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World-class research and education

RESEARCH, DEVELOPMENT AND INNOVATION ACTIVITIES

ANNUAL REPORT 2022

JVTC LULEÅ RAILWAY RESEARCH CENTER
at Luleå University of Technology

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Chairman´s Message

Railway traffic has largely bounced back after the pandemic and is back on or even surpassed the growth curve from before Covid-19. At the same time the war in Ukraine as well as rapidly increasing energy prices raise new challenges for the industry; Safety, system resilience and efficient utilization of resources becomes even more important. It adds new demands on the maintenance and operation of the railway system. The climate change remains a key challenge and opportunity to the industry. Railway is undoubtedly part of the solution, at the same time efforts need to be increased both to make railway even more climate friendly as well as prepare it for the adverse effects the change may have.

The possibilities of data driven monitoring, analysis, decision making, and automation is a big opportunity as well as a big challenge for the railway industry. Throughout the years, JVTC has produced excellent results in research for new ways to utilize this technology to make maintenance and operations in the railway sector more efficient and effective. With the closeness between academia and industry that JVTC offers, this has made it possible to accelerate the adoption of new technologies in the industry. JVTC is uniquely placed, with its emphasis on finding new technology and methods in maintenance, to a close to 200 years old industry with systems in operation that stretches from brand new to century old.

As JVTC closes the books on its 24th year of operation, the need for research in the field of maintenance and operation in the railway sector is greater than ever. New ways need to be found to make better use of the resources for maintenance; people, material, information and energy in order to be able to offer travellers and freight customers an available, competitive and safe transport option as well as build for a better, climate friendly society.

I want to thank the board, the management team, and the dedicated researchers for a successful year.

Björn Dellås, Trafikverket, Chairman
Luleå Railway Research Center
March 2023

“...solutions to mitigate the adverse effects of climate change on railway assets...”

Director´s Report

JVTC was formally established in 1998 to address some of the challenges faced by the heavy haul transport system in Northern Sweden. However, with the turn of the millennium, the strategic focus was brought to operation and maintenance of railway assets to address the issues related to the operational reliability of the railway network. Looking back, our achievements and history make us enormously proud and happy.

Our quest to develop new and futuristic technology for the operation and maintenance of railway system has led us to explore and investigate the future of maintenance aligned and adapted to the framework of Industry 4.0 founded on the digital transformation of railway operation and maintenance.

In addition, over the last 5 years, we have placed added focus on the role of maintenance and maintenance technology to address the challenges arising from climate change. At present, we are working on several projects aimed at developing tools, technology, and methodology to integrate climate change models into our maintenance optimization models. Our objective is to adapt these solutions to mitigate the adverse effects of climate change on railway assets.

I would like to convey my sincere gratitude to all my colleagues for their commitment and effort as a team, as well as to our partners in industry and the university management for their continuous support and guidance. It gives me immense pleasure to present the annual report for the year 2022, highlighting some of the important milestones, a few of our ongoing projects, a few success stories, and some happy moments from the year.

Uday Kumar, Luleå University of Technology, Director
Luleå Railway Research Center
February 2023

Research, Development and Innovation activities at JVTC

Järnvägstekniskt centrum (JVTC) was formally established in 1998 and has during the last 24 years, built up a research and innovation program adopting a distinctive multidisciplinary approach to meet short-term and long-term challenges faced by the operation and maintenance engineers of the railway sector. In 2023 JVTC will celebrate the 25th anniversary.

A key challenge for the modern railway sector is to improve its competitiveness while ensuring a reliable and sustainable mode of transportation for passengers and goods. This essentially necessitates an effective and efficient operation and maintenance of infrastructure and rolling stocks. The strategic focus of JVTC is to develop methods, models, methodologies, and technology to make the railway sector competitive and a sustainable mode of transportation through industry sponsored Research & Innovation (R&I).

Keeping in mind the fact that operation and maintenance of the railway system is a multidisciplinary area, the management at JVTC has continuously been working to strengthen its position by networking with researchers with similar interests locally and all over the world. Today, JVTC have collaboration with researchers from Australia, India, China, France, Norway, UK, Germany etc. through various EU sponsored or other applied projects. The main focus of JVTC is to develop innovative engineering solutions to enhance the effectiveness and efficiency of the operation and maintenance of railway systems to ensure an economically viable, reliable, punctual safe and sustainable mode of transport system. The R&I activities of JVTC are built around the keywords: Safety, Sustainability, Availability and Capacity.

The center has built up world-class competence in the areas of reliability, availability, maintainability and safety (RAMS), Condition based maintenance and eMaintenance. These three research areas bring strategic focus to some critical research topics, which have considerable impact on the performance of railway systems. During the last years, JVTC has also initiated efforts to mitigate the impact of climate change in operations of railway.

Through extensive collaboration activities with member companies, JVTC ensures that results from research are relevant, requested, and applicable in the railway industry.

The center has also succeeded in funding, developing, and establishing platforms such as AI Factory, ePilot and Testbed Railway to create conditions for excellent research within Operation and Maintenance for the Railway system.

