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# **Transformative Maintenance Technology for Railway Assets: Issues, Challenges and Future Direction**

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## **Abstract**

A key challenge for the modern-day railway sector is to improve its competitiveness while ensuring reliable and sustainable mode of transportation for passengers and goods on demand. To meet these challenges, the strategic focus of the railway sector has been to find transformative technology and business solutions for the railway assets that will ensure safe and failure free railway asset operation and maintenance at the lowest cost. Accordingly, managers in railway sector have aligned their strategic thinking towards asset wide application of digital technologies for achieving excellence in asset operation and maintenance. However, these digital transformation journey needs to resolve many issues and challenges, namely technological, business and governance related challenges to make railway sustainable and economically viable. The paper presents a short description of such digital and enabling technologies, associated issues and challenges, together with future trends.

**Keywords:** Digital technology, Data driven decision, Maintenance technology roadmap, Artificial Intelligence (AI).

## **1 Introduction**

In the past, railway assets were overdesigned and underutilized making the need for maintenance planning non-existence. With passing years, these assets (infrastructure and rolling stocks) are getting old and, at the same time, their utilization has increased manifold mainly due to societal consciousness about climate and railway being

marketed as the most sustainable mode of transport. The major challenge is to find the time slot to perform maintenance on the infrastructure and rolling stocks to maintain its functionality and ensure safe train operation. Furthermore, railway systems have complex technologies, with a wide range of standard maintenance solutions and organization forms. Maintenance process of railway assets, especially infrastructure which can be described as linear and distributed asset is unique in its complexity. In the past, railway has been deploying standard technologies and tools required to maintain the railway assets in a routine manner which has failed to meet the challenges faced by increase in demand on capacity.

The above-mentioned challenges have led to implementation of new and emerging technologies in search of innovative solutions as and when it is economically and technologically viable. These technologies can be broadly classified as supporting, optimizing and transformative technologies, as outlined in Figure 1, and collectively provide the foundation for the predictive technologies, being used for the estimation of the Remaining Useful Life (RUL) of assets. Condition monitoring, multiphysics simulation, RAMS (Reliability, Availability, Maintainability and Safety) modelling, LCC (Life-Cycle Costs) analysis, etc. arrive at the correct optimal maintenance decision form the core of supporting and optimizing technologies. Other technologies such as Virtual Reality (VR), Augmented Reality (AR), predictive and prescriptive analytics, Industrial Internet of Things (IIoT), 5G communication technologies can offer near perfect solutions (even in real time) for the maintenance of the ageing railway assets and are collectively termed as transformative technologies.

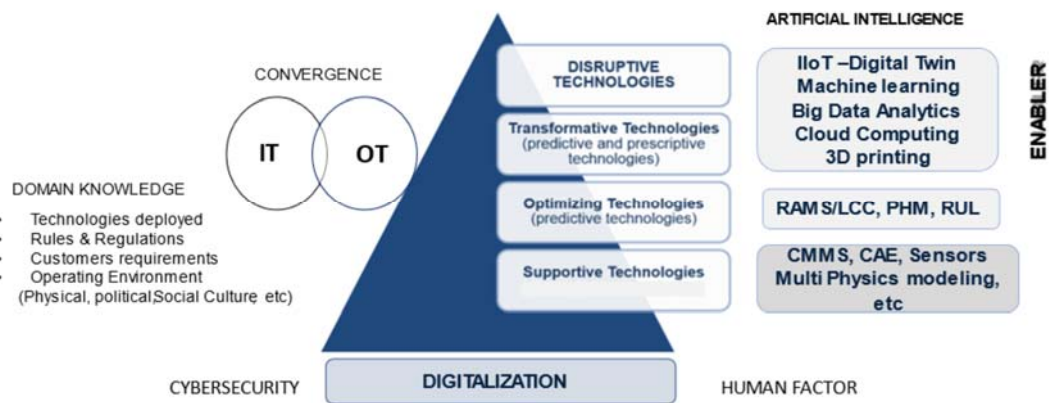


Figure 1: Transformative maintenance technology framework

The transformative technologies facilitate or are expected to facilitate correct decisions and actions at the lowest possible cost using the power of predictive and prescriptive analytics by the railway managers. Such solutions are expected to support railway’s digital transformation journey and operations goals. Furthermore, for the successful development and implementation of transformative technologies and solutions, there is a spoken need for the convergence of the Operational Technology (OT) and Information Technology (IT).

