processes.

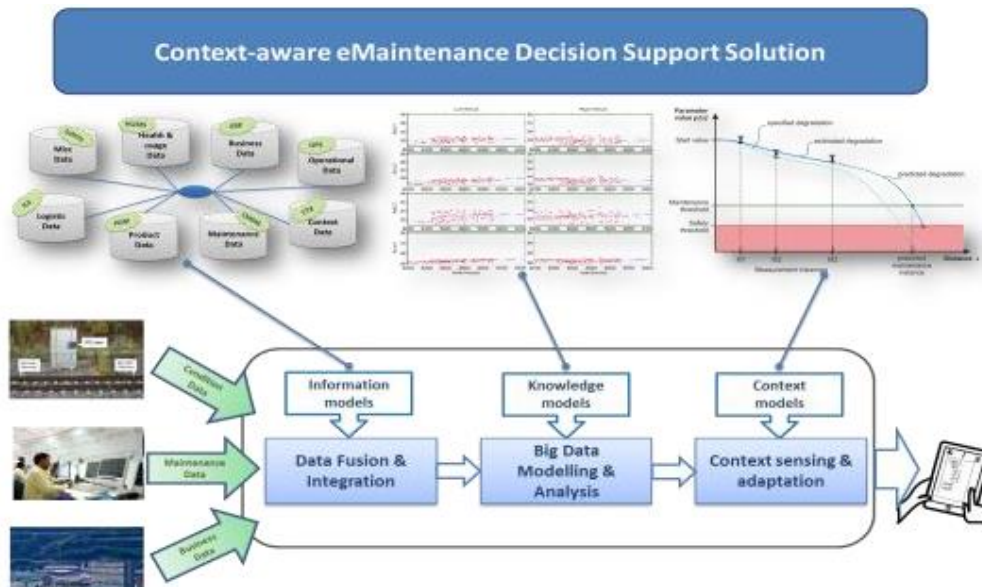


Figure 22 – eMaintenance solution for Maintenance Analytics

Source: [<https://doi.org/10.1016/j.ifacol.2016.11.037>]

According to Karim *et al.* (2016), Maintenance Analytic is made up of four interconnected phases: Descriptive Maintenance Analysis; Diagnostic Maintenance Analysis; Predictive Maintenance Analysis and Prescriptive Maintenance Analysis.

In Descriptive Maintenance Analysis, the aim is to answer, "What happened?". In this phase, access to data is fundamental to understanding the relationship between events and states during analysis. In the next phase, Maintenance Diagnostic Analysis, the aim is to answer, "Why did something happen?". In this phase it is necessary to have all the reliability data available; in addition to the data that was made available in the previous phase. The next phase, Predictive Maintenance Analysis, aims to answer, "What will happen in the future?" This stage requires the availability of reliability and maintenance data, which goes beyond the data from the previous phase to predict future failures. The fourth and final phase aims to answer, "What needs to be done?". In addition to predicting future failures, it is necessary to provide resource data.

With this maintenance analysis, the provision of logistical information is essential. Figure 22 shows that eMaintenance aims "to support maintenance decision-making". (Karim *et al.*, 2016)

According to Karim *et al.* (2016), "However, eMaintenance implements a wide range of tools, technologies and methodologies aimed at maintenance decision-making, including analyses."

4.3 Condition Monitoring and (CBM) Research Programme

CBM maintenance is a process of systematically collecting data on the condition of components, I.e. Based on the CBM decision, maintenance is based on degradation rates and useful time so that corrective maintenance can be avoided. Bearing in mind that maintenance costs can be one of the main factors in maintenance decisions.

The CBM Laboratory is dedicated to checking the condition of railway and mechanical machinery, including gears, bearings, etc. With the advance of technology, the laboratory has made an investment which has enabled it to upgrade the CBMLAB, which has a state-of-the-art Bombardier machine for digitising and adapting intelligent algorithms for the future of the railway.

Condition-Based Maintenance (CBM) is a strategy designed to monitor the actual condition of an asset and thus decide what maintenance should be carried out. This maintenance should only be carried out when the indicators under study reveal a decline in performance or imminent failure.

In the railway sector, there are various condition monitoring and inspections, including vibration measurements (rolling stock passing on the line), temperature measurements, sound, and magnetic fields. After checking the diagnosis and prognosis, the data is analysed, and then processed. Diagnostic solutions are more closely linked to defect detection and root cause analysis. Considering the prediction of the useful life of the part (EOL). To know the useful life of a component, there are models that can help predict degradation. However, these prediction models are being developed to include a machine learning and AI approach in combination with physical models.

The final stage of the CBM process consists of an optimisation phase where different scenarios will be evaluated based on the simulations that have been carried out and then made available as a function of the assets in combination with risk and Life Cycle Profit (LCP) analysis.

4.4 Increased management of railway assets

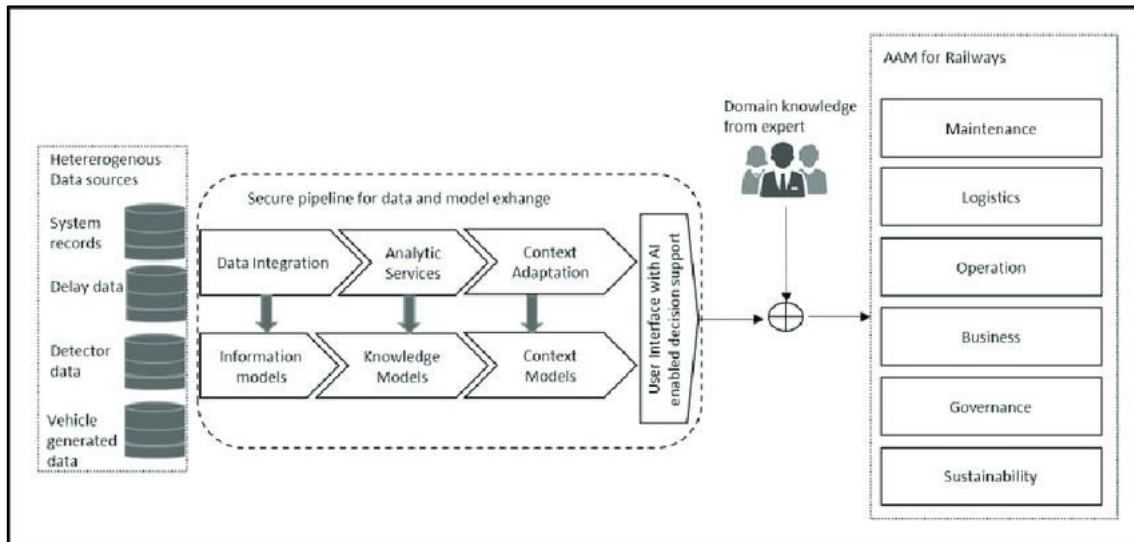


Figure 23 – The proposed end-to-end AAM concept for railways

Source:

[https://www.researchgate.net/publication/354554200_Augmented_asset_management_in_railways_-_Issues_and_challenges_in_rolling_stock?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QiLCJwYWdlIjoiX2RpcmVjdCJ9fQ, Accessed in 2023.10.26]

Augmented Asset Management (AAM) is a set of processes that integrates asset-related data from multiple heterogeneous sources and transforms it into information, knowledge, and models. In Figure 23, help us understand the AAM procedure. As a first step, the AAM process receives, stores and pre-processes asset-related data.