Veronica Jägare, Deputy Director
Luleå Railway Research center
February 2023

About JVTC

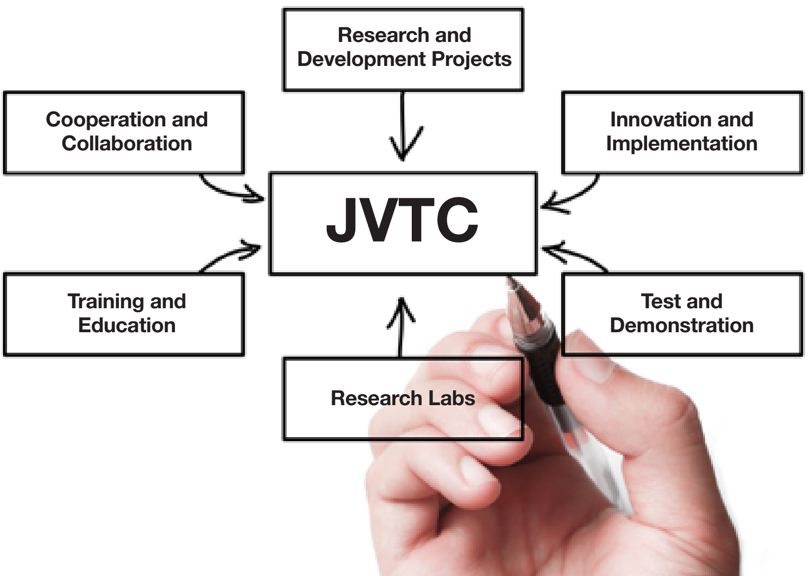
JVTC is a collaborative research platform at Luleå University of Technology (LTU). It was established in 1998. The main purpose of the center is for researchers to engage with its stakeholders from the industry to conduct applicable R&I in operations and maintenance in order to create a robust and reliable railway system.

Through research and involvement in the innovation process, JVTC contributes to the railway industry with better concepts, tools, and methods. What is unique about JVTC is the location, industry connections that provides access to data, the eMaintenance LAB and the CBM LAB. The expertise of the researchers at JVTC includes the entire maintenance process, with emphasis on RAMS (Reliability, Availability, Maintainability, and Safety), LCC (Life Cycle Cost), risk, maintenance limits, Industrial AI, eMaintenance and the development of maintenance strategies where methods like RAMS and LCC are interwoven applicable to a whole. Other areas of expertise are integration between data sources, analysis, maintenance history, management, climate adaptation and procurement. Efforts are now being made to develop transformative technologies, tools, and solutions for maintenance of railway systems. In this respect, many projects are initiated in the areas of digital transformation of maintenance and AI, Big Data, Machine Learning etc.

The center operates under the aegis of the vice chancellor of LTU and the director of JVTC is Professor Uday Kumar. JVTC has 16 members representing different segments of railway and is funded by the railway industry.

Members 2022

- Luleå tekniska universitet
- Alstom
- Bane Nor
- Damill
- Duroc Rail
- Infranord
- LKAB
- Norut Teknologi
- Predge
- SJ
- SWECO
- Trafikverket
- Transitio
- Tyréns
- Tåg i Bergslagen
- Vossloh Nordic Switch Systems



25 years of research and innovation at JVTC

JVTC was established by Luleå University of Technology together with a number of interested companies in 1998 with support from Luleå Growth Academy, in order to make the area of heavy railway transports in cold climate (Tunga Transporter i Kallt Klimat, T2K2) and mixed traffic more efficient. During the autumn of 2000 the research and development activities were focused on operation and maintenance issues of the railway.

Heavy transports in cold climate

During the 1990s due to heavier trains on the iron ore line and later, heavier freight trains on other tracks, T2K2 worked actively to develop the knowledge, skills, and experience in heavy railway transports. This was unique in Europe and the work has led to many improvements in the Swedish railway system since the formal start of upgrading the iron ore line to 30 tons axle load.

Sustainable bridges

A European research project initiated by Construction Technology was a so-called integrated project, submitted in April 2004. The 4-year project started in 2004 and had 32 participants from 12 countries. The program had a turnover of 100 million SEK, of which about 65 million SEK came from EU. The goal was to increase the allowable bearing capacity and train speed on the railway bridges in Europe by developing better methods for classification calculations, measurement of the condition and operation, repair, and reinforcement.

The establishment of a research station

A requirement for many of JVTC´s ongoing research projects is the availability of data from the railway system. In 2006, JVTC established, closely with the member company Damill AB, a monitoring station in Sävast on the Iron Ore Line. The measuring station has instruments to measure forces from vehicles on the track and the data is stored in a system. An accelerometer is used to measure the vibration of the track when the train passes. Measurement data was transferred to the eMaintenance LAB, established 2011. This was the first step in creating a Testbed for Railway.

Expansion through European projects

During 2011-2015, JVTC participated in several major European projects in the Seventh Framework Programme (FP7) i.e., AUTOMAIN, SUSTRAIL, TRND, BGLC, MAINLINE, SAFT Inspect and OPTIRAIL etc. During this time, the number of PhD candidates and researchers increased at JVTC.

