Shift2Rail

RUN2Rail

Innovative **RUN**ning gear soluTiOns for new dependable, sustainable, intelligent and comfortable **RAIL** vehicles and comfortable **RAIL** vehicles.

CONTENTS

FOREWORD

RUN2Rail (Innovative RUNning gear soluTiOns for new dependable, sustainable, intelligent and comfortable RAIL vehicles) is a Shift2Rail Open Call project which contributes to the four main objectives for Innovation Programme 1 – Cost efficient and reliable trains –

- Increase the physical capacity of vehicles.
- Reduce the travel disruptions for passengers by increasing operational reliability and availability of vehicles.
- Reduce life cycle cost of the vehicle.
- Increase energy efficiency of the vehicle and reduce vehicle mass.

The overall objective of the project is to identify and develop the key methods and tools that are required to allow the design and manufacture of the next generation of running gear.

The development of a new generation of running gear is pivotal to the achievement of the ambitious goals set by Shift2Rail for future European trains, encompassing the substantial reduction of life cycle costs, improved reliability and energy efficiency, the reduction of noise emissions and of other externalities and the achievement of full interoperability of the rolling stock.

Looking into ways to design trains that are more reliable, lighter, less damaging to the track, more comfortable and less noisy, RUN2Rail has explored an ensemble of technical developments to contribute to build a Running Gear Technology Demonstrator (TD1.4) that paves the way for the next generation of passenger rail vehicles.

WP1 INNOVATIVE SENSORS & CONDITION MONITORING

Implementing condition-based maintenance (CBM) strategies is a key priority for the next generation of railway running gear and will contribute significantly towards reducing the life cycle cost of the vehicle, at the same time increasing safety, reliability and availability of the rolling stock. RUN2Rail is exploring the potential for advanced applications of condition monitoring (CM) in the next generation of running gear, looking at solutions already available in other sectors but also aiming to formulate new solutions specific to railway vehicles. Concepts were developed for three case studies:

- Monitoring of wheelsets;
- Monitoring of the powertrain and bearings;
- Monitoring of suspension components based on bogie-mounted acceleration sensors.

In the first part of the project, a thorough analysis of existing solutions for condition monitoring was performed, considering solutions already available in other fields of engineering, particularly automotive and energy. Furthermore, a prioritisation of needs for CM in the running gear was performed based on experience and historical data available at the partners. Afterwards, a modular, flexible architecture was designed for the on-board CM system to enable the integration of the different components of the CM system.

After these initial steps, work has been performed along two main directions: the selection of suitable hardware components for a condition monitoring system and the development of algorithms to process the measured data.

Condition Monitoring Systems

Building on the definition of needs for CM and on the general system architecture defined in the initial part of the project, one research stream focused on the selection of suitable components for the condition monitoring systems which would support the implementation of the running gear of the future. The work has been based around condition monitoring systems suitable for three representative case studies covering different parts of a railway vehicle:

- The running gear for a typical railway vehicle where the potential for performance improvement is high.
- The traction system including gearboxes and bearings where significant failures occur that can result in loss of availability and reduction in levels of service.
- A railway wheelset including full implementation details.

Specific examples have been developed for each of the three case studies and for each of these examples components and sub-systems that can be incorporated into a suitable condition monitoring system have been selected. The condition monitoring systems are developed to different levels of detail in each case study but, in all three cases, suitable commercial components have been identified for sensors and data acquisition. Additionally, for the wheelset case, commercially available hardware has been identified also for power supply and wireless data transmission. The potential use of energy harvesting units was investigated and requirements were defined for e.g. electromagnetic compatibility, robustness to vibration, frequency range, sampling rates.

Methods for condition monitoring and fault detection

Data processing and fault detection and classification methods have been developed to allow monitoring of the health state of various sub-systems in the running gear such as axles, wheels, suspensions, bearings, gearboxes. For wheelset axles, the monitoring of in-service stresses using embedded self-powered sensors has been investigated, with the final aim of continuously estimating the service load spectra and updating the estimate of crack propagation speed, thereby optimizing the Non-Destructive Testing (NDT) inspection of the axle. Figure 1 shows a schematic view of the wheelset load monitoring system. A system embedded in the axle is also being developed for measuring axle accelerations in three directions, which can be used to detect wheel flats and wheel out-of-roundness and to identify excessive wear of the transversal wheel profile causing increased conicity. The feasibility of using acceleration signals from the embedded unit to detect a cracked axle has also been investigated.

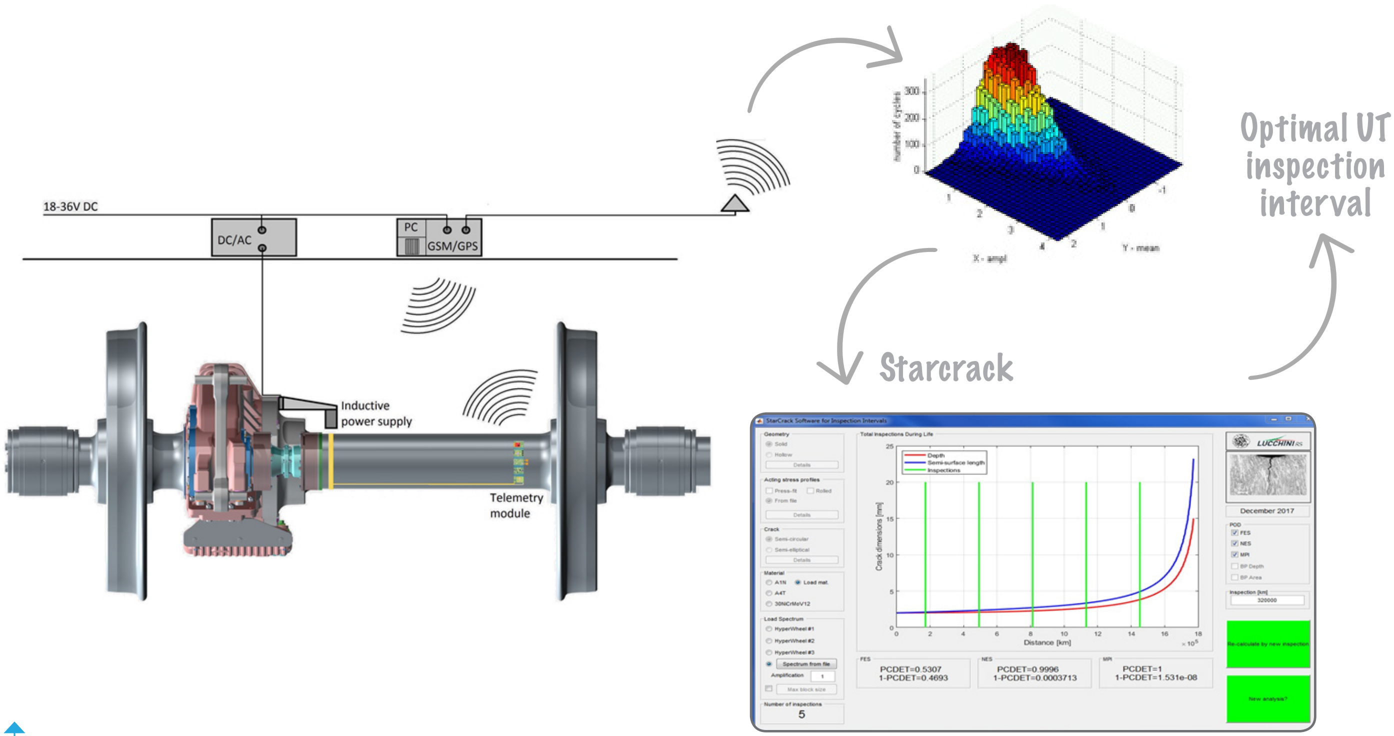


Figure ① Wheelset load monitoring system for optimizing the NDT inspection plan

Another stream of research is concerned with assessing the feasibility of a new low-cost Wheel/wheelset In-Service Force Monitoring (WISE-FM). This system provides the opportunity to monitor wheel/rail contact forces during service based on a simple and relatively inexpensive measuring set-up. By measuring contact forces, anomalies in the running condition of the vehicle can be detected, reducing wear and rolling contact fatigue damage and increasing running safety.