It then generates knowledge models based on the information collected, and from this data it is possible to identify hidden patterns and relationships. This is followed by predictions and suggestions based on the patterns and relationships observed. With all this information collected and revealed to the experts, it will be revealed to the domain, such as operation, maintenance, life cycle cost, logistics, business, governance, sustainability to increase asset management decisions.

With the increase of asset management, there is a need for rolling stock management that is structured into three categories: organisational; technological; and economic. Asset management encompasses maintenance, logistics, operations, business, governance, and sustainability, all of which are not independent of each other.

Metaverso belongs to the Meta company and has been used for social interaction and can be used in the railway industry to improve maintenance activities. The introduction of Metaverso for Asset Management will make it possible to improve operation and maintenance processes on railways using AI, digitisation, and XR technologies. In the inspection process phase, Metaverso will facilitate decision-making in the railway industry's operation and maintenance. Some virtual railway

assets (wheels and rails) were used in Metaverso to show how these assets can be inspected remotely. It can be concluded that Metaverso has come to help improve the inspection process, which will have a very positive impact on decision-making processes in the railway sector. In this way, Metaverso will be a great help to researchers and to students in the field of education.

With climate change, it is necessary to create a climate-resilient infrastructure. Infrastructures that are resilient to climate change are distinguished in their utilisation, and adaptation from the planning, design, construction, and maintenance of the life cycle of infrastructures to anticipate, prepare for and adapt to changing climatic conditions.

To improve the reliability of services and increase the useful life of assets so, as to guarantee a return on assets, several factors are needed: "Management measures, such as changes to maintenance planning; adaptive management to reduce future uncertainty about the reliability, availability, maintainability and safety measures of assets; and structural measures, such as updating current standards relating to snow loads in the Nordic countries." (Annual Review 2022 - Climate Resilient Infrastructure - Towards a more reliable and sustainable future)

Individual structures, such as bridges or railway lines, are not enough to ensure that the system remains functional and resilient against climate change. According to Amir Gamabaki, project leader, Climate Resilient Infrastructure, says that "to meet these challenges, measures to increase resilience at the system level must be integrated into a strategic approach to infrastructure network planning that considers both the direct and indirect impacts of climate change and climate variability".

4.5 Project 1 – SIMTRACK

The SIMTRACK project involves several researchers: Alireza Ahmadi (PL), Arne Nissen (PL Trafikverket), Adithya Thaduri, Iman Soleimanmeigouni, Hamid Khajei. This project will facilitate the simulation and development of tools, methodologies and techniques for optimising track planning, scheduling and maintenance. These results will make it possible to increase safety, maximise capacity utilisation, and thus result in an efficient and economical maintenance programme. Bearing in mind that one of the main prerequisites for predicting faults in track geometry is processing data in such a way as to maximise position errors. In this project, they use a database with a record of all maintenance work, the level of degradation and the frequency of rolling stock passing over the tracks to obtain a track degradation rate. They are now able to use the Artificial Neural Network (ANN) model to forecast the variation in degradation rates.

According to the project leader, Alireza Ahmadi, the ultimate goal is to provide decision support to minimise total maintenance costs while keeping the tracks at an acceptable level.

4.6 Project 2 – Digiswitch

Another project, Digiswitch, aims to increase transport capacity over time and indirectly reduce the environmental impact and operational disruption of rail interruptions, thereby increasing the punctuality of rail traffic. With the development of new knowledge and skills comes a real-life traffic aid that should be able to utilise IoT, AI and intelligent algorithms with pattern recognition and provide continuous information on its changing status. This will enable maintenance to be planned and carried out in the best possible way to increase the availability of switches and thus reduce disruption to railway traffic.

The Digiswitch project involves several researchers, Jan Lundberg (PL), Taoufik Najeh and Veronica Jagare, and is sponsored by Bombardier, the Swedish Transport Administration and Infranord. The leader of the Digiswitch project, Jan Lundberg, indicates the status and results of this project: Squats, Sleepers, Crossing, Middle rail, Switch blade, Support rail, Wheel plates, Towed switch, Compaction error and the AI demonstrator.

With the evolution of technologies, digitisation, and the implementation of AI in the rail sector depend heavily on the availability and accessibility of data for a geographically distributed system. AIF/R is a set of cloud-based intelligent data services aimed at accelerating the digitisation of the railway sector. These AIF/R services make it possible to provide capabilities such as the acquisition, integration,

transformation, and processing of data related to rail transport at terminals. AIF/R is built on storage and computing services.

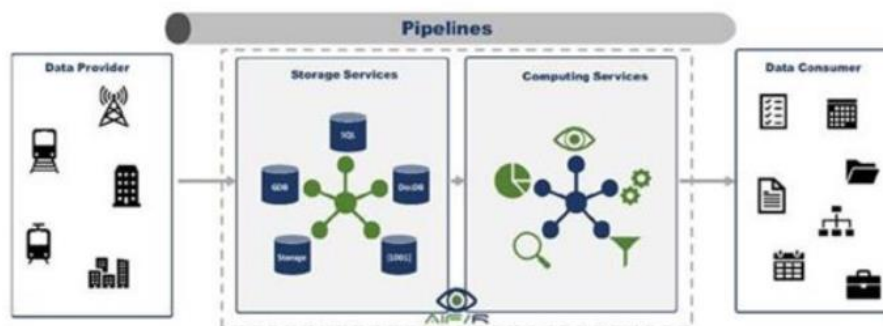


Figure 24 – AIF/R conceptual model

Source: [<https://emaintenancelab.com/ai-factory/>, Accessed in 2023.10.27]

AIF/R provides digital pipelines between supplying data and consuming data, as shown in Figure 24. Each pipeline represents a set of activities that will be extracted, transferred, loaded, and processed in a data set between the supplier and the consumer. Bearing in mind that the AIF/R pipelines can be configurable, for example, in communication, storage and processing, this allows for adaptability in the context and meets user requirements.

4.7 Project 3 - ePilot

The ePilot project is an innovation platform for creating innovations in the railway ecosystem, incorporating eMaintenance, Industrial AI and Testbed Railway with the aim of creating and improving conditions for good research in the railway sector.

This platform aims to collaborate in the development of solutions for decision-making in the maintenance area. These solutions most often result in increased punctuality and minimisation of interruptions in the railway system, with the aim of guaranteeing better accessibility and a higher quality of efficient and rapid maintenance.

This project was created and developed by the Luleå University of Technology (LTU) together with Trafikverket and a larger number of interested railway industry companies.

The ePilot project leader, Veronica Jagare, emphasises the importance of using the ePilot tool by aligning its purpose and promoting reflection on the future use of this project. ePilot's mission is to provide an innovative collaborative platform that is operational in the railway system through eMaintenance and AI Industry. This

project's vision is to enable a more robust, efficient, reliable, resilient and digitised railway system, with the aim of being attractive and safe. The aim is to incorporate the most revealing results of research and development into the railway system, thereby contributing to greater reliability, punctuality and sustainability in the railway area and considering greater cost efficiency in operation and maintenance.

From 2013 to 2020, this project will be part of 38 sub-projects.

Figure 25, shows some of the partners who collaborated in the creation of ePilot and have some prominence in both the railway sector and industry.