Establishment of labs and platforms

During 2013-2022, JVTC increased the capability of connected labs and platforms to support excellent research and innovation mainly. The ePilot project was initiated and developed in close collaboration between Trafikverket, JVTC, and many stakeholders from the railway industry. Within the ePilot, 38 sub projects were conducted during 2013 to 2020. ePilot is an innovation platform that enables the creation of innovations for the rail ecosystem within eMaintenance and Industrial AI. Research within ePilot resulted in a framework that facilitates digitalisation of operation and maintenance in the Swedish railway. The ePilot was included in the Royal Swedish Science Academy 100 list 2020 and awarded with Strukton´s innovation award 2019.

JVTC board and management group on February 11, 2003. JVTC Chairman Jan Hertting in the middle of the picture.

JVTC board and management group on May 13, 2009. JVTC Chairman, late Rune Lindberg, fourth from the left in the picture.

A list of examined PhD candidates (1998-2022)

Ansel Berghuvud, 2001
Peter Söderholm, 2005
Mattias Holmgren, 2006
Patrik Waara, 2006
Ulla Espling (Juntti), 2007
Thomas Åhrén, 2008
Rikard Granström, 2008
Saurabh Kumar, 2008
Birre Nyström, 2008
Stefan Niska, 2008
Arne Nissen, 2009
Ambika Patra, 2009
Yuan Fuqing, 2011
Iman Arasteh Khouy, 2013
Andreas Eitzenberger, 2013
Mikael Palo, 2014
Christer Stenström, 2014
Yasser Mahmood, 2015
Amparo Morant, 2015
Stephen Mayowa Famurewa, 2015
Jonny Nilimaa, 2015
Matthias Asplund, 2016
Mustafa Aljumaili, 2016
Levis Zhang, 2017
Anna Malou Petersson, 2017
Madhav Mishra, 2018
Juhamatti Saari, 2018
Saad Ahmed Khan, 2019
Iman Soleimanmeigouni, 2019
Prasanna Illankoon, 2020
Ravdeep Kour, 2020
Hamid Khajehei, 2021
Rayendra Anandika, 2021
Praneeth Chandran, 2022
Antonio Galvez, 2022
Veronica Jägare, 2022

Strategic Research and Innovation Programs

The strategic focus of the railway research and innovation programs is to develop new tools, methods and models using the power of new and emerging technologies that will facilitate innovative solutions in order to improve and strengthen the railway system.

The strategic focus of the research programs is to ensure increased availability, capacity, safety and sustainability of the railway network and rolling stocks by effective operation and maintenance. Considerable research is being undertaken to study the track maintenance and renewal issues with focus on grinding, lubrication, maintenance strategies and track degradation.

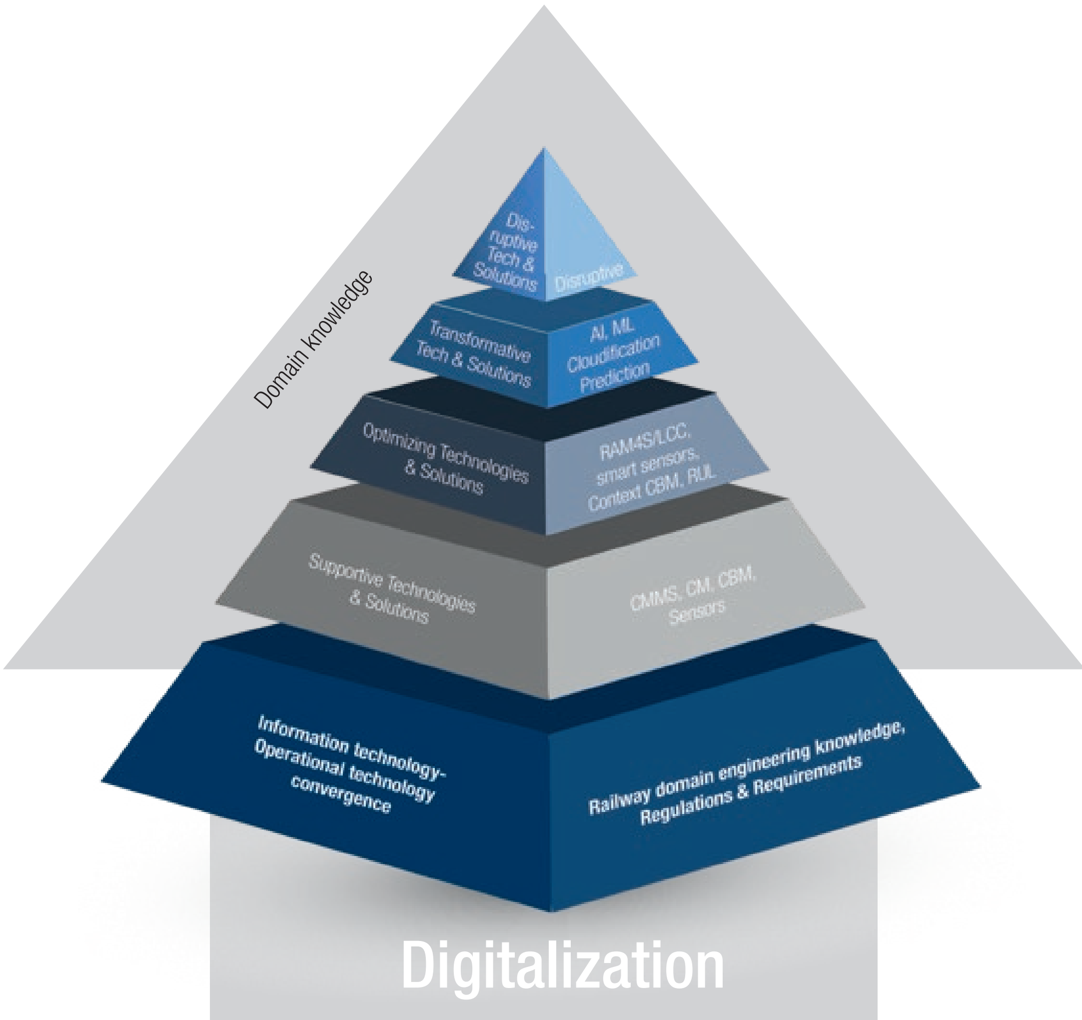
Supportive technologies and solutions are being utilized together with strong domain knowledge, in order to build optimizing technologies and solutions for operation and maintenance. By applying transformative technologies, the aim is to ensure increased availability, capacity, safety and sustainability of the railway system. Areas included in the JVTC R&I Programs have the objective of finding answers to the main research question: How to estimate the remaining useful life of railway components and systems in a specific operating condition? This will facilitate development of predictive technologies and solutions for the railway sector and will facilitate correct decision-making leading to effective and efficient maintenance planning. The transformative technologies will also facilitate finding the answer to the question "What is to be done, how should it be done and who should do it?" It will facilitate development of prescriptive analytics and tools, which will ultimately facilitate optimized maintenance resource allocation and maintenance task execution.