At Luleå Railway Research Center, which is identified by Swedish National Road Administration as a partner to build excellence in railway maintenance, have developed a framework for digital transformation of maintenance process and formulation of maintenance technology roadmap, as represented in Figure 1. As highlighted, for successful implementation of transformative technologies, a deeper insight into railway engineering and business domain is a must.

## **2 New Technology for Railway Maintenance**

As indicated in the framework, the effort to develop and implement new technology is founded on digitalization of railway assets. The digitalisation process in industry and the corresponding implementation of AI technologies require availability and accessibility of both data and models. Data and models are considered digital assets that affect system's dependability during its whole lifecycle.

### **2.1 Maintenance Technology Roadmap**

Maintenance Technology Roadmap is a high-level visual plan which shows the organization's maintenance technology strategy in relation to corporate technology strategy, maintenance technology procurement, development and implementation plan with milestones and required resources. It provides directions for digitization, digitalization and digital transformation of maintenance process.

- Digitization is the process of converting analog information to digital format. It is the conversion of information (i.e., objects, images, sounds, documents, data, etc.) into an electronically stored digital format that can be accessed with right tools, authorization and infrastructures.
- Digitalization is the process of leveraging value hidden in the data to improve business processes. Digitalization facilitates use of digital technologies and data to visualize the physical health of the asset and develop optimal solution for the operation and maintenance.

In summary, Digitisation encompasses technologies that are aimed to enable the process of transforming analogue data to digital data. Digitalisation on the other hand encompassed to the provision of digital services which creates value to its user. Examples of digitisation technologies relevant in railway transport are:

- Stationary sensors detectors – for measurement of wheel geometry, light beam, noise, loads, angle-of-attack, current, etc.
- Mobile sensors – for measurement of cracks, speed, noise, light beam, thermal, position, fluid, weather, navigation etc.

Data from these sensors are necessary to enable data-driven maintenance actions. However, even though data is a must for implementing a data-driven approach, data itself is of no value. Data must be processed for data integration, data filtering, data

processing, and data visualisation, etc. Data-driven approach is often associated with the processing a vast amount of data.. In industrial context, it is often assumed that necessary data is acquired and available, but in practice the availability of high quality and right type of data and measurements are limited. In order to overcome the lack of data for analytics, augmentation techniques have been developed. Data augmentation refers to techniques that are aimed to generate new synthetic datasets based on original datasets, e.g. by copying and slightly modifying or enriching the features in a datasets. For example a coloured photo can be augmented by generating a grey-scaled-version of the same photo, and both the photos can then be fed to the AI-engine to increase its recognition capability. These techniques are commonly used in learning phase of AI ( Karim, 2021).

- Digital transformation is the transformation of business activities, processes, products, and models by use of digital technologies to create added value in the business process. The main goal is to facilitate correct decision making considering several contextual variables to optimize maintenance decisions considering total business risk, as represented in Figure 2. Digital transformation is enabling railway managers to keep pace with evolving customer requirements to customized business solution by integrating changing needs in real time without deploying additional resources [1].



Figure 2: Digitalization and digital transformation

## 2.2 Automation, Robotics and AI in Railways

Automation, Robotics and AI are key drivers for improving railway sector maintenance practices and reliability. Automation of track and vehicle inspection have improved and accelerated the decision-making process for maintenance. The deployment of robots and application of digital twins have changed the way maintenance tasks (failures) are identified, corrective measures are planned and executed by maintenance engineers.

During the last two years, railway sector has seen an exponential increase in application of robot dogs and UAV drones and digital twins to manage the business of maintenance more effectively and efficiently.

- Robot dogs are increasingly being used for inspection of vehicles and, in some cases, for inspection of tracks. Robot dogs are designed to be able to move up and down stairs, unlike mobile wheeled robots and have replaced human for inspection of vehicles and infrastructures. These robots would not only localize faults, but also do some initial maintenance actions and, hence, the overall inspection and maintenance downtimes will be significantly reduced.
- Drones have recently gained popularity for track inspections. Images are usually processed from the front camera of the drones. Fast image processing and analysis will be used in the near future in drone-based track inspection. A combination of dogs and drones will enhance the capability of digital twins in a day-to-day management of rain operation and maintenance planning [2].
- Digital Twins are defined as a digital representation of a physical asset, system or process designed to detect, prevent, predict, control and optimize through real time analytics to deliver maintenance engineering and business solution.