Figure 25 – Cooperating companies

Source: [<https://www.ltu.se/research/subjects/Drift-och-underhall/Forskningsprojekt/ePilot/Om-ePilot/Samarbetsparter?l=en>, Accessed in 2023.10.27]

This project has had a number of positive impacts, which have led to greater collaboration with these companies.

According to the project leader, ePilot has contributed to a wider range of work, from ongoing initiatives and projects at Trafikverket and in industry, including European projects (Horizon Europe), Maintenance System (GUS) and Asset Data (ANDA).

4.8 Researchers

The researchers of this annual magazine have participated and continue to participate in several projects. Some of these projects are now closed, but others are still ongoing. However, these projects are highlighted due to their importance: IN2TRACK3 (Research into optimised and future railway infrastructures 3); IN2SMART (Innovative Smart Asset Maintenance by Integrated Technologies 2); FR8RAIL II, III and IV (Innovation focused on the use of rail freight for the European Union); A physics-based framework for predicting ballast degradation; Railway track damage detection; Challenge-oriented framework for railway innovations; Intelligent operation and maintenance for traction motor bearings, eMaintenance solution for enhanced assets Railway Management - Using Industrial AI; Fleet of sensors for autonomous monitoring of railway conditions and others.

5 EUROPEAN PROJECTS

5.1 General framework

The EU funds many projects and programs, applying very strict rules to control the funds that are strictly used. In this way, it ensures that funding is done in a responsible way. In Figure 26 shows 17 global targets of the Sustainable Development Goals. The EU funding programme for research and innovation also includes some Sustainable Development Goals.

The EU's key funding programs for research and innovation: are

- Fighting climate change;
- Contributing to achieving the Sustainable Development Goals;
- Promoting EU competitiveness and growth;
- Strengthening research and innovation for development;
- Supporting the dissemination of technologies and knowledge of excellence;
- Encourage the participation of the EU talent pool;
- Encourage economic growth and thus promote industrial competitiveness and optimise the impact of investment in the European Area.



Figure 26 – Sustainable Development Goals

Source: [<https://www.un.org/en/sustainable-development-goals>, Accessed in 2023.06.08]

5.2 Pathfinder projects

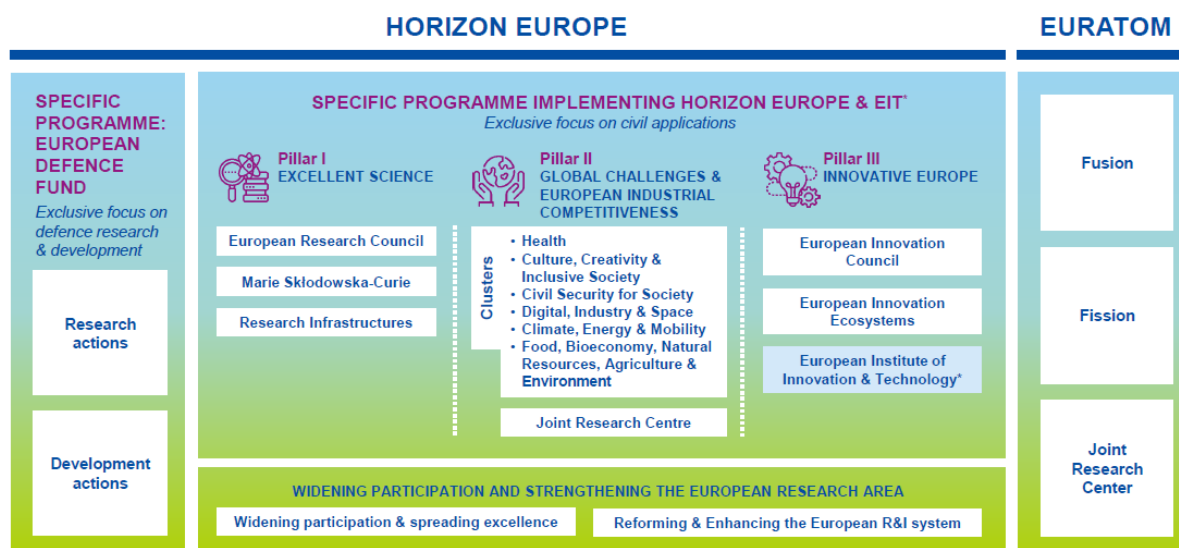
The Pathfinder programme funds research to develop a scientific foundation that will underpin cutting-edge technologies.

Pathfinder has two types of Funding Regimes:

- Pathfinder Open
 - Open: Any field of science, technology, or applications with no thematic priorities
- Pathfinder Challenges
 - Top-down Approach is challenged or portfolio - oriented. That is, support proposals in a pre-defined thematic area that have specific objectives.

5.3 HORIZON projects

Horizon Projects is a European Union Framework Programme for Research and Innovation. This program has a duration of 6 years (2021-2027) and a budget of 95.5 billion Euros for support and innovation activities.



* The European Institute of Innovation & Technology (EIT) is not part of the Specific Programme



Figure 27 – Specific Programme Implementing Horizon Europe & EIT

Source: [(https://research-and-innovation.ec.europa.eu/system/files/2022-06/ec_rtd_he-investing-to-shape-our-future_0.pdf), Accessed in 2023.05.03]

Figure 27 shows the structure of the Horizon Europe regulation. This structure is divided into 3 pillars and 1 part for widening participation and strengthening the European Research Area.

Pillar I

- World-class science for technologies, wellness;
- Attracting, retaining and developing research talent;
- Improved access to infrastructure;

Pillar II

- Concerns of citizens and society;
- Develop, demonstrate innovative solutions;
- Top-down opportunities.

Pillar III

- Strategic investments;
- Attracting private investments for research and innovation;
- Innovation for Business Job creation and growth.

5.4 Funded program path

In a funded programme it goes through six distinct points:

1. Innovative concepts/ideas. Read the needs of both stakeholders;
2. Search for a project and read the description of the programmes;
3. Looking for a consortium to join the project!
4. Complete the application form (part A) and the Technical Description form (part B);
5. Submission platform;
6. Submit.

5.5 Registration on the platform

To participate in a European project there are several steps you should consider. First, research which theme of the project you are going to participate in and then submit the application.

The participant must create his ORCID which is a digital identifier that differentiates the researchers. On this platform you can share revealing information, apply for grants and, in this way, ensure that you are recognised in all contributions.

The organisation must be registered with the European Commission to participate in the project. Upon registration, a Participant Identification Code (PIC) and a nickname are assigned.

5.6 Search for EU funding programmes

In Figure 28, we can see a webpage that is the electronic platform where all the EU funding programmes are: <https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/home>.

To access the funding programmes, you need to have some knowledge about how the electronic platform in which the EU-funded projects are inserted works.

So, I will explain it in 6 points.