For the powertrain and bearings, a signal analysis toolbox was created, which enables the processing of the measured signals to elaborate several different condition indicators and implements Machine Learning algorithms for fault detection and classification. The toolbox was assessed using measurements taken in run-to-fail tests performed on a test bench at VIBRATEC, see Figure 2. The results obtained showed that incipient failures of the gear box can be detected several service-hours in advance before the failure leads to a serious damage of the gearbox causing loss of functionality.

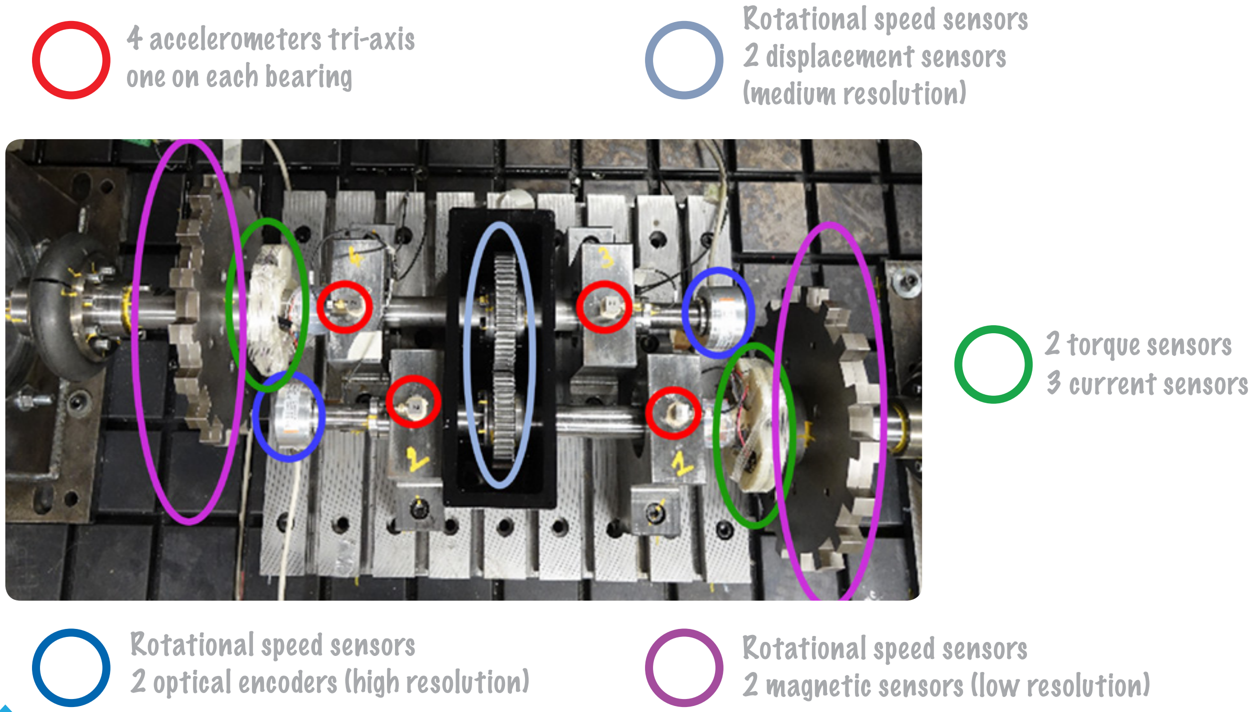


Figure ② Test bench for experiments on fault detection in gearboxes

Finally, as far as suspension components are concerned, different techniques have been tested and compared based on numerical experiments performed on a Multi-Body Systems model of a railway vehicle. The results show the potential to detect failures in primary suspension components such as springs and dampers, using relatively simple measuring set-ups consisting of a small number of accelerometers per bogie, and based on simple data processing techniques that can be implemented using low-cost data acquisition and data processing units.

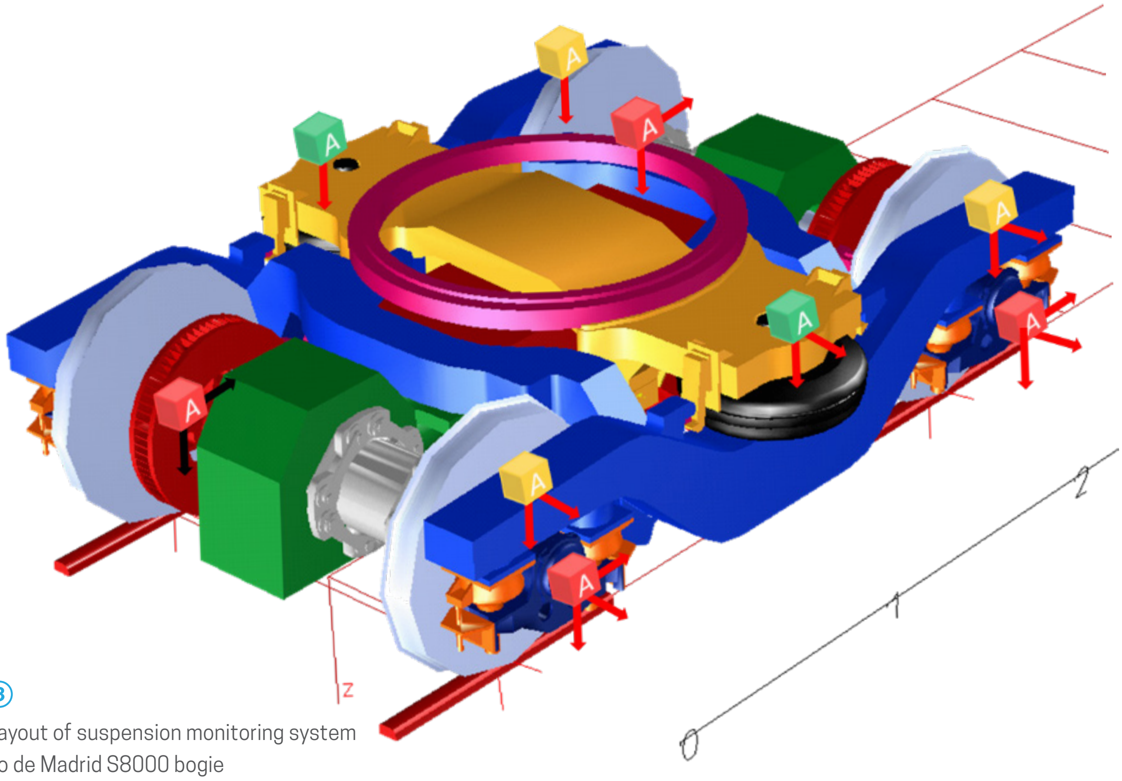


Figure ③
Sensor layout of suspension monitoring system for Metro de Madrid S8000 bogie

WP2 OPTIMISED MATERIALS AND MANUFACTURING TECHNOLOGIES

I Novel materials bring enormous potential in the design of running gear for example in reducing weight and forces and in improving reliability but different techniques are required in both design and manufacturing to allow this potential to be realised.