### **3 Some Examples of Industrial Projects**

All over the world railway sector is challenged with increasing demand on reliability of services at the lowest possible cost. With this in mind, railway sector is busy developing and adapting new transformative technology to ensure high level of reliability and quality of services to meet the customers demand. As digital technologies are being perceived as possible solution to meet these challenges, it has resulted in several Research Development and Innovation (RDI) projects for digital transformation of operation and maintenance process in railway sector. In the following some of the Swedish Projects are presented:

#### **3.1) Train based Differential Eddy current sensor System for Detection of Missing Rail Fasteners - Lindometer**

Inspections of railway track and its components are carried out at regular intervals, and usually take place via manual inspections or by employing special measurement trains. However, such measurement methods are difficult to implement during regular train traffic and usually requires a clear view, which is not always the case when the track and its components are submerged under snow or sand. In a collaboration with Bombardier (now Alstom), a robust measurement system Lindometer, based on magnetic field measurement, was developed to detect deviations and defects along a railway track. The work was initially focused on inspecting the status of railway fastening systems and has attracted a great deal of attention within the European rail

research program- Shift2Rail. The work has included numerous field tests and tests from different locomotive types, where excellent results have been demonstrated. Fastening systems with missing clamps have been identified and distinguished from intact fastening systems at speeds up to 70 km/h. Theoretically, this speed can be increased in future tests.

Figure 3 shows the field measurement carried out along the iron ore line in Sweden, using the sensor system mounted on a freight train. The sensor was successful in capturing all the fastener signature from a distance of 110mm above the railhead, during an actual train measurement. Signal processing techniques and feature extraction methods were used to extract useful informations from the raw signal pertaining to the fastener signature. Unsupervised anomaly detection techniques based on machine learning algorithms were implemented to identify and segregate the anomalous data points from the healthy or normal fasteners. Figure 4 and Figure 5 depicts the output of the detection algorithm for a measurement carried out over a track section of approximately 2.5 km. The detection algorithm was able to detect all the anomalous points precisely and separate them from the healthy group of points. Further, the proposed clustering model was also able to detect missing clamps (both one and two) from fastening systems and weld joints and segregate them with distinct boundaries.



Figure 3 Lindometer mounted on iron ore locomotive of Icab

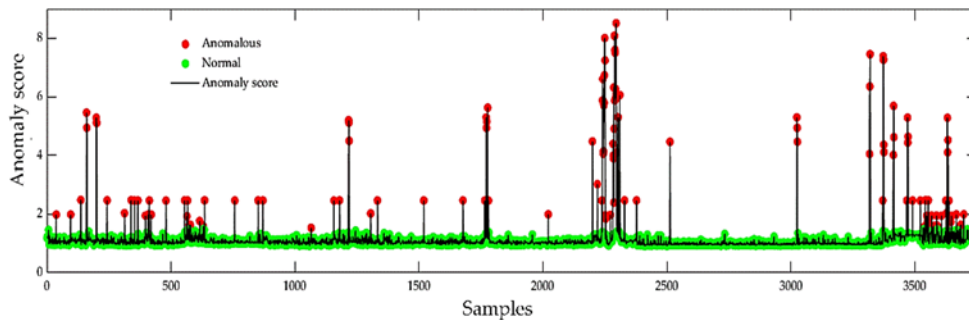


Figure 4 Anomaly score of the detection model. Anomalous points are marked with red indicators and normal/healthy fasteners with green indicators