JVTC Engineering and Management Programs describe JVTC's areas of excellence needed to solve the challenges in the railway industry. Providing competence to the programs is ensured through education and research at LTU.

Strategic research and innovation programs:

Condition monitoring and CBM	RAM4S	Asset management, Risk and Human Factors	Industrial AI / eMaintenance
▪ 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	▪ Dependability ▪ LCC ▪ Risk analysis and modeling ▪ Maintenance optimization and modeling ▪ Design for reliability and maintainability ▪ Remaining useful life ▪ RAMS/LCC Risk optimization	▪ 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	▪ 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

New technologies and solutions provides the conditions for developing implementable concepts and demonstrators for the industry.



JVTC Research and innovation framework.

Technologies and models are used together with strong domain knowledge to build new solutions for operation and maintenance of railways.

The researchers work in agile clusters where they work with deliveries in short iterative cycles where they make prototypes, test, analyze and improve to find solutions to societal challenges.

Strategic research and innovat

Condition Monitoring and (CBM) Research Program

The concept of maintenance limit is an innovative way to look at the operation and maintenance of railway system as a single entity to ensure high level of transport system reliability. The concept is based and analogous to safety limit used since many decades. The term maintenance limits is used to show that the maintenance decision should be based on knowledge about degradation rates and taken in such a good time that corrective maintenance can be avoided. Maintenance limits also implicates that the total cost for maintaining rail and wheel sets combined, should be used as a parameter for maintenance decisions. Currently, JVTC is conducting research projects in this area.