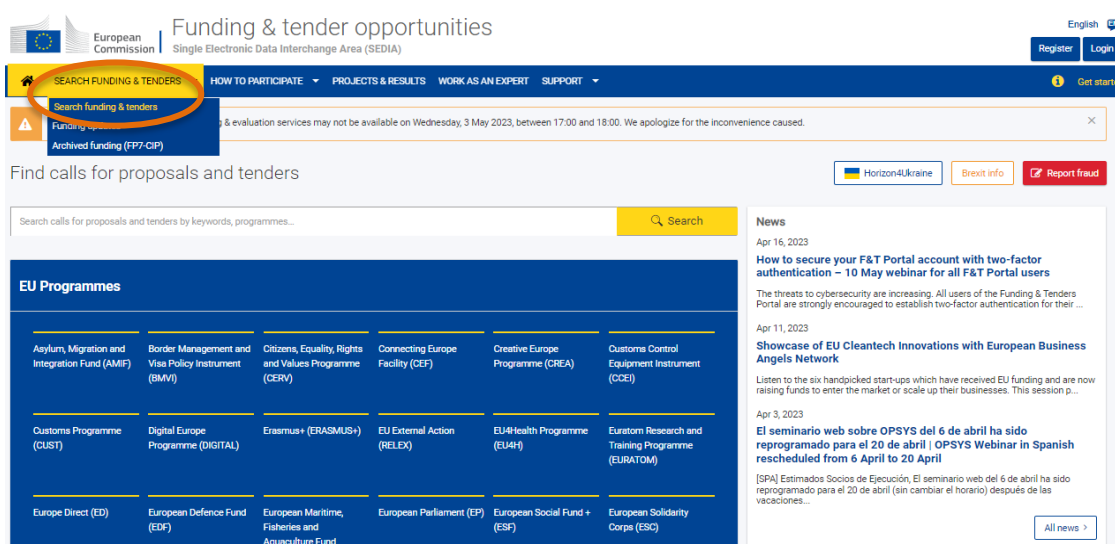


Figure 28 – Site the Funding & Tender opportunities

Source: [(<https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/home>), Accessed in 2023.06.05]

In the second step, we access the platform and select "Search funding & tenders", as shown in Figure 29.

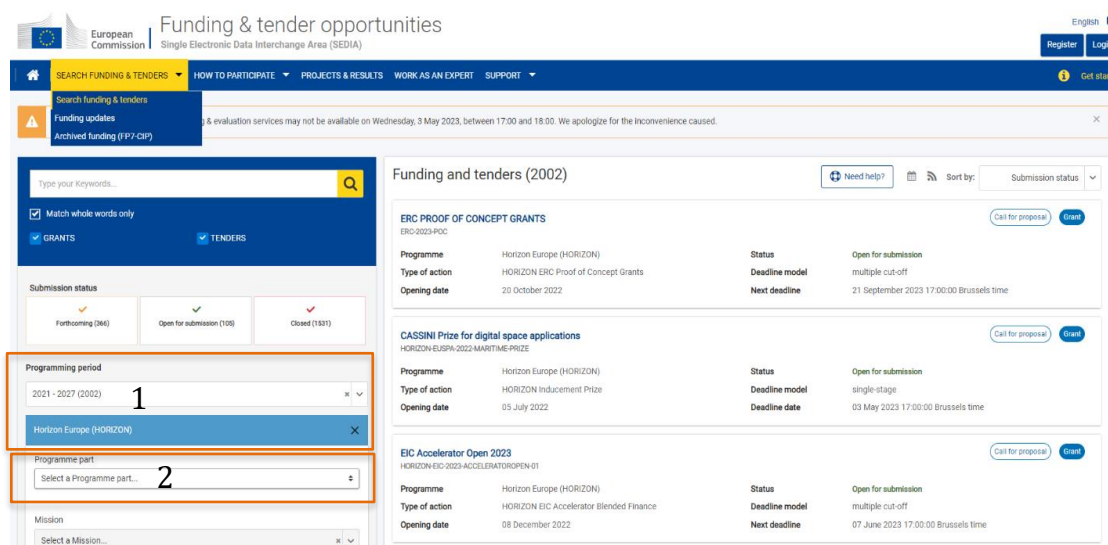


Figure 29 – Search funding & Tender through filtration

Source: [<https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-search>], Accessed in 2023.06.05]

In Figure 29, several funding programmes, appear. As there are many programmes, we use filters to choose the programme we are interested in. In point 1, we select the year we want (2021-2027) and in point 2 we choose the group (Horizon Europe). On the platform of financing and competition opportunities, we look for projects, whose theme is of our interest.

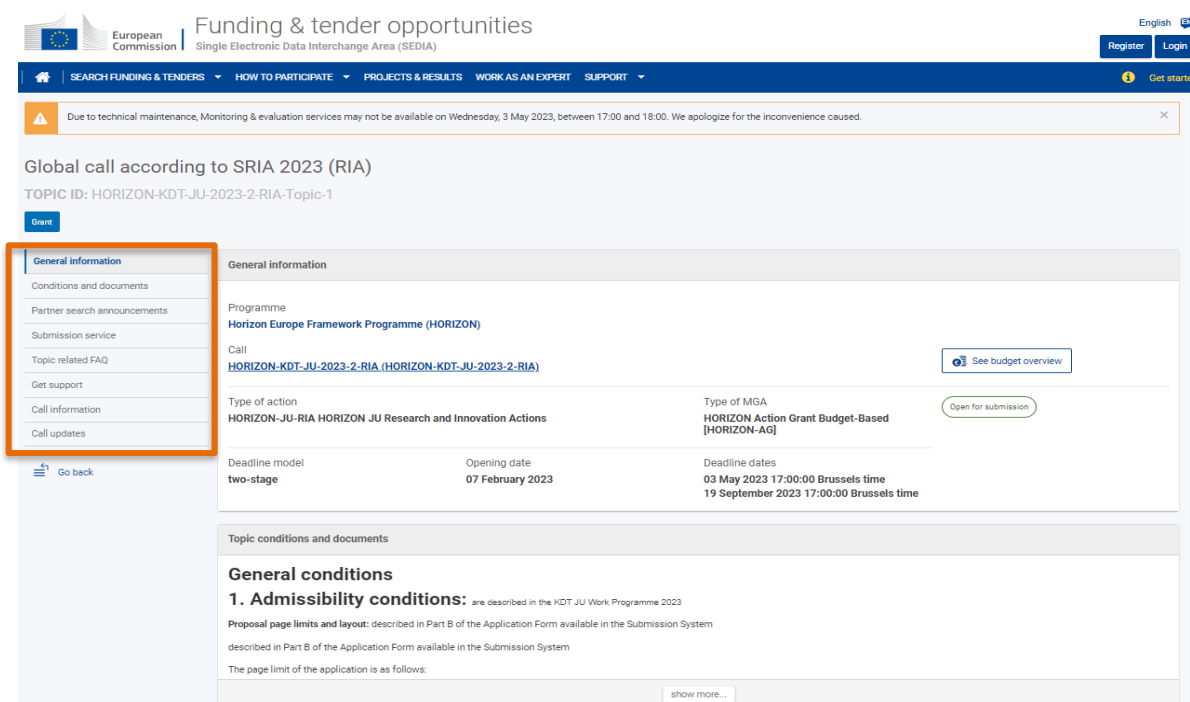


Figure 30 – Electronic platform of the funded program

Source: [(https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-kdt-ju-2023-2-ria-topic-1), Accessed in 2023.06.05]

After identifying the Call, the next step is to consult all the documents which are available (Topics, Rules for participation, Annexes, and the Handbook), we can see in Figure 30. After consulting the documents mentioned above, the proposal preparation is done (Meet with the consortium, divide, and define the tasks, prepare the administrative and technical information, and review the proposal).

After choosing the theme we check if we can meet the necessary requirements to participate in this project. Considering the Opening Date and Closing Date.

After verifying all the information mentioned above, we proceed to the next stage, reading all the documents that are available on the program page.