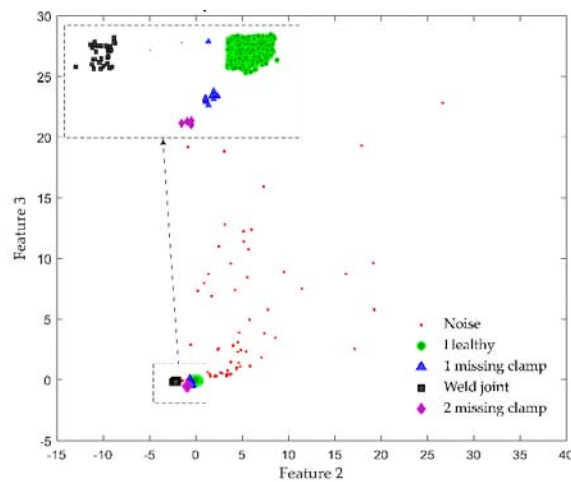


Figure 5 Scatter plot for clusters formed with the detection model

This work is a typical example of *transformative inspection technology* where metrology solutions in combination with Artificial Intelligence have been able to create a new robust way of detecting defects along the railway tracks. Further studies are now ongoing where other types of defects such as rail breakages or other rail damages will be analysed. It is expected that the Lindometer system will be able to facilitate the effort to get a digital representation of the technical integrity of the track and reduce the number of manual inputs along the rail networks ([www.jvtc.ltu.se](http://www.jvtc.ltu.se)).

### 3.2) IN2SMART (Shift2RAIL Project)

The project IN2SMART facilitates optimal planning and scheduling of track geometry maintenance through a decision support tool providing status of the track geometry condition, the maintenance needs, and the available scenarios necessary for maintenance planning and scheduling. Figure 3 shows the basic building blocks of the decision support tool.



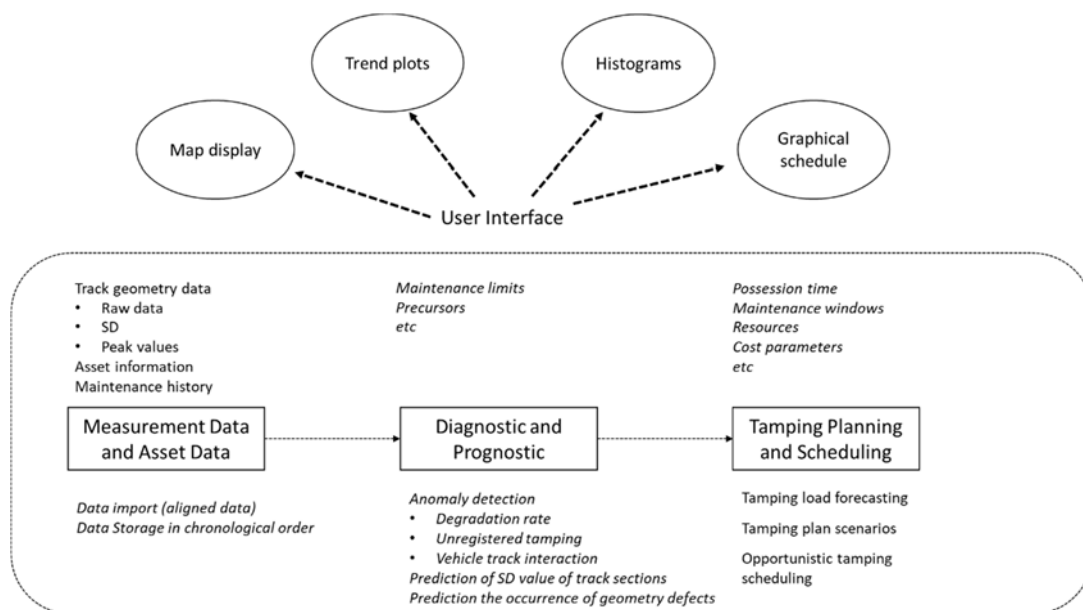


Figure 6. Design of decision support tool for track geometry maintenance planning

Different data-driven algorithms for anomaly detection, prediction of **SDLL** (Standard Deviation of Longitudinal level) values of track sections, and prediction of the occurrence of single defects are developed within this project. To predict the track geometry degradation rate in different locations of track, Artificial Neural Network (ANN) model is applied, where different influencing factors have been considered. The proposed predictive models within the project are used to simulate long-term track geometry behaviour considering different maintenance and inspection scenarios. The main parameters feeding the track geometry diagnostic and prognostic process are the geometry measurement and asset data, maintenance limits, and precursors. The main outputs from the projects are tamping load forecasting, tamping plan scenarios, and opportunistic tamping schedule which will facilitate opportunistic maintenance of track geometry. The decision support tool developed during the project also provides an assessment of current geometry state and provides prediction of the future track geometry condition.