The main objectives of WP2 are to explore the potential for the use of novel materials and manufacturing methods in the running gear of a railway vehicle. A wide range of materials and manufacturing methods were explored and two case studies were selected:

1 — An axle box manufactured using additive manufacturing with aluminium
2 — A bogie side frame using robotically laid up carbon fibre.

Relevant standards and previous research are also included in deliverable D2.1. To provide data for the design of the components using the novel materials and methods a computer model has been set up and a load case compiled. This has been included in deliverable D2.2.

Prior to design of the two components several concept designs were created including the novel bogie shown in Figure 4.

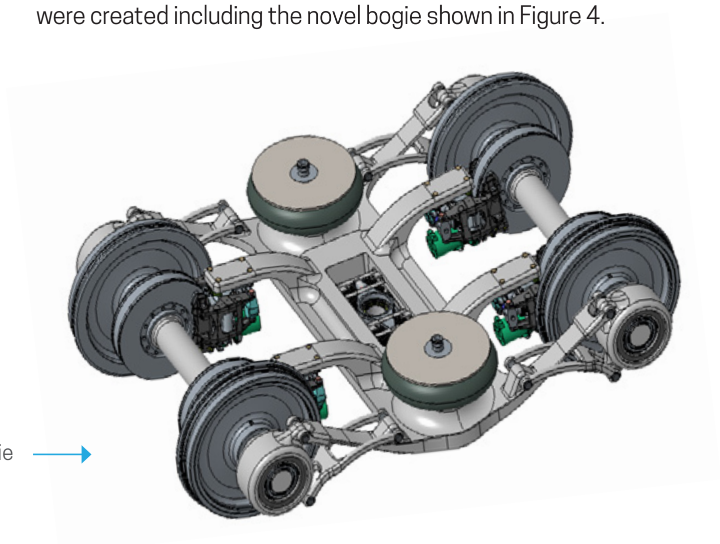


Figure 4 Concept designs: novel bogie

For the additive manufactured axle box component the partners have started by prototyping a novel Al-alloy based metal matrix composites for lightweight and high strength parts. By joining forces, the partners were able to define the material requirements, run a small batch powder production and produce miniature samples for characterization in a highly efficient and cost effective manner. Figure 5 shows the powder particles and the selective laser melting process and the produced material samples which are now being tested.

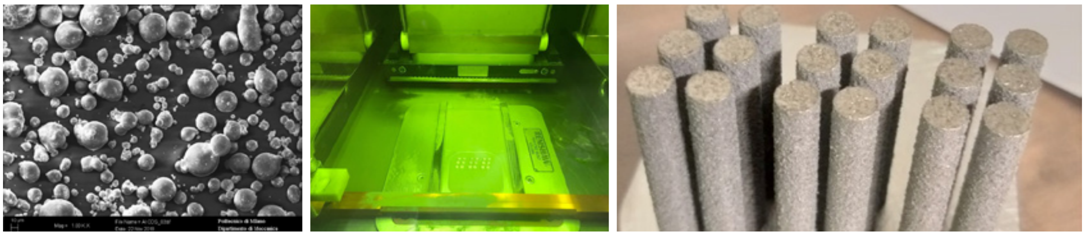


Figure 5 Tests on powder particles and the selective laser melting process and the produced material samples

A lot of consideration has been given to the production process and post production treatment and a lattice structure has been chosen. Due to size limitations, a quarter of the axlebox has been produced and is being tested (see Fig. 6)

The final part of the work package includes a life cycle cost analysis for both the axle box and the bogie side frame. This will be reported on at the end of the project

Figure 6 The prototype additive manufactured ¼ axlebox

WP3 ACTIVE SUSPENSION & CONTROL TECHNOLOGY

Research on active dynamic suspension in rail vehicles has been carried out for several decades. Very few studies, however, reached implementation in commercial vehicles. Reasons for that are increased first cost of the vehicle and a fear for reduced reliability due to more complexity in the vehicles. Another issue that might prevent the introduction of active suspension is that the authorisation process might become unrealistically extensive.

The project addressed these issues by investigating the fault tolerance behaviour of different actuation solutions to increase reliability of active systems. Further, a single axle vehicle concept with only one suspension step was introduced to reduce cost and weight. The basic idea was to start with a simple low-cost concept and to achieve satisfactory performance by introducing active suspension. Finally, the project made proposals for a possible future authorisation process based on procedures already used in other areas than railway vehicles today.

Fault tolerant analysis

In the project a quantitative method to assess the Risk Priority Number (RPN) for a given solution based on Failure Mode and Effect Analysis (FMEA) is developed, RPN = Severity x Occurrence.

The safety evaluation criteria for new rail vehicles in Europe are stipulated in EN14363. When active suspension fails, the increase of the assessment quantities and remaining margin from the limit value reflect the severity levels. The level of occurrence indicates how likely a failure mode is. For a number of actuator failures then the RPN value is determined. The active steering schemes investigated can be seen in Figure 7.

Results show that implementing a redundant actuation system scheme is an efficient method to improve the fault tolerance of an actuation system. The RPN value of configuration C3 for failure mode “harmonic excitation” for example is 4, while it is 20 for configuration B2.

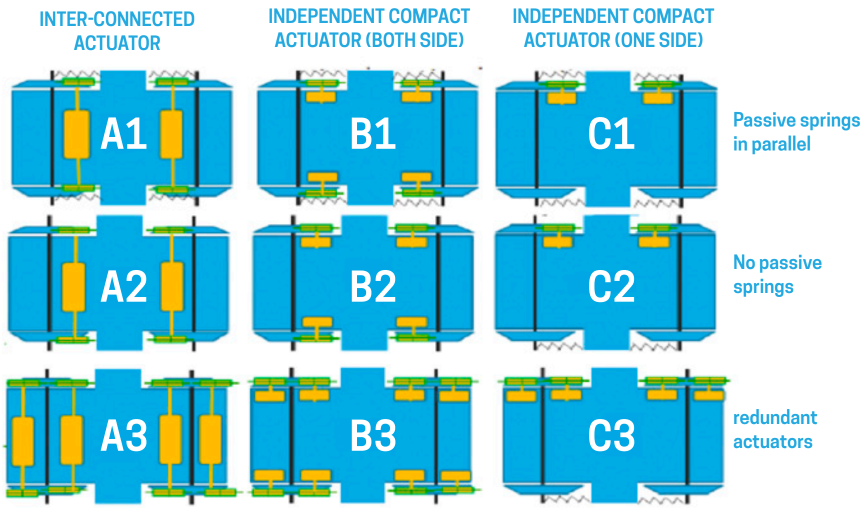


Figure 7 Active steering schemes investigated

Single axle running gear

A reduction of the vertical and lateral vibration levels in the carbody to improve the ride comfort is generally not economically interesting enough to achieve a breakthrough of active technology. A ride comfort improvement has to go along with other features like increased passenger capacity, reduced maintenance cost for vehicle and track or lower vehicle cost by simplified vehicle layout. Therefore, the project proposes the single axle, single suspension step concept shown in Figure 8. The concept is compared with the existing class 8000 trainset from Metro de Madrid. Our calculations indicate that a weight reduction of 400 kg/m is possible.