When reading all the information that is made available, it is essential to take out all the important information from Admissibility conditions, Eligible countries, other eligibility conditions, Financial and operational capacity and exclusion, Evaluation and award: evaluation criteria, scoring and thresholds, legal and financial set-up of the grants and specific conditions. Also available are some important documents about Call. They can download these documents or read them from the website itself. In addition to these documents that are recommended, you can see others that are of reference.

Next, we have a section where consortia or other research companies offer their availability about the project, mentioning their expertise and objectives. And in this

way, they can get partners who have the same goals, In the future, there will be an exchange of contacts so that they can work together on this project.

If the organisation meets all the requirements and is interested in participating in the project, select "Submission service", select the submission and click start. When you click on start, a form will appear asking you to confirm if you want to continue. After confirming, a window will open with a form to create the proposal and then submit it together with the Part A and Part B forms. In the following section we have the help support where you can clarify the doubts that arise throughout the project from information about the project, access to the platform and filling out the form, project that can be solved by email.

In the following section, the call information points out revealing information about the development of the project.

It should be borne in mind that there are several calls for different applications. Table 3 has been adapted based on information taken from the European Commission - Horizon Europe - How to apply.

Table 3 – Horizon Europe: How to apply

Action Type	Applicants	Objective	Funding
Research and innovation action (RIA)	Research Institute. Higher Education Institutions; Companies; NGOs; Industry;	new knowledge or exploring a new or improved technology, product, process, service or solution	EU funding covers up to 100%
Innovation action (IA)	Research Institute. Higher Education Institutions; Companies; NGOs; Industry;	produces plans or designs for new or improved products, processes or services including prototyping, testing, demonstrating, piloting, large-scale product validation and market replication.	EU funding covers up to 70%
Coordination and support action (CSA)	Research Institute. Higher Education Institutions; Companies; NGOs; Industry;	cooperation among EU and associated countries to strengthen the European Research Area including, for example, standardisation, dissemination, awareness-raising, communication and networking activities, policy dialogues, mutual learning, or studies.	EU funding covers up to 100%
Programme co-fund action (COFUND)	Public and private partners	provides multi-annual co-funding for European partnerships.	EU funding covers between 30% and 70%

5.7 Technology Readiness Levels (TRL)

In general, a project can be divided into three distinct phases: first, research into the state of the art; after carrying out the necessary research, the next phase is technological development, prototyping, and demonstration, and finally, product launch.

With numerous projects, there was the need to create a tool that could provide the TRL autonomously and thus facilitate the classification. Two "TRL Calculators" were developed, one by the United States Air Force Research Laboratory and the other by the New York State Energy Research and Development Authority (NYSERDA). Both calculators aim to automatically assign the most appropriate TRL scale to the process or project. Bearing in mind that there are phases of the project that are quite general and therefore the attribution of the TRL scale in each project is not easy.

The European Commission has adopted the TRL scale as an indicator to verify the maturity of projects. However, this scale allows applicants and reviewers to align with the objectives proposed by the EC.

As European projects are large, the TRL scale (Technology readiness levels) has proven that the project can be divided into nine phases. Each of the phases indicates the maturity of the project to the applicant / reviewer. It is also possible to divide the TRL scale into three phases. Figure 31 shows that the TRL scale can be divided into three phases. The first phase is Research (TRL 0-3), the second phase is technological development, prototype, and demonstration (TRL 4-8) and the last phase is the market (TRL 9-10).

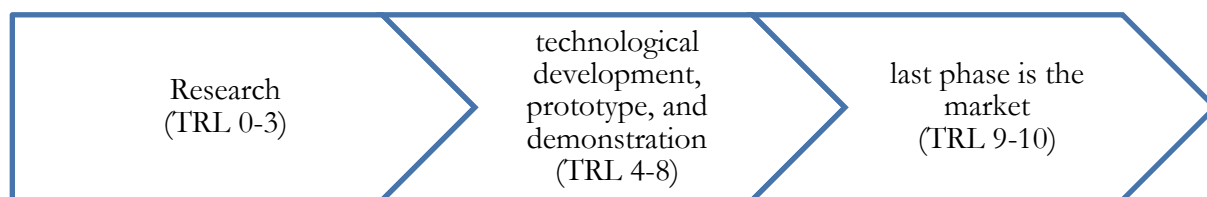


Figure 31 – Representation of the TRL scale (Technology readiness levels).

Source: [https://www.ccdr-n.pt/storage/app/media/files/horizonte2020_20140915.pdf],
Accessed in 2023.05.01]

For example, when a project is reviewed and scores low on the TRL scale, it indicates that it is a research-based project; if the TRL scale is high, it indicates that the project is focused on finding a more targeted solution.

After the project has passed through the "TRL calculator" it is automatically classified and then an evaluation is performed, which is no less than a verification of

several TRL definitions. In Annex C we can see the TRL scale available on the Horizon Europe platform - Annex G.

Considering that the TRL scale is quite complex as it has several definitions, this implies that it is fundamental to understand the different phases to proceed with the project.

In Figure 32, we can see what the action type (1) is, who can participate (2) and indicates what is the centre of gravity in TRL (3) of the project.

Call information

This call encompasses 2 topics:

Topic 1 Global call according to SRIA 2023 (RIA)

Focus Topic 2 - Ecodesigned smart electronic systems supporting the Green Deal objectives (RIA)

1 A KDT Research and Innovation Action (RIA) primarily consists of activities aiming to establish new knowledge and/or to explore the feasibility of a new or improved technology, product, process, service, method, tool or solution. For this purpose they may include applied research, technology development and/or method/tool and integration, testing and validation on a small-scale prototype in a laboratory or simulated environment. The activities have their centre of gravity at TRL 3-4. 3

A RIA proposal is characterised by:

- Execution by a consortium that may consist of SMEs, large enterprises, universities, institutes, public organizations; 2
- Developing innovative technologies and/or using them in innovative ways;
- Targeting demonstration of the innovative approach in a relevant product, service or capability, clearly addressing the applications relevant for societal challenges;
- Demonstrating value and potential in a realistic lab environment reproducing the targeted application;
- Having a deployment plan showing the valorisation for the KDT ecosystem and the contribution to the KDT goals and objectives.
- In order to maximize effective implementation of the KDT top-level objectives, the list of RIA proposals to be retained for public funding shall constitute a balanced portfolio of projects developing innovative technologies and applying them in different domains. The domains represent the demand side of technologies, and the development of new technologies represents the supply side of technologies.

show less...

Figure 32 – Call information (TRL)

Source: [(<https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-kdt-ju-2023-2-ria-topic-1>), Accessed in 2023.06.05]

In the last section are all Call updates/rectifications since it was released to date.

5.8 Complete the form

When we select the "Submission Start" tab, we select the project that we want to participate in; then, we confirm the choice that has been made and, then we log onto the page. When logging in, an identical window will appear as shown in Figure 33.

When we log on to the platform, we select the topic we want to work on and start by filling in the required subjects. On this same page, we download the templates of Part B to be submitted as a document. We can check it out in Figure 33.