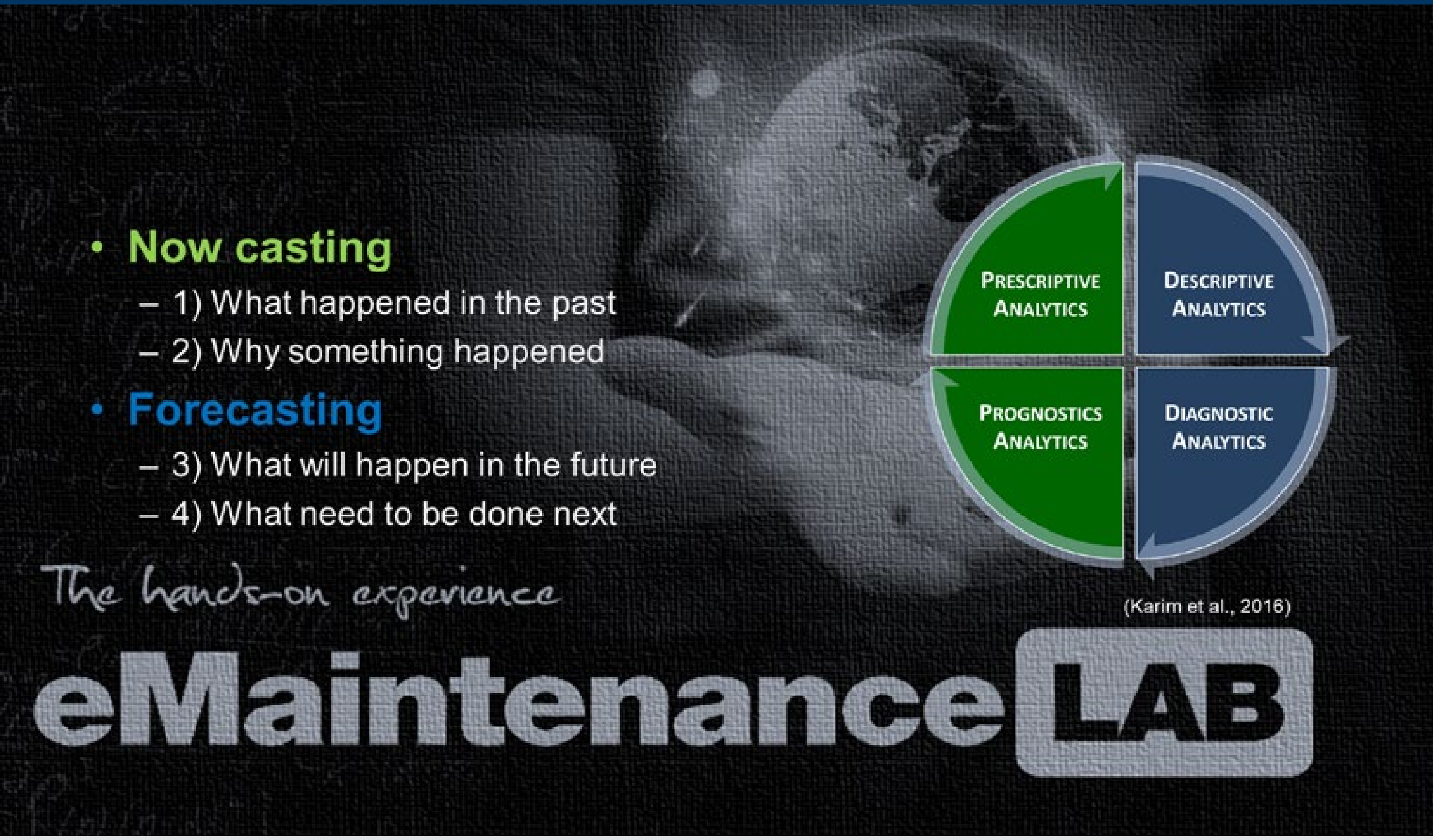
RAM4S Research Program

RAM4S (Reliability, Availability, Maintainability and Safety, also incl. Supportability, Security and Sustainability) characteristics for a railway system can be described as the confidence with which it can guarantee the achievement of an agreed volume of traffic with defined quality in a given period. With an increase in performance demands from governments, infrastructure managers and train operators are under pressure, to enhance the RAMS characteristics of their operating systems. As a result, RAMS issues have become critical for competitiveness and economic viability of the railway systems all over the world. Currently, JVTC is engaged in projects that have direct or indirect focus on RAMS analysis. Some of these projects are within European projects and JVTC is one of the key players for the analysis of RAMS of railway systems.

Asset Management, Risk & Human Factors Research Program

The importance of the concept and application of human factors in maintenance management for the railway infrastructure is gaining more acceptance. Human errors play a vital role in safety of rail infrastructure. Issues like, man-machine-machine interface coupled with ergonomics is compelling the rail infrastructure managers to look for innovative solutions. Factors like, increased capacity, reliability and availability of the rail infrastructure require knowledge and skill enhancement support. The human factors related projects focus on the increased capacity of the existing railway infrastructure through effective and efficient maintenance processes. The overall purpose of this part of the program is to help the Swedish railway sector to increase their competitiveness by improving maintenance work processes, safety, and the reduction of human error/or failure during maintenance activities through the implementation of human factors principles. The fundamental goal of the human factor is that all tools, devices, equipment, machines, and environments should advance, directly or indirectly, the safety, well-being, and performance of humans.

ion programs



Industrial AI / eMaintenance Research Program

The Industrial AI/eMaintenance Research Program (eMRP) enables Operational Excellence by empowering operation and maintenance with Artificial Intelligence. eMRP focuses on research and innovations that augment the decision-making processes in industrial contexts through enhanced analytics. In eMRP, frameworks, approaches, methodologies, technologies, and tools such as Industrial Artificial Intelligence, Machine Learning, Deep Learning, eXplainable AI, serviceoriented and event- oriented approaches, digitalisation, IoT and IIoT, and information logistics are getting orchestrated to achieve excellence in research and innovation. Our research approach is built upon the understanding of the concept of system-of-systems and considers systems' whole lifecycle. This to create a holistic system thinking in our research process, and enhance the practical implications of our research findings.