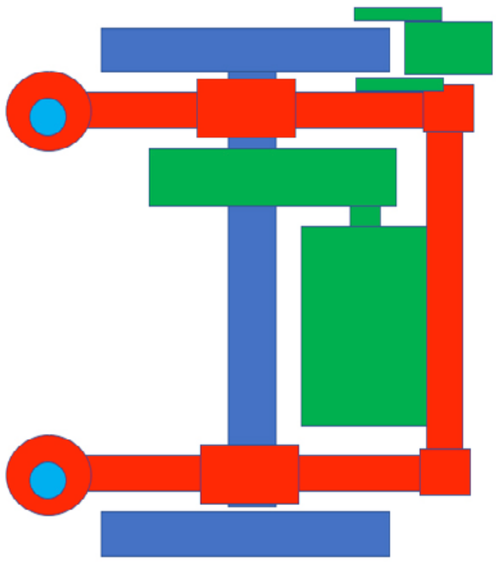


Figure 8 Proposed single axle running gear

As can be seen in Figure 9, the ride comfort of the vehicle without active suspension would be unacceptable. With active suspension however, the ride comfort is good.

With active radial steering also the wheel wear rate can be significantly reduced (70%-90%) compared to the existing class 8000 bogie vehicle, while it would be increased by about 45% without active steering

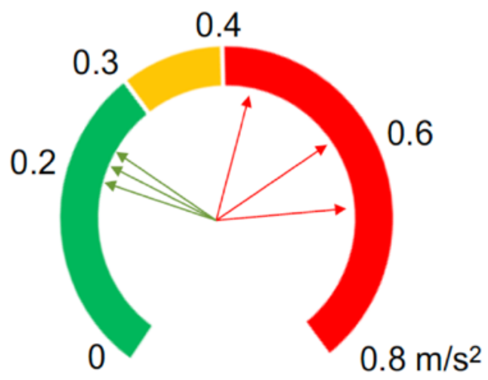


Figure 9
Ride comfort of two-axle vehicle with (green arrows) and without (red arrows) active suspension

Authorisation strategy

One important code of practice is EN14363. The standard, however, is still not completely tailored to new vehicles with active secondary and/or primary suspension components. For secondary suspensions, each fault mode may require on-track tests to be performed again, leading to a high burden even if there is only one fault mode that needs to be tested. For primary suspensions the proliferation of test requirements could become even more burdensome.

EN50129 supports the principles of establishing multiple related safety cases, stating that the following three different types of safety case can be considered:

- Generic Product Safety Case (GPSC) provides evidence that a generic product is safe in a variety of applications;
- a Generic Application Safety Case (GASC) provides evidence that a generic product is safe in a specific class of applications;
- a Specific Application Safety Case (SASC) that is relevant to one specific application.

The approach is illustrated in the authorisation framework proposed in the project has decide to adopt the approach in EN50129. Figure 10 presents the modular set of safety case documents proposed. Templates for the different safety cases are developed and tested for example for an electromechanical actuation. It is concluded that the proposed framework has the potential to become a basis for an authorisation procedure of active suspension systems in the railway area.

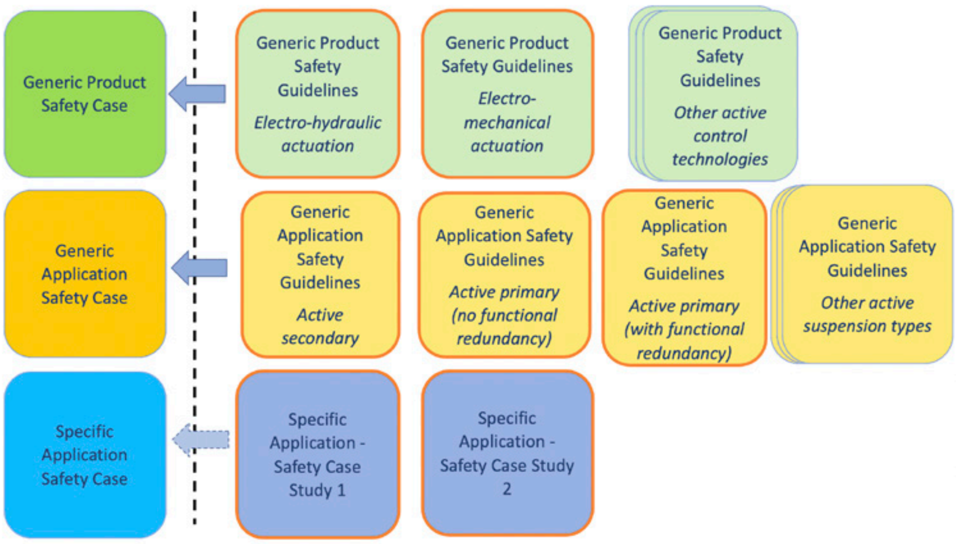
Dissemination activities:

Two papers on active suspension will be presented on IAVSD conference in August 2019

A paper on the proposed authorisation strategy will be presented on WCRR in October 2019.

KTH presented the single axle vehicle concept at a seminar with 150 participants in May 2019.

Figure 10
Framework of safety cases based on EN50126



WP4 NOISE & VIBRATION

The acoustic environment inside rail vehicles is an important aspect of the comfort of passengers and staff. The main source of noise in many situations is generated at the wheel/rail interface. This is transmitted from the running gear to the carbody, (i) through structure-borne paths, i.e. through vibration of the suspension and the bogie frame, and (ii) through airborne paths, i.e. sound impinging on external panels. These paths are complex and current prediction methodologies are not sufficiently reliable. The project therefore aims to develop validated tools and methodologies for predicting the transmission of noise and vibration from the running gear into the carbody. The work is focussed on developing simulation models that can be used as 'virtual test methods' and validating them using field experiments.

Field tests

An extensive test campaign was carried out in March 2018 at the facilities of Metro de Madrid. The purpose of the tests was to quantify experimentally the various airborne and structure-borne paths by which sound is transmitted into the vehicle from the running gear. Static tests were performed to measure the vibration behaviour of the bogie using impact hammer excitation for verification of numerical models of the bogie frame. The airborne sound transmission through the walls, doors, gangway etc. was also measured using a known sound source.

Running tests were carried out on a test track to determine the vibration and noise behaviour of the bogie under running conditions. Moreover, the characteristics of the test track, such as rail roughness and track decay rates, were also measured. These results are used for validation of the completed models.

Virtual test methods for airborne and structure-borne noise transmission

Models have been developed for both airborne and structure-borne transmission. A target vehicle has been selected based on one of Metro de Madrid's vehicles, as used in the field tests, and a finite element model of the wheelset and the bogie frame has been produced (see Figure 11). This has been verified against the static field tests.