The screenshot shows the 'Create proposal' form on the European Commission Funding: Submission Service platform. The form is divided into several sections:

- Deadline:** 03 May 2023 17:00:00 Brussels Local Time. Closing today at 17:00:00.
- Call data:** Call: HORIZON-KDT-JU-2023-2-RIA, Topic: HORIZON-KDT-JU-2023-2-RIA-Topic-1, Type of action: HORIZON-JU-RIA, Type of MGA: HORIZON-AG.
- Find your organisation:** Fields for PIC (250) and Short name (250) with a Search button.
- Your role:** Please indicate your role in this proposal. Options: Main contact (selected), Contact person.
- Your proposal:** It will appear also in the "General Information" section of the Application Form Part A and can also be updated there. Fields for Acronym (20) and Short Summary (2000).
- Download Part B templates:** A button labeled 'Download part B templates' is highlighted with an orange box.
- Support & Helpdesk:** Links for Online Manual, IT How To, IT Helpdesk, and FAQ.
- Service Desk:** Email address: EC-FUNDING-TENDER-SERVICE-DESK@ec.europa.eu.

A 'SAVE AND GO TO NEXT STEP' button is located at the bottom right of the form.

Figure 33 – Completing the form.

Source: [(<https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-kdt-ju-2023-2-ria-topic-1>), Accessed in 2023.05.01]

The form may vary from Calls to Calls, but all forms are divided into two parts: Part A and Part B.

Part A is completed online directly from the European Commission platform and Part B is made available in an editable word file and thus proceeds to complete it and submitted as an attachment on the platform.

There are several important pieces of information that are entered in Part A of the form:

1. General information: Creation of the Acronym; Proposal title; Duration in months; free keywords and describe disciplines that characterise the theme of the proposal. Once we write the abstract of the project, we finally accept all the declarations that are imposed on us by the EU.
2. Participants: describe list of participating organizations mention participating organisation legal name, country, role, and action. Once you have mentioned, all the participants will appear on a form to fill out in detail the information of each organisation: Legal name; Address; Specific legal status; Department carrying out the proposed work; main contact person and other contact persons and research involved in the proposal. Then we select the most appropriate role of the participant of the organisation that is involved in the project. Finally, describe up to 15 publications that involve their own authorships. 5 publications that contain widely used datasets, software, goods, services, or any other achievements relevant to the call content; 5 most relevant previous projects or activities, connected to the subject of this proposal and 5 descriptions of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work. The last topic of Part A is to select whether the institution meets all the requirements of gender equality.
3. After having filled in all the revealing information about the institutions and organisations, we must fill out the Budget (Annex B) is a table where it is possible to enter all the expenses that may have throughout the investigation and implementation of the prototype, if applicable.
4. In point 4, the topic addressed is ethics and security. Most of the answers to the questions are Yes or No, however there are two questions that must be described. For example:
 - a. Human Embryonic Stem Cells and Human Embryos;
 - b. Humans;
 - c. Human Cells / Tissues (not covered by section 1);
 - d. Personal Data;
 - e. Animals;
 - f. Non-EU Countries;
 - g. Environment, Health and Safety;
 - h. Artificial Intelligence;
 - i. Other Ethics Issues;
 - j. Ethical dimension of the objectives, methodology and likely impact;
 - k. Compliance with ethical principles and relevant legislation.

5. Security issues table
 - a. EU Classified Information (*EUCI*)²;
 - b. Misuse;
 - c. Other Security Issues.

6. Security self-assessment
 - a. Describe used material for the project.

Part B is available on the Funding and Tenders website. In this second part the description is more on a technical level. We can see in Annex A.

6 DEVELOPMENT

6.1 Description of the application submitted

This "Markerless Augmented Reality to Support Equipment Repair with Self-Diagnosis" application proposed the creation of an innovative solution for the maintenance and repair of rolling stock, using augmented reality technology. This project aims to develop a system that allows technicians to visualise detailed information about the condition of the equipment and repair instructions on the actual image of the component. With this development, it is possible to make it easier to identify faults and carry out repairs, thereby minimising any errors that may arise. This project is aimed at modernising maintenance in the railway sector and thus taking advantage of the capabilities of augmented reality technology to improve the efficiency, safety, and quality of maintenance services.

6.2 Search for EU funding programmes

In Figure 34 we look for the program that interests us. In point 1, we select the year we want (2021-2027) and in point 2 we choose the group (Horizon Europe).

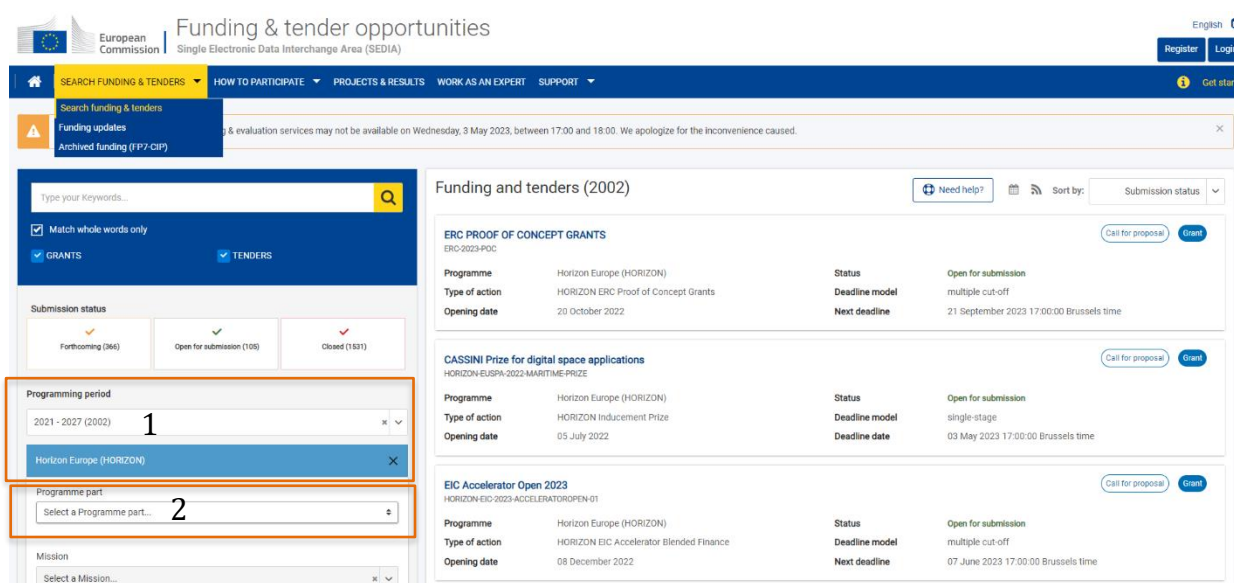


Figure 34 – Search funding & Tender through filtration

Source: [(<https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-search>), Accessed in 2023.06.05]

On the funding and tender opportunities platform, we are looking for projects that involve the area of railway maintenance or digitisation.

Contributions for Portuguese and European Projects to help increasing the Railway Sector

After finding the call we consulted all the available documents (Topics, Rules for Participation, Annexes and Manual). After consulting the documents mentioned above, we proceed to the preparation of the proposal (meet with the consortium, divide, and define the tasks, prepare the administrative and technical information, and review the proposal).