The overarching objective of the Industrial AI/eMaintenance Research Program is to enable the railway industry to achieve operation excellence. This through a) conduct multi-disciplinary applied research in maintenance analytics; b) develop and provide an appropriate education platform in eMaintenance; c) establish an innovation process which supports implementation of research outcomes to real-world applications. eMRP focuses on topics which reflect issues and challenges within industry and academia. Some of these topics are: Industrial Artificial Intelligence, Machine Learning, Deep Learning, eXplainable AI, service-oriented and event- oriented approaches, digitalisation, IoT and IIoT, Big Data Analytics, cloud computing, distributed computing, crowd sourcing, information logistics, data integration, data fusion, data processing, data visualisation, and context adaptation. The program also aims to design, develop, and provide artefacts based on edge technology to demonstrate proof-of-concept within the aforementioned topics. The main objective of these demonstrators is to validate academic outcome in industrial contexts. To achieve this, EMRP collaborate with the eMaintenance LAB.

Areas of EXCELLENCE

Trafikverket, together with the participating universities and institutes, have developed the direction for railway research for the period 2021-2030. Ten areas of excellence have been defined where the universities collaborate and build up knowledge within their respective excellence areas.

The ten excellence areas are:

- Area 1: Track vehicle technology and dynamics
- Area 2: Wheels and braking systems
- Area 3: Track technology
- Area 4: Art and land construction / Constructions (focus on bridges)
- Area 5: Electric power technology
- Area 6: Signal safety systems
- Area 7: Traffic planning and control
- Area 8: Operation and maintenance
- Area 9: Capacity and punctuality
- Area 10: Cross-cutting system perspective of the railway system

JVTC at Luleå University of Technology has been given responsibility for Area 8 - Operation and Maintenance, due to the research and innovation that has been conducted in the center for many years.

Excellence-creating projects will be conducted in collaboration with other academy parties according to a business plan approved by Trafikverket and participation will continue within European projects.

JVTC / LTU is also involved in other areas of excellence, mainly: 2, 3, 4 and 10.

The Swedish universities and institutes that collaborates in Trafikverket's areas of excellence are:

- Luleå Railway Research Center (JVTC), Luleå University of Technology
- Charmec, Chalmers
- Järnvägsgruppen, Royal Institute of Technology (KTH)
- KAJT industry program (KTH, Linköping University, Blekinge tekniska högskola, RISE, Uppsala University, Lund University, VTI)

Excellence area 8: Operation and maintenance

Responsible for excellence area 8: Uday Kumar

Duration: 2021-2030

Excellence area 8 "Operation and maintenance" shall implement applicable research, education and innovation in operation and maintenance to strengthen the railway system, ie. infrastructure and rolling stock.

Reliability is a basic necessity for the Swedish railway system's sustainability, reliability, robustness, punctuality and capacity. The operational safety of the railway system consists of its functional safety, maintenance and maintenance safety. Achieving a high degree of operational reliability requires optimization of these three aspects, throughout the life cycle of the railway system.

Research in operation and maintenance technology focuses on optimizing a system's operational reliability during its lifetime. This is done through streamlining of the operation and maintenance processes through appropriate maintenance strategies such as predetermined, condition-based, predictive or corrective maintenance as well as fact-based decision support.

Figure. Excellence area 8: Operation and Maintenance.

Railway systems in general and the Swedish railway system in particular, including infrastructure and rolling stock, are complex technical systems with a large number of components and a broad heterogeneous stakeholder picture. The complex composition of the system increases the complexity of the analysis and optimization process.

Excellence is created by conducting activities and merging knowledge in transformative high-risk projects (THP) to create a functioning whole. There are three identified THP´s.

THP1 Autonomous maintenance of infrastructure, rolling stock and interface

This THP aims to establish research and innovation to increase autonomy in the maintenance process as the railway system's various system components become increasingly automated. This THP will conduct research and innovation in areas such as automated inspection, condition assessment, and safety monitoring. This THP is expected to result in increased autonomy in the operation and maintenance process through the design of context-based digital twins for automated decision support based on e.g. digital technology. The benefits for the industry consist of improved operational reliability, robustness, safety and sustainability (technical, economic and environmental).

Autonomous maintenance of infrastructure, rolling stock and interfaces

Researchers: Matti Rantatalo (PL), Jan Lundberg, Taoufik Najeh, Yang Zou (PhD candidate)

Goal: Develop algorithms to detect and quantify defects of an S&C by means of on-site measurements data.

Project Status and Results: The project builds on previous research results and data obtained from DigiSwitch, at Luleå University of Technology. The project aims to design algorithms, approaches, technologies and methodologies based on using feature extraction and artificial intelligence technologies to perform anomaly detection on Railway S&Cs. The methods and concepts on which the project will be based on are: machine learning, signal processing and vibration sensors. Yang Zou presented his licentiate thesis on October 27, 2022. Thesis: Zuo, Y. (2022). Squat Detection in Railway Switches and Crossings Using Point Machine Vibration (Licentiate dissertation, Luleå University of Technology). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-93191

Duration: 2021

THP2 AI Factory for Railway Operation and Maintenance

This THP focuses on establishing research and innovation for the development of frameworks, approaches, processes, organization, technologies, architectures and models for enhanced analytical ability in decision-making processes using AI technology. Some examples that areas that this package will include are: a) Industrial AI; b) eMaintenance; c) distributed data processing; d) distributed information logistics; e) contextual data analysis; f) visualization (incl. AR, VR, MR); g) cyber twin (digital twin); h) deep learning, machine learning; i) cyber security; j) eGovernance; k) eChange management; l) human-system interaction. This is expected to result in a technology platform and associated demonstrators that can be used as a template for the design of automated decision production using AI technology as well as a number of concrete frameworks, technologies and methodologies that can be used to diagnose, predict and prevent safety risks related to the human´s interaction with other system components. The benefit for the industry is that various stakeholders in the railway will be able to accelerate their digitalisation journey and the introduction of AI technology as well as a framework with an associated platform intended for democratization of railway data.