### 3.3) AI Factory for Railway

This umbrella project has several ongoing projects aiming at transform the way maintenance is performed in railway sector by exploiting the power of new technology: For example: Prognostics and Health Management of Catenary System, Augmented Asset Management, Cyber Security, ePilot, Digital Railway Switches and Crossings, Predictive maintenance for railway wheel sets, etc. For details see [www.jvtc.ltu.se](http://www.jvtc.ltu.se). Digitalisation and implementation of AI in railway characterised as



a linear and distributed asset is a challenging task as it is multidisciplinary in nature involving and engaging an array of technologies and professionals with different backgrounds.

With this in mind, during the year 2020 Luleå Railway research Center, in cooperation with a number of Swedish railway stakeholders, namely fleet managers, railway undertakings, infrastructure managers and Original Equipment Manufacturers (OEM), has launched an umbrella project to build a universal AI platform 'the AI Factory for Railway (AIF/R). The purpose is to facilitate railway sector to create new data driven solutions for operation and maintenance of railway sector, digital technology and tools and , digital technologies, digital transformation road map , etc. Within the framework of project 15 use cases representing different interest groups have been identified in close cooperation with stakeholders. The purpose is to facilitate seamless integration of data from on board sensors (monitoring track condition, way side sensors monitoring trains physical status through monitoring the temperature vibration) and ERP of the operating companies providing status of the available resources, customer requirements in real time so that correct and most appropriate decision regarding repair and maintenance action can be taken ( even in real time) . The AI platform essentially includes big data analytics, considering different operating environment such as moisture, temperature, snow fall and rain) .

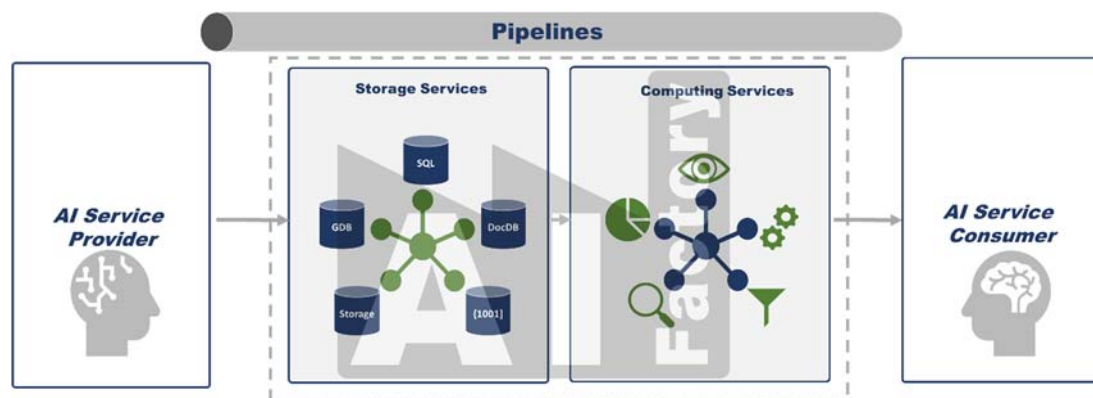


Figure 7. Generic concept of 'AI Factory'

### 3.4) PHM of Railway Catenary (An architecture for predictive maintenance using 3D imaging: A case study on railway overhead catenary)

Prognostic and Health Management (PHM) of Railway Overhead Catenary (ROC) is necessary to improve the dependability of railway operations. PHM of ROC can be enhanced by implementing a data-driven approach. A data-driven approach to PHM is highly dependent on the availability and accessibility of data, data acquisition, processing and decision-support. Acquiring data for PHM of ROC can be used through various methods, such as manual inspections and specialised equipment. Current methods of inspection of ROC are time-consuming and costly. Another approach for assessing the health of ROC is through condition monitoring using 3D scanning of ROC utilising LiDAR technology.