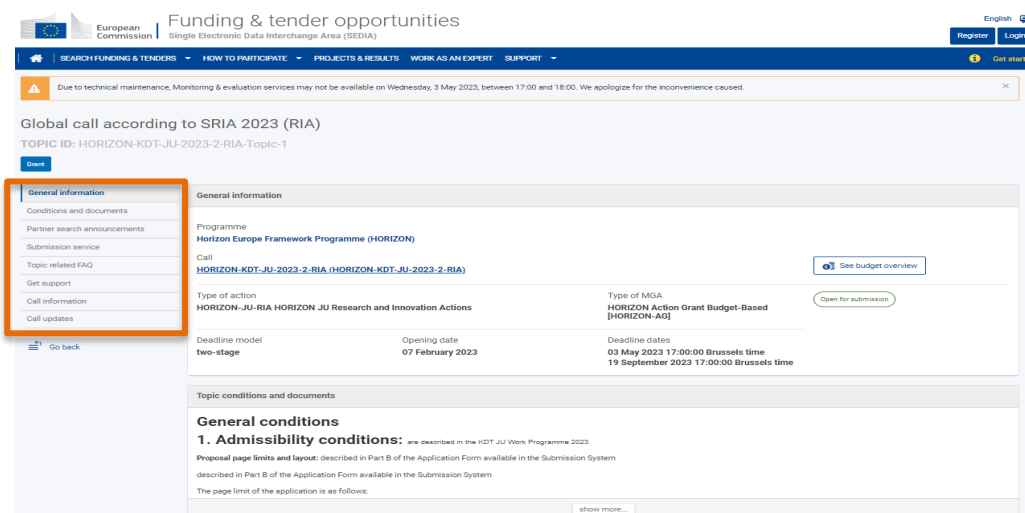


Figure 35 – Electronic platform of the funded programme

Source: [(<https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-kdt-ju-2023-2-ria-topic-1>), Accessed in 2023.05.01]

In Figure 35, it can be seen all the information available about the project, i.e. after selecting the topic, we will have to analyse all the information to meet all the requirements necessary to take part in this project. Bear in mind the closing date.

After reading all the information available on the site, we have highlighted the most important. After choosing the topic, we started by researching the state of the art.

6.3 Filling in excel

An excel file was created to insert all the research related to the subject under study. After the research, a selection of articles was made, the state of the art was elaborated to be framed in the European project. A table was created containing fields that should be filled in, such as: Title, Link, Document type, H-index, Classification, Main subject, Keywords and Year.

I will now explain the descriptions of the respective fields:

- Title: Description of the research title;
- Link: address where the article was found;
- Document: description of the consulted document, e.g. (scientific journal, journal, publications and conference);
- H-Index: has as its main goal in quantifying scientists is productivity and impact based on articles that are most cited;
- Classification: is the Knowledge-Based Systems;
- Main subject: describe the main areas of study within Railway including (maintenance, industry 4.0, artificial intelligence, etc.);
- Keywords: are keywords that summary the main themes throughout the article under study;
- Years: is to refer from the most recent articles to the oldest.

Table 4 – With description of all researched articles

TITLE	LINKS	Type of Document	H-INDEX	Classification	Main Subject	Keywords	Year
Evaluation of CO2 emissions from Maintenance management of railway	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	119	Q1	CO2 emissions	Carbon footprint; Green house gas emission; Railway resurfacing; Strategic ma	2018
Big data and stream processing	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	80	Q1	Maintenance management	Weibull analysis; System reliability analysis; Railway infrastructure; Safety and	2012
RCM2 predictive maintenance of integrated condition-based track	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	157	Q1	Industry 4.0	Industry 4.0; Big Data; Stream processing; Predictive maintenance; Railway; Wi	2020
The model predictive control strategy	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	147	Q1	Maintenance	condition monitoring; condition-based maintenance planning; chance	2004
Reliability and availability assessment of Condition-based inspection.	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	173	Q1	maintenance planning	condition-based maintenance; condition-based maintenance planning; chance	2019
Smart rail pads for the continuous	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	138	Q1	CO2 air conditioning system	condition-based maintenance; condition-based maintenance planning; chance	2021
Interferometric optical fiber sensor for A review of railway infrastructure	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	83	Q1	Bogie maintenance	condition-based maintenance; condition-based maintenance planning; chance	2021
A rigorous fastener inspection	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	160	Q1	condition-based maintenance	condition-based maintenance; condition-based maintenance planning; chance	2020
Real-time monitoring of railway	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	155	Q1	light sensors	condition-based maintenance; condition-based maintenance planning; chance	2018
Combined use of sensor data and	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	180	Q1	sensor data and	condition-based maintenance; condition-based maintenance planning; chance	2015
Study on fretting fatigue crack initiation	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	147	Q1	railway axes	condition-based maintenance; condition-based maintenance planning; chance	2008
A Framework for Selecting Data	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	169	Q1	Automation	condition-based maintenance; condition-based maintenance planning; chance	2023
Intelligent emergency management	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	78	NOT YET	Predictive Maintenance	condition-based maintenance; condition-based maintenance planning; chance	2021
Detection of anomalies in the proximity	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	51	NOT YET	Intelligent emergency	condition-based maintenance; condition-based maintenance planning; chance	2022
Enabling Certification of Satellite Based	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	76	Q3	Detection of anomalies	condition-based maintenance; condition-based maintenance planning; chance	2016
Spectral Noise of Sensors for	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	136	Q1	Satellite Based Localization	condition-based maintenance; condition-based maintenance planning; chance	2021
Hierarchical multi-agent predictive	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	51	NOT YET	Sensors	condition-based maintenance; condition-based maintenance planning; chance	2021
Parametric analysis of railway	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	86	Q1	predictive maintenance	condition-based maintenance; condition-based maintenance planning; chance	2023
Development of Strategies for	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	51	NOT YET	Rolling Stock; Diagnostics; Electronic Noise; Sensor	condition-based maintenance; condition-based maintenance planning; chance	2022
Evaluation of Human Error Probability	https://www.sciencedirect.com/science/article/abs/pii/S0969811320375416	Scientific paper	55	NOT YET	Human error; Maintenance; Error probability	condition-based maintenance; condition-based maintenance planning; chance	2015
Maintenance intelligence for rail	https://www.mobility.siemens.com/global/en/press-releases/2020/09/24	site SIEMENS	-----	-----	railway track; organization; routine track maintenance; track works; operating	condition-based maintenance; predictive maintenance; machine learning; condition-based maintenance; condition-based maintenance planning; chance	2021
A Survey on Data-Driven Predictive	https://www.researchgate.net/publication/354163	Journal	196	Q1	Maintenance intelligence	condition-based maintenance; predictive maintenance; machine learning; condition-based maintenance; condition-based maintenance planning; chance	2021
Intelligent Optical Fibre Sensing	https://ieeexplore.ieee.org/document/8641602	Conference	5	NOT YET	Predictive Maintenance	condition-based maintenance; predictive maintenance; machine learning; condition-based maintenance; condition-based maintenance planning; chance	2018
Predictive maintenance of rail	https://www.brunel.ac.uk/research/projects/pred	Projects	-----	-----	Predictive maintenance	condition-based maintenance; predictive maintenance; machine learning; condition-based maintenance; condition-based maintenance planning; chance	?
UTC RAIL SYSTEM	https://usc.org/IMG/pdf/artificial_intelligence_cas	Publications	155	Q1	Artificial Intelligence	condition-based maintenance; predictive maintenance; machine learning; condition-based maintenance; condition-based maintenance planning; chance	2021
Centralized Maintenance Time	https://www.hindawi.com/journals/mpe/2020/924	Journal	68	Q2	Maintenance Time Prediction	condition-based maintenance; predictive maintenance; machine learning; condition-based maintenance; condition-based maintenance planning; chance	2020
System uses AI and Industrial IoT to	https://cordis.europa.eu/article/id/418452-system	Projects	-----	-----	Industrial IoT	condition-based maintenance; predictive maintenance; machine learning; condition-based maintenance; condition-based maintenance planning; chance	?
Research aims to develop predictive	https://www.railjournal.com/technology/research	Projects	-----	-----	predictive maintenance	condition-based maintenance; predictive maintenance; machine learning; condition-based maintenance; condition-based maintenance planning; chance	2018
Complex Fuzzy System Based	https://ieeexplore.ieee.org/abstract/document/	Publications	151	Q1	Predictive Maintenance	condition-based maintenance; predictive maintenance; machine learning; condition-based maintenance; condition-based maintenance planning; chance	2020

