The railway sector faces an increasing complexity and diversity of factors that directly affect its competitiveness. Due to the liberalisation of the market and digitalisation, the European railway market must adapt accordingly. In the future, condition-based and predictive maintenance will play a key role for identifying additional potential in terms of cost-effectiveness and revenues in the use of existing assets.

The high-level objectives for the rail system are:

- Reducing operational costs of rolling stock and infrastructure
- Maximising availability of rolling stock and infrastructure

From corrective to predictive maintenance

In order to achieve these goals, a change in maintenance strategies can be observed on the market. Maintenance plans with settled time intervals are increasingly replaced by maintenance systems, based on condition monitoring and predictive analysis. Therefore, reliable and robust methodologies must be developed, which extract the following information out of field data from the railway system:

- Current status to enable condition-based maintenance
- Future status to plan activities on a strategic and operational level
- Impact of measure to verify changes in the system

With the help of powerful, reliable and cost-effective sensors, communication units and computing platforms - to process mass
data and evaluate them with the aid of algorithms – it is now possible to identify, simulate and interpret patterns in operating parameters. These factors enable a more exact prediction of the remaining useful lifetime and the consolidation of all operating data in a higher-level overall system. The ability to create accurate predictions opens the door to targeted and well-founded decisions, especially in maintenance.

At VIRTUAL VEHILCE the working group Digital Operation Rail Systems acts as a partner for developing solutions (algorithms and tools) by providing the following key factors:

- **Context-based knowledge:** System knowledge is crucial to provide and develop solutions within the complex railway system. The interaction between vehicle and track as the interaction prognosis has a significant role in the field of railway operations.

- **Context-based method selection:** The aim-oriented and intelligent combination of approaches and methods is the key to provide an optimal decision basis for maintenance systems. Depending on the issue or target component of the system, different combinations of methods (e.g. model-based and/or data-driven) lead to a reliable and robust solution.

- **International partner network:** With our broad partner network of industry and science we can offer an environment in which complex issues can be answered.

### Our research aspects

Knowledge, methods and tools must be available and in place to establish a decision basis for maintenance systems. Fig.2 shows an overview of our approach of developing solutions for maintenance support.

As mentioned before, context-based system knowledge is the key to provide an optimal basis for decision support systems. Different questions and components require different methods and approaches for the development of solutions. Target components for continuous vehicle and continuous track monitoring can be:

- **Rolling stock:** Coupling elements (e.g. spring, damper, bushings, etc.); vehicle dynamics (e.g. stability, ride comfort, safety against derailment, etc.); wheelset (e.g. monitoring of wheel profile wear)

- **Infrastructure:** Track geometry (e.g. monitoring from axle box sensors by in-service vehicle); switches (e.g. condition of the geometry) and superstructure

For these components the questions about the current and future status must be answered. Tools and frameworks must be available to develop such solutions. These frameworks allow a structured and effective development of monitoring algorithms under the aspect of our context-based combination of different approaches - the so-called "Triple Hybrid Approach" (THA).
VIRTUAL VEHICLE provides the following frameworks:

- **Health Monitoring Framework**: Providing methods and tools to monitor and estimate the current status (healthiness) of the target component. The main task is to describe the system behaviour by model-based and/or data-driven approaches.

- **Prognosis System Framework**: Predicting the future status of the target component by modelling approaches. This allows a change in maintenance from fixed time intervals to a real condition-based approach.

- **Prescriptive Analysis Framework**: This is the most challenging part in the Digital Operation concept. This framework allows measuring the impact of changes in the system (e.g. estimation of system behaviour and maintenance effort when replacing a spring-damper by a novel concept).

The basis for this development is an adequate infrastructure (hardware and software), which consists of the following parts:

- **Data acquisition**: Sensors and measurement systems (on-board & wayside) for monitoring the components
- **Data transmission**: Safe and efficient systems and the knowledge of transmission
- **Data management**: Big data volumes and complex information must be managed in an efficient way to run easy analysis.

**Conclusion**

Based on extensive expertise in Digital Operation (railway and automotive), VIRTUAL VEHICLE provides methods to integrate all relevant aspects into the monitoring and maintenance process in a systematic and customer-specific way. Reliable and robust methodologies are developed under the aspect of context-based combination of different approaches (Triple Hybrid Approach) as well as based on context-based system knowledge at VIRTUAL VEHICLE.