Presently, 3D scanning systems like LiDAR scanners present new avenues for data acquisition of such physical assets. Large amounts of spatial data can be collected from aerial, on-ground, and subterranean environments. Handling and processing this large amount of data requires addressing multiple challenges like data collection, algorithms, information extraction, information representation, and decision support

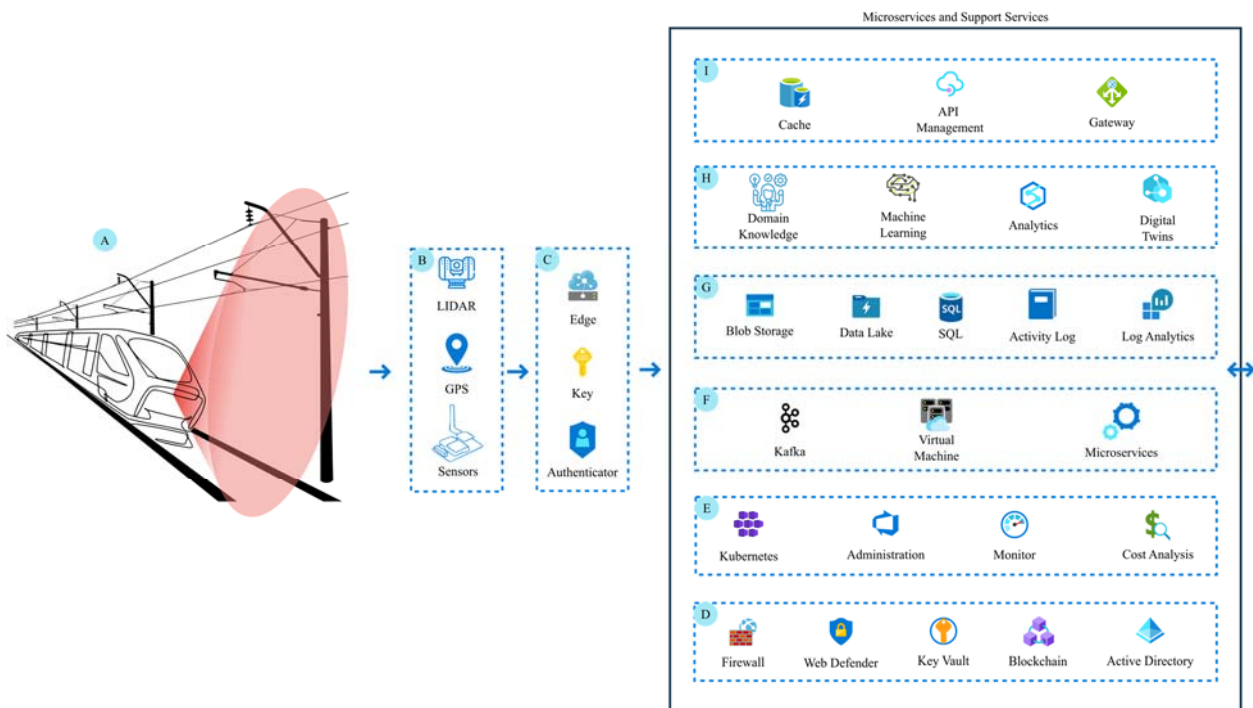


Figure 8. Microservices base architecture for point cloud data processing

tools. Current approaches concentrate more on data processing but lack the maturity to support the end-to-end process. based on utilisation of LiDAR technology.