In Table 4, it is elaborated the state of the art of remote maintenance and predictive maintenance of the railway, it allows us to obtain more knowledge about the current state of the railway, both nationally and worldwide. Some countries have made large investments and thus allowed great development in railways, particularly in the areas of predictive maintenance. Regarding remote maintenance, this is one of the areas that is being developed in the railway. It is still in the testing stages because of the

new electronic equipment that requires good data communication. There are still many places that still can't have access to the Internet of Things (IoT) for example (areas like tunnels, mountains, etc.). Remote maintenance is essential, which will allow quick detection of the breakdown, allowing less time to repair the locomotive / train and ensure maximum safety of transporting passengers or goods.

6.4 Form completion

After completing the forms (Part A and Part B) it should be submitted on the platform 24 hours before. EU recommends submitting before the closing of the application in case there is difficulty in delivery to have time to report to the responsible IT. All applications are only valid if submitted on the platform.

After submission, the application will be analysed, if it meets all the requirements, for example (number of pages, fonts, etc..) and then a report containing the submitted application will be sent by email to the person responsible for the submission confirming that the application was delivered successfully, as we can see in the photo shown in Figure 36. From that moment on, the application will go to the reviewers for evaluation.

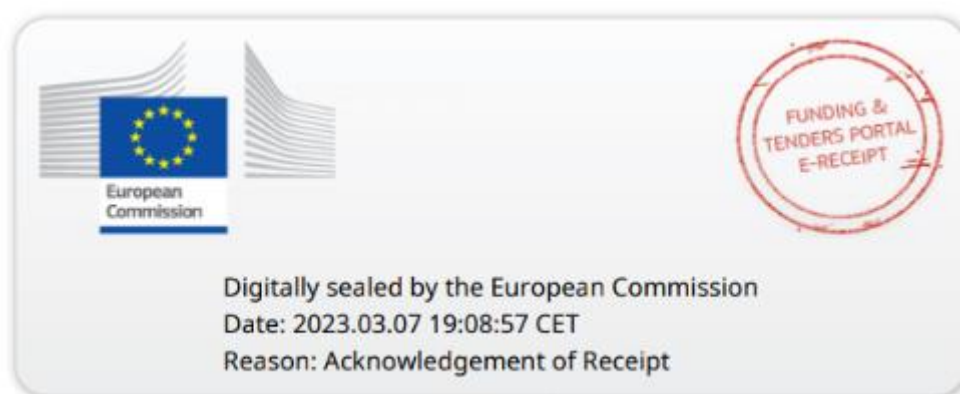


Figure 36 – Funding & Tenders Portal Receipt

After receiving the *email*, the reviewers will analyse the application. If there are no doubts, the application goes to the next phase. In this specific case, some doubts arose to the reviewers, and they sent a document to the email of the person responsible with all the doubts to be answered within a certain period that is stipulated by the reviewers.

After answering the questions by the reviewers and if they are clarified, we move on to the next phase. If they are not clarified, our application will not advance to the next phase.

7 CONCLUSION

Throughout this work we have tried to contextualise the railway both at national and European level, trying to establish a link between the member states, but focusing mainly on the subject we were asked to tackle. Due to the complexity of this subject, we are aware that the subject matter is very vast and complex and that there are many other issues that could have been much more elaborate and in-depth, which could be done in a doctoral thesis.

As we worked on this paper, we took care to illustrate and comment on the railway in its most specific and up-to-date aspects.

This work was an objective investigation and collection about the railway. However, in this project we have endeavoured to frame the subject from various angles, from its emergence to the present day. All this work is done in a sequential and interconnected way. The work has been subdivided into chapters to make it more structured, considering the correspondence between the parts to make it compatible with the research.

From this research, we can see that the railway had a beginning and then an evolutionary path, with various factors such as pollution, environmental protection, economic development and improving people's quality of life.

Despite this, there is no doubt that Europe is investing in the railway as an intelligent and sustainable system. However, the railway is a means of transport that offers sustainable solutions for both energy and the environment.

In Portugal, investment in the railway sector has been aimed at restoring inoperable rolling stock and maintaining lines that were already in a state of disrepair.

As a member of the European Union, Portugal has received funds to improve its infrastructure.

This aid from the European Union will allow for geographical and community reinforcement. This will allow for greater flexibility in mobilising people and goods between European countries.

The Railway Competence Centre (CCF) with ISEC has been looking into new forms of predictive maintenance using Augmented Reality to prevent human error in recovering from breakdowns.

To make this possible, an attempt was made to submit an European application aimed at predictive and remote maintenance in the railway area. Although it didn't go ahead as expected; it emerged as an enriching exercise with substantial implications for both theory and practice. These processes broaden the understanding of the complexity and requirements inherent in European funding.

From this experience, there must be a great deal of inter-institutional collaboration, because there is a need to adapt different funding guidelines and it takes a well-

founded proposal to enter a competitive EU funding environment. This kind of process is extremely important in both persistence and the ability to extract knowledge.

Although it didn't achieve the best result, this application was a very significant milestone that reflects the complexity of innovating and seeking support in a highly competitive European environment. With this great effort, we can have a vision that allow us to open new horizons for future applications, promising significant contributions both for the university and for professional fulfilment in the search for efficiency, safety, and innovation in the field of railways.

Finally, it should be emphasised that the railway is extremely important for several reasons, both economic and social. Over time, trains have become more sustainable than cars, enabling faster and more comfortable journeys.

It can therefore be concluded that the trans-European railway line is important for the development of European countries.

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ANNEXES

Annex A



**KDT Joint Undertaking
Innovations Actions (IA) &
Research and Innovations Actions (RIA)**

**Application Form
(Horizon-KDT-JU-IA and RIA)
1st Stage – PO**

**Technical description (Part B)
Proposal (ACRONYM)**

TITLE OF THE PROPOSAL

Project acronym	
Major Challenges or Focus Topic addressed by the proposal*	
Anticipated start date of project	
Duration of project in months	
Coordinator contact person	

List of participants

Participant No *	Participant organisation name	Participant short name	Country	National eligibility checked by participant (Y/N)
1 (Coordinator)				
2				
3				
.....				

Table of Contents

1. Excellence

1.1 Objectives and ambition

Insert here text for your proposal

1.2 Methodology

Insert here text for your proposal

2. Impact

2.1 Project's pathways towards impact

Insert here text for your proposal

3. Quality and efficiency of the implementation

3.1 Work plan and consortium composition

Insert here text for your proposal

Annex B

Annex C

G. Technology readiness levels (TRL)

Where a topic description refers to a TRL, the following definitions apply, unless otherwise specified:

TRL 1 – basic principles observed

- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)





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