The airborne noise is modelled using the TWINS model. Although this is well-known and widely used, particular attention had to be paid to the way in which the sound propagates beneath the vehicle and around the outside of the carbody. For the propagation beneath the vehicle a statistical energy analysis approach was used while for the sound propagation around the sides of the vehicle a so-called 2.5D boundary element approach has been used. Both of these approaches have been verified against the field measurements (Figure 12).

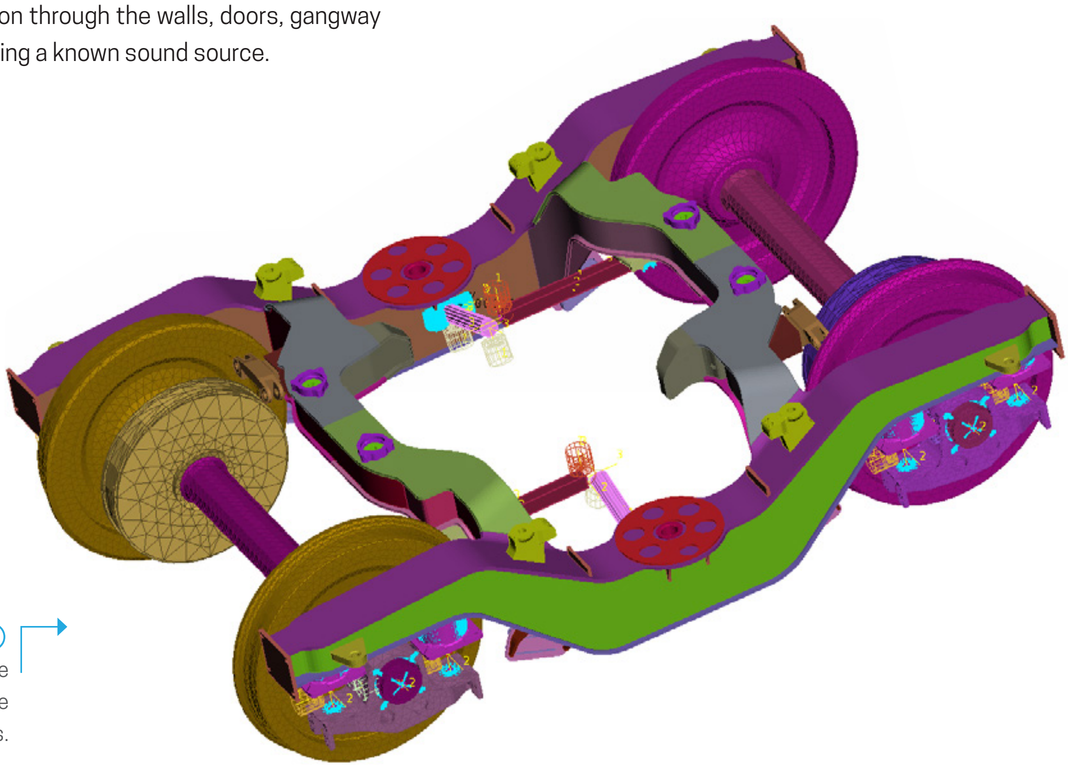


Figure 11
Finite element model of the bogie used for structure-borne noise calculations.

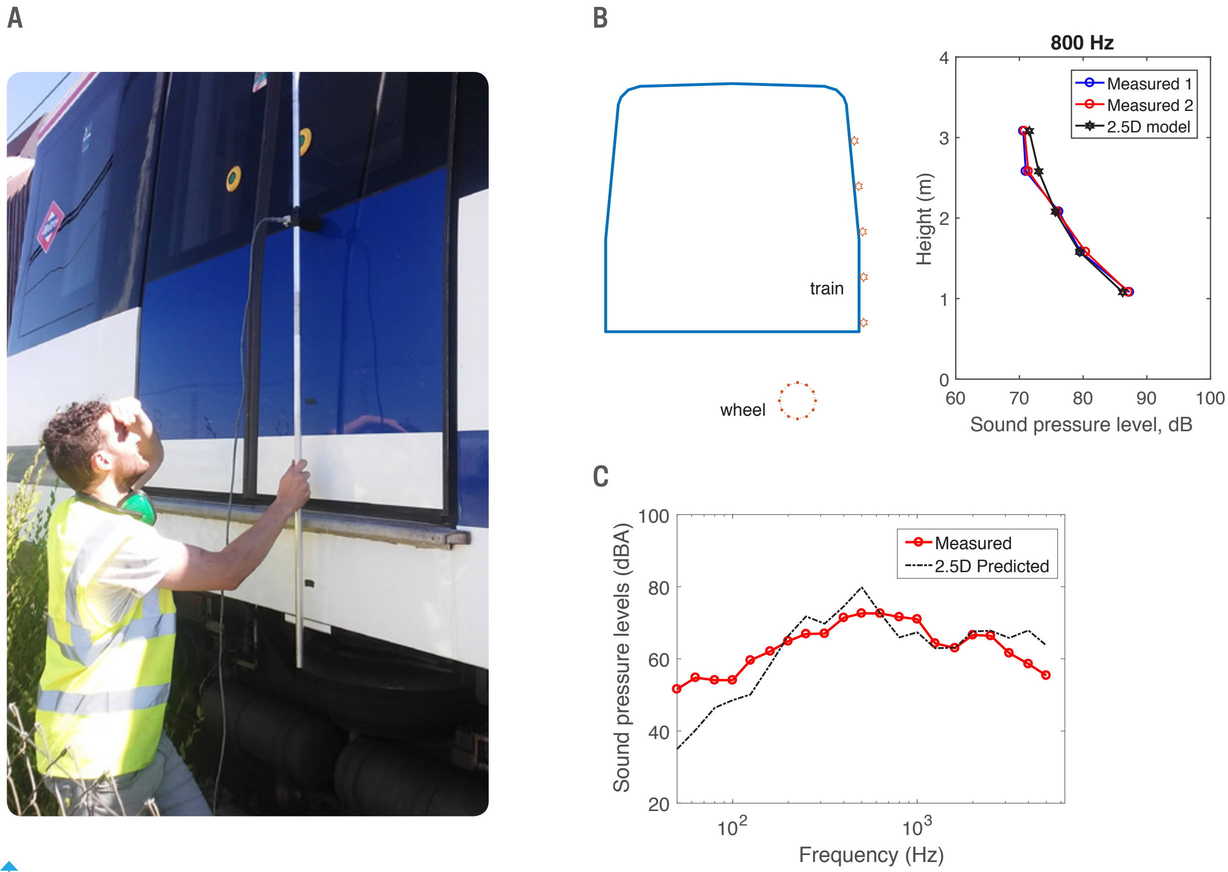


Figure 12 **A** : Measurements from a source under the train to the sound pressure on the sidewall;
B : Comparison with predictions using 2.5D model;
C : Example of noise on the sidewall predicted using 2.5D BE model and measured during train passage

Characterising suspension elements

The suspension elements, such as springs and dampers, and other connections such as traction bars, form an important part of the structural transmission path. However, their behaviour is complex due to internal resonances and non-linear material behaviour. Consequently it is necessary to determine their properties using laboratory tests. Measurements were carried out on a rubber primary suspension spring, a lateral damper and a traction bar. In the latter cases the rubber bushings are critical components and so these were studied separately. From these measurements, reduced-order models have been developed that can be combined with the model of the bogie frame to form the overall structure-borne noise model.