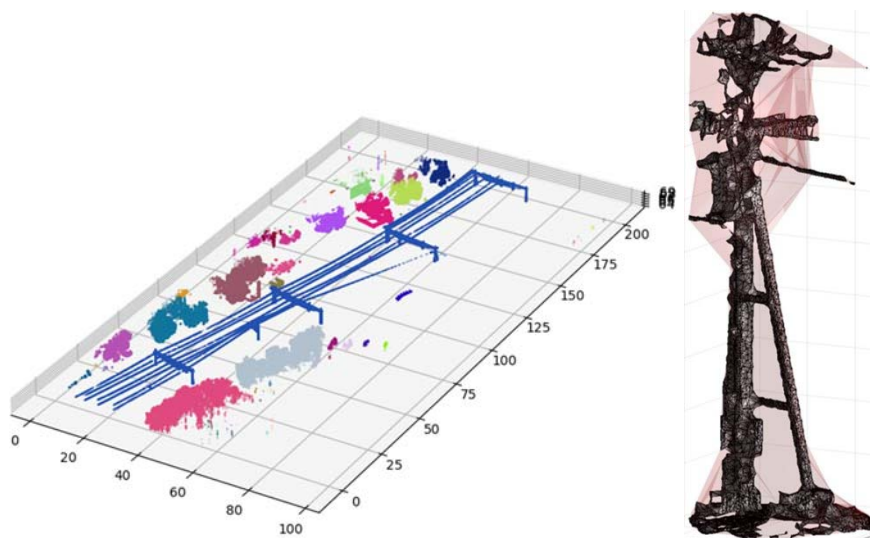


Figure 9 . PCD Clustering and 3D models

### 3.5) The Digital Railway Switches

The project has developed AI empowered demonstrator that shows that it is possible to correlate the measured vibration in the point machine against actual wear and damages in different positions using artificial neural network as demonstrated by experiment on the test rig using full size test bogie. Now the demonstrator is ready for full scale trial . If succeeded ,a new digital technology will be deployed for monitoring the health of Switches all over the Sweden . This will reduce the traffic disruption and considerably reduce the cost of maintenance. The project was funded by Swedish Government and Swedish Transport Administration.

### 3.6) Fr8RAIL – Predictive maintenance for rolling stocks

The Project deals with development of functional requirements for sustainable and reliable European Rail Freight and is funded by EU under Shift2Rail Program. The purpose is to develop a methodology based on extracting temperature signatures of train wagons from the Hot Box/Hot wheel measurements to ensure the quality of data between different detectors. These deviation could give rise to false alarms and may also affect the preselected features used for prognostics purposes.

### 3.7) Adapting Urban Rail Infrastructure to Climate Change

The Adapt Urban Rail goal is to improve the resilience of urban railway infrastructure from adverse future climate conditions by implementing climate adaptation strategy in design,

construction, operation, and maintenance. The goal will be achieved by developing a solution that integrates urban railway infrastructure features with climate change models and Satellite images and climate data. One of the important outcome will be adaptation of maintenance regime in railway sector to climate change ( see Figure 10) .

*This project addresses the following targets:*

- Better understanding of the climatic impact mechanism, causal relationship and trend projection of climate change for urban railway network.
- Developing resilient solution for urban railway infrastructure by integrating climate change model and satellite data in operation and maintenance plan.
- Developing cost benefit analyses for urban railway climate adaptation.
- Climate change risk and vulnerability analyses for urban railway network.
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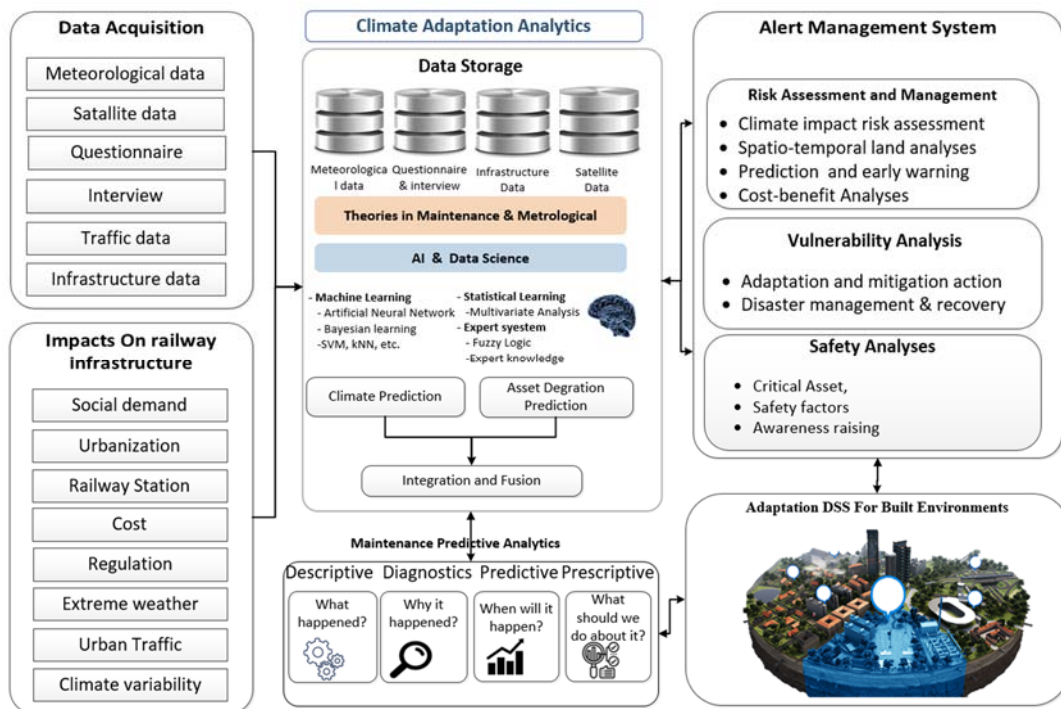