Railway Digital Twin

Researchers: Ramin Karim (PL), Adithya Thaduri, Miguel Castano, Ravdeep Kour, Jaya Kumari, Amit Patwardhan, Daniel Voorwald

Goal: The main goal of the research undertaken is to develop and demonstrate a concept and a platform for enablement of Digital Twin in railway.

Projects status and results: The project has initiated activities to explore and identify system-of-interest and also the enabling systems related to railway infrastructure and rolling stock. Daniel Voorwald published his master thesis: Voorwald, D. (2022). Lidar data processing for railway catenary systems. Master thesis from Luleå University of Technology.

Duration: 2021-2022

AI Factory MetaAnalyser®

Researchers: Ramin Karim (PL), Adithya Thaduri, Miguel Castano, Ravdeep Kour, Jaya Kumari, Amit Patwardhan, Kevin Karim, Martin Arenbro

Goal: The main goal of this project is to establish a platform and toolkit for an autonomous cloud-based analytics using AI and cognitive services.

Projects status and results: The project has initiated activities to explore, investigate, and propose appropriate framework, concept, architecture, infrastructure, methodologies, technologies for development and deployment of 'AI Factory MetaAnalyser'.

Duration: 2021-22

Lidar-based catenary data processing

Researchers: Ramin Karim (PL), Amit Patwardhan (PhD candidate), Miguel Castano.

Goal: One of the main goals of this project is to measure the distance between two wires namely the reinforcement wire and the tension wire. Various data analysis steps such as filtering, clustering, feature extraction etc. are used to extract the assets from the point cloud.

Projects status and results: Till now the project has focused on detection and extraction of assets from the point cloud. This resulted in extraction of masts and provides the location of individual masts in Latitude and Longitude. The wires are extracted individually and exported as parameterized equations (catenary equation and second order polynomial in 3D space). Different techniques for identification of wires have also been explored. Currently the focus is on developing techniques to measure the distance between the wires hence, numerical and analytical methods are being explored. Amit Patwardhan presented his licentiate thesis on October 14, 2022. Thesis: Patwardhan, A. (2022). Enablement of digital twins for railway overhead catenary system (Licentiate dissertation, Luleå University of Technology).
Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-92656

Duration: 2021-2024

eMaintenance Solution for Enhanced Asset Management in Railway - Using Industrial AI

Researchers: Ramin Karim (PL), Jaya Kumari (PhD candidate)

Goal: The project aims to streamline and optimize asset management and rail maintenance, with a focus on railway infrastructure. From an academic perspective, the project will explore and investigate how technologies and methodologies in the so-called. 'Industrial Artificial Intelligence (IAI)', incl. deep learning, can be used to develop eMaintenance solutions that help to improve TAK, OEE and streamline the infrastructure management of railway infrastructure.

Projects status and results: The project is in the state of literature survey and state of the art review in the field of Railway infrastructure, Artificial intelligence, and Machine Learning methodologies. Jaya Kumari presented her licentiate thesis on June 9, 2022. Thesis: Kumari, J. (2022). Augmented Asset Management of Railway System Empowered by Industrial AI (Licentiate dissertation, Luleå University of Technology). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-90416

Duration: 2021-2023

Prestudy – Human AI Interface, AR, VR, UX

Researchers: Ramin Karim (PL), Ravdeep Kour, Manish Kumar, Robin Karim and Phillip Tretten

Goal: The main goal of the research undertaken is to investigate utilisation of wearables for maintenance collaboration and inspections

Projects status and results: To further strengthen research & innovation within 'AI Factory', we aim to conduct a pre-study with focus on Human-AI-Interaction (HAI). The project specifically focuses on utilisation of wearables e.g. jacket, glasses, helmet, watches etc. for maintenance collaboration and inspections and to improve the User Experience (UX).

User experience (UX) design process aims to create relevance, context-awareness, and meaningfulness for end-user. In railway contexts, it is believed that applying a human-centric model in the development of AI-based artefacts, will enhance the usability of the solution, which will have positive impact on the decision-making processes. In this project, the applicability of such advanced technologies i.e., Virtual Reality (VR), Mixed Reality (MR), and AI have been reviewed for the railway asset management.

To carry out this research work, literature review has been conducted related to available VR/AR/MR technologies and their applications within railways. It has been found that these technologies are available, but not applied in railway asset management. Thus, the aim of this project is to provide Human-AI-Interaction (HAI) and improve UX for the enhancement of railway asset management using Artificial Intelligence (AI), VR, and MR technologies (Figure below). The practical implication of the findings from this project will benefit in increased efficiency and effectiveness of the operation and maintenance processes in railway.