Noise reduction technologies including new materials

The newly developed and validated models are being used to study techniques for reducing noise and vibration transmission from running gear in order to improve passenger comfort. The models are used to find the critical paths and to optimise the structure. The implications for noise of introducing new lightweight materials and active control solutions developed in other parts of the project are also being assessed. The possibility of using magneto-sensitive rubber to control vehicle hunting is also being investigated.

Dissemination activities

Two papers on this work will be presented at the IWRN conference in September 2019.

IMPACT ASSESSMENT

The cross-cutting impact assessment work stream of RUN2Rail aims at supporting the end-users of RUN2Rail results in quantifying their impacts: costs and benefits for the rail sector stakeholders, economic impacts outside the sector, environmental and social impacts for governance. Impacts on Regulatory & Standardisation (R&S) have been given special attention and are managed separately.

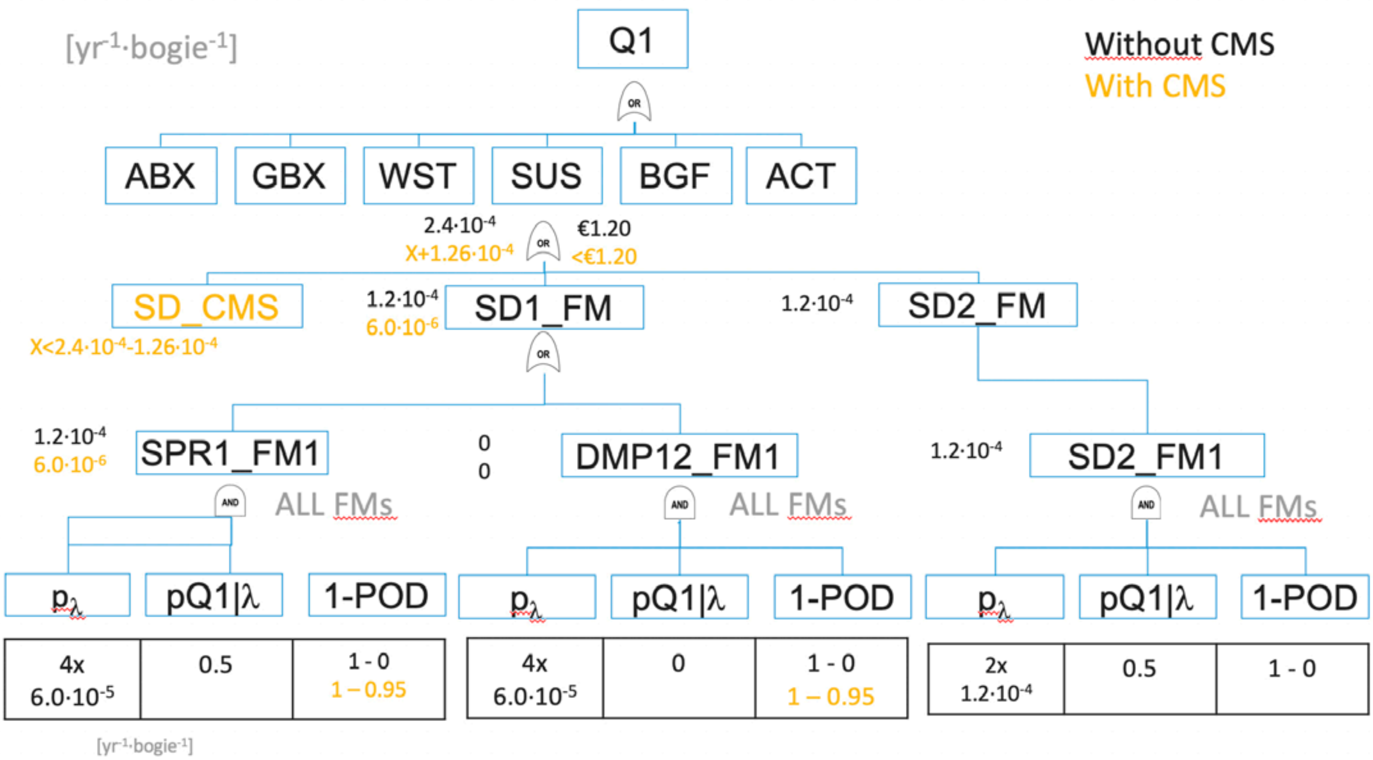
Some key questions have been addressed and the results are being incorporated into the deliverables for WPs 1, 2, 3 and 5. Some indications on the progress regarding the key questions are given below.

- **How can condition monitoring improve maintenance?**

The findings of WP1 are summarised and put together by imagining the running gear for a metro trainset to be equipped with some of the innovations proposed: wheelset, gearbox, suspension monitoring. The case study for RUN2Rail comes from its consortium member Metro de Madrid. The information on its series 8000 trainset, including failure rates of running gear components, are used to develop a Fault Tree Analysis (Figure 13) which fits into ROLL2RAIL's Universal Cost Model UCM to make some initial quantifications of operational unavailability (Q) and hazard (H) costs. It is found that, apart from the failure rates, key information is the probability of a failure in generating a particular type of unavailability or consequence of a hazard. Information for this is generally not collected, so some assumptions are made. Moreover, the probability of detection of a fault in time to prevent the consequence is needed. Some assumptions are made for this based on findings in WP1.

The methodology developed sets requirements for the reliability of the CMS and supports the decision of whether a CMS for each particular subsystem is convenient or not.

Figure 13
Fault Tree Analysis methodology integrating the Universal Cost Model to quantify unavailability cost improvements due to the introduction of a suspension CMS

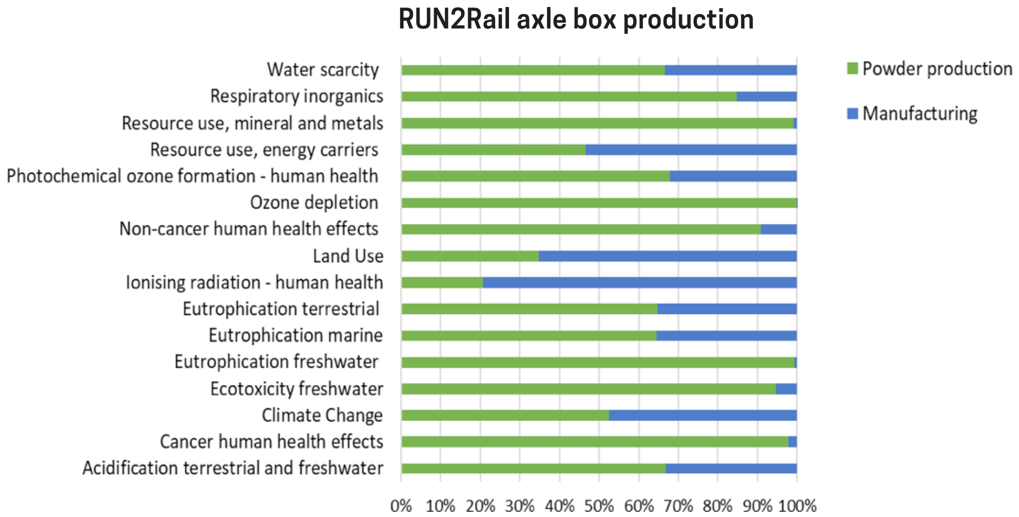


- **What are the environmental impacts of novel materials and manufacturing processes?**

A key potential impact of the introduction of novel materials and manufacturing processes involves stakeholders outside the rail sector – environmental impact. Based on the on the ILCD guidelines issued by DG JRC/IES, a cradle-to-gate quantification of several environmental aspects is performed, that might arise due to the introduction of Additive Manufacturing or robotic layup of carbon fibre for smaller running gear parts such as axle-box and/or side-frame.