Figure 10 : Overall methodology and process

If succeeded the project will provide new technology empowered decision tool to plan and adapt operation and maintenance actions to climate change without any ( major )disruption in traffic.

## **4 Issues and Challenges Associated with Implementation of Transformative Technologies**

Data-driven approach has been evolved significantly during the decades. With the emergence of AI technologies and digitalisation, the data-driven approach has become a tool for industry in general and the transport industry in particular. Today in transport industry, there are number of promises associated with the data-driven approach such as fact-based decision-making, capability of prediction of remaining useful life of assets, improved capacity, cost efficiency and improved sustainability with respect to environment, technology and economy [3].

The following challenges are associated with data driven decision making that need to be addressed:

- Governance – governance of a digital infrastructure and associated processes for enabling a data-driven approach refers to the aspects of organisation, processes, policies etc., which regulates collaboration and cooperation of the digital community in a digital environment.
- Business – in the context of data-driven approach business refers to models and incentives that stimulate to digital transaction between involved parties in the community. These models support the agreed governance model and facilitate implementation of data-driven approach.
- Data Democratisation – in a digitalised environment, the democratisation refers to availability and accessibility of data and models for the “digital stakeholders”, i.e., individuals and organisations agreed on and committed to the defined digital governance model.
- Cybersecurity/ Information assurance – information assurance in data-driven approach refers to mechanisms aimed for ensuring the aspects of cybersecurity, digital safety and resilience of the data-driven assets, e.g., models and datasets. Cybersecurity is the weakest link in digitalisation of transport systems.
- Data Integration – distributing digital assets needs to be supporting by smart integration. Integration in data-driven approach refers to mechanisms aimed for orchestration, fusion and integration of digital assets, e.g., datasets and models.
- Data Quality – quality in data-driven approach refers mainly to measurement of aspects related quality-of-services, quality-of-data, quality-of-model. Measing and explaining the precision of data-driven components are highly important for acceptance and fidelity models.

- **Data Ownership** - The modern-day railway transportation process is characterized by multiple actors, namely owners of infrastructure, owners of rolling stock, maintainers of infrastructure, maintainers of rolling stock, rolling stock operators, etc. making extremely difficult to identify the owner of the data generated during operation and maintenance process. It is a complex issue and not easy to resolve if the collaboration is not built on trust and confidence at organization and individual level.
- **Standardization** - Without standardization, it is difficult to implement a digital transformation in railway sector as it involves many actors with different background using different languages.
- **Organizational Culture** - must be aligned to adapt and adopt new technology. It needs careful planning to manage changes in an organisation, etc.

## **5 Future Direction**

As more and more railway assets are instrumented, interconnected and automated to meet the vision of digital railway, the strategic thinking of modern-day industry is focused on deployment of transformative technologies and solutions to ensure safe and failure-free operation at a competitive cost. The maintenance technology road map must be aligned to address challenges arising out of climate change and facilitate climate change adaptation of maintenance process. In addition, new technology should also facilitate performance-based design that will lead to reduce material consumption in construction and maintenance activities. However, it is not enough to bring strategic focus only on adaptation and implementation of new and emerging technologies, but equal focus needs to be on human and organizational culture for seamless implementation of these technologies, and realization of the vision of zero accident and safest mode of transport.

## **6 Concluding Remarks**

Digital technology has emerged as a great enabler of the efficient operation and maintenance of engineering assets leading to transformative engineering and business solutions. Maintenance technology roadmap must address the organizational issue while implementing transformative technologies in an organization. Powered by new technology, driven by data, railway is all set to transform its operation and maintenance practices to become a popular, cheap and green mode of transport all over the world.

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