Duration: 2021-2022

Figure 1. Virtual Reality (VR) and Mixed Reality (MR) for maintenance collaboration and inspections.

Advanced solutions to Improve Cybersecurity in Railway

Researchers: Ravdeep Kour, Ramin Karim (PL)

Goal: The main goal of the research undertaken is to minimize the risk of cyber threats and to quantify them.

Projects status and results: Railway maintenance based on information and communications technologies (ICT), generally depends on Internet infrastructure, and this makes it vulnerable to cybersecurity threats. These cyber threats may have negative impact on railway stakeholders e.g., threat to the safety, loss of railway data integrity and confidentiality, reputational damage, monetary loss, service unavailability, loss of dependability, etc. Therefore, there is a need to develop advance cybersecurity solutions for railway to minimize the risk of these cyber threats. This research is using both qualitative and quantitative methods for collecting cybersecurity data. Collecting cybersecurity data is really a challenging task because of its sensitivity due to its safety and security issues.

In the current research, we have identified various issues and challenges that can be faced by railway organizations. We have also estimated the cybersecurity maturity levels of railway organizations and proposed cybersecurity framework for railways. Next, we have conducted a systematic review and outline cybersecurity emerging trends and approaches, and identified possible solutions by querying literature, academic and industrial, for future directions. In addition, we have proposed a methodology on how to deals with OT security in the railway signaling using Failure Mode, Effects and Criticality Analysis (FMECA) and ISA/IEC 62443 security risk assessment methodologies to quantify cyber threats. We have also proposed a systematic approach, based on an enhanced Cyber Kill Chain model, to improve the overall system resilience through monitoring and prediction (Figure below). We have also disseminated the research work in various journals and conferences.

Duration: 2021-22

´THP3 Life extension of the railway system

This THP aims to establish research and innovation to develop methodologies, technologies, guidelines and tools intended for life expectancy calculation and life cycle cost benefit analysis of so-called aging components of the railway system. New and emerging technology for dynamic risk assessment with alarms and real-time alerts will be used. Develop technology / methodology to extend the life of existing aging assets and propose a management roadmap (material degradation, obsolescence, human and organizational problems / issues) to ensure a sustainable, safe, resilient and robust infrastructure that is reliable according to current standards and standards to low cost. The benefits to the industry consist of new knowledge and tools that help ensure the technical and operational integrity of these aging technical systems.

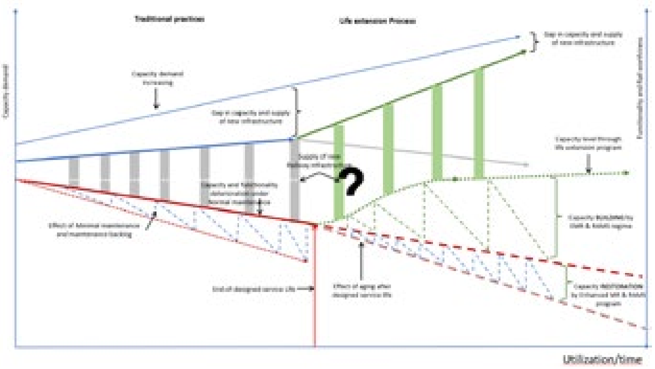
Roadmap for Life extension of the railway system

Researchers: Alireza Ahmadi (PL), Ulla Juntti, and more.

Goal: A roadmap containing a proposal for a dynamic framework that describes life extension of railway systems.

Project Status and Results: A report is being written describing existing frameworks from other industries or other countries in the railway sector, what standards apply to the area, what is included in the system, what are the asset management life factors and how to connect RAMS structures to the framework. A case study are being described where the framework can be applied.

Duration: 2021-22



Excellence area 4: Railway structures

Condition and capacity assessment of railway bridges

LTU responsible for excellence area 4: Gabriel Sas (PL),

KTH responsible for overall coordination of the area.

Duration: 2021-2030

Full scale laboratory test of trough bridges

Researchers: Gabriel Sas (PL)

Goal: The scope of this project is to improve current loads standards and regulations by providing a more realistic evaluation of the capacity of reinforced concrete trough bridges. The methodology that will be used include testing of two real scale bridges in the lab, development and testing of scaled down bridges, finite element analysis and evaluation of structural reliability. The project will also deal with finding the actual distribution of the train loads in the bridge.

Project Status and Results: The following tests are planned to be performed: load at service limit, ultimate and fatigue limit state. Realistic loads will be used. In 2022, the casting of two real scale trough bridges finished and activities related to procurement of equipment to carry out the testing in 2023 took place.

Duration: 2021-ongoing

Digitalization of railway bridges based on photogrammetry

Researchers: Jaime Gonzalez-Libreros (PL)

Goal: The scope of this project is to develop methods for digitalization of the bridges by performing ground-based photogrammetry, develop technology to identify and present changes over time, and develop required procedures including quality assurance.

Project Status and Results: Four surveys