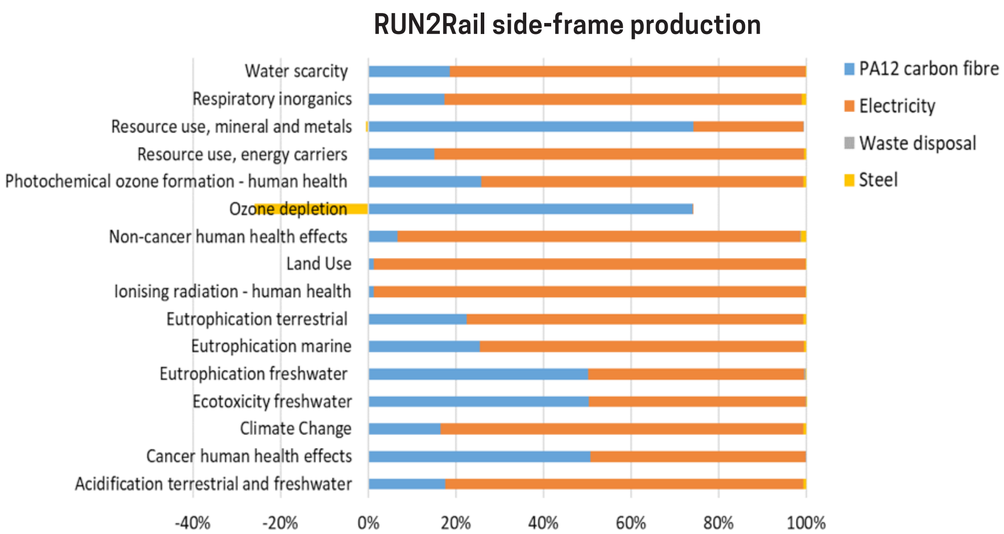
Comparing the RUN2Rail solution (i.e. AlSi7Mg axle box via Additive Manufacturing) with the benchmark one (i.e. steel axle box via sand casting), results highlight that it leads to many benefits from the environmental point of view. It is worth considering that the RUN2Rail axle box is lighter than the benchmark one, thus its use in a trainset during its lifespan (i.e. 30 years) would reduce the environmental and economic impacts, thanks to energy savings. More in detail, considering the RUN2Rail axle box production chain, the powder production is the major contributor of the environmental burden (see Figure 14).

Figure 14
Environmental impact of Additive Manufacturing for the axle-box



Similar considerations apply to robotic layup of carbon fibres to manufacture a bogie side-frame. The RUN2Rail lightweight side-frame applied to a trainset would lead to decrease of environmental impacts, despite the high energy consumption within the manufacturing phase (see Figure 15).

Figure 15
Environmental impact of RUN2Rail lightweight-side-frame production



REGULATORY AND STANDARDIZATION ISSUES

Another key question that has been addressed is the following:

- What needs to be done to make authorisation of vehicles with active components inexpensive, easy and safe?

  This is one – probably the most important – of the several aspects addressed by RUN2Rail that is related to R&S issues.

It has been the core item of discussion with RUN2Rail's R&S Advisory Group, comprising representatives from ERA, CEN and the SHIFT2RAIL Call-For-Members project PIVOT. Interactions started in summer 2018 and progressed regularly (tele-conference 17/12/2018, e-mail update 18/04/2019, tele-conference 19/06/2019). The diagram (Figure 15) discussed in the last tele-conference shows how the RUN2Rail WP3 work could fit into the regulatory framework. It was also suggested that in the shorter term active systems could go through the "innovative solutions" channel of the TSIs, and in the longer term it is hoped that the methodologies developed will become established codes of practice.

R&S issues related to condition monitoring, materials/ manufacturing process, and noise are also being reported in the deliverables.

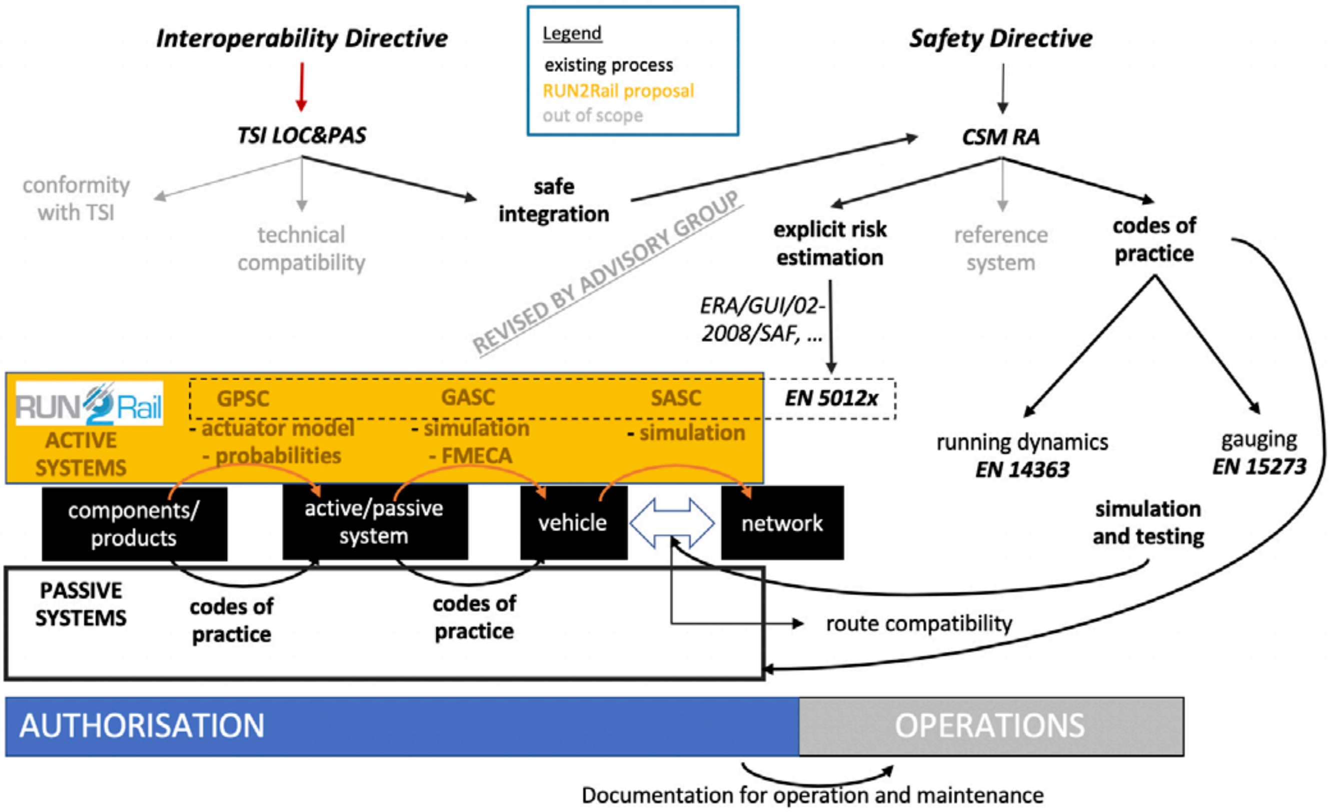
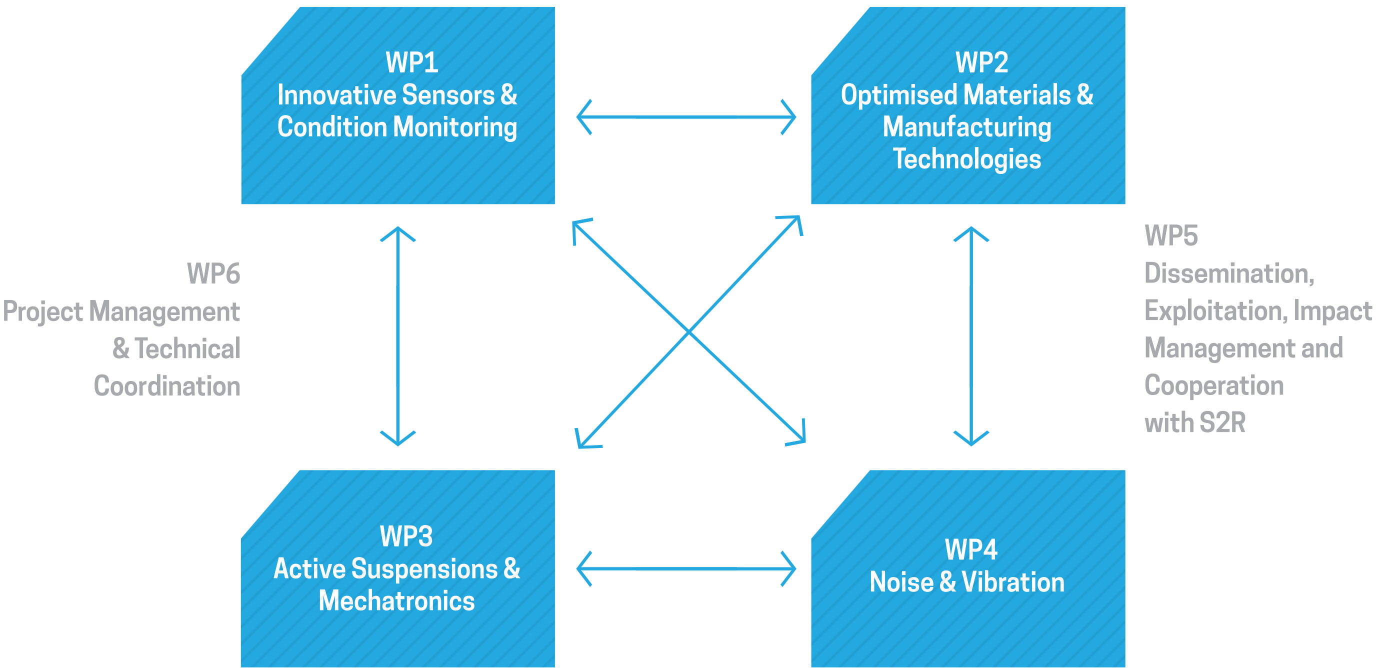
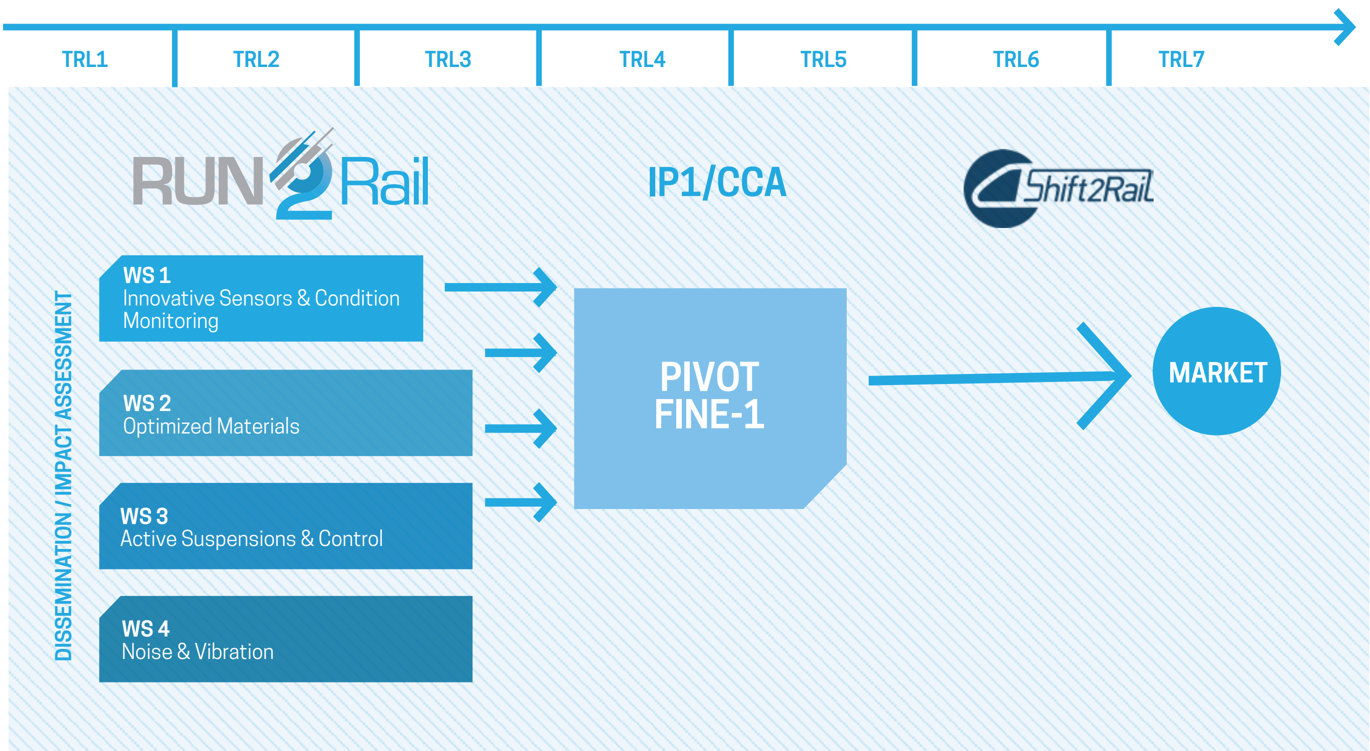


Figure 16
integration of WP3 authorisation strategy into the R&S framework

PROJECT STRUCTURE



RUN2RAIL WITHIN THE S2R ENVIRONMENT



PARTNERS

PROJECT COORDINATOR

TECHNICAL LEADER

BENEFICIARIES

FACT AND FIGURES

Total Project Value
2.7M €

Duration
24 Months

Partners
15

Contact us
Marta Andreoni (UNIFE)
Project Coordinator
Marta.andreoni@unife.org
www.run2rail.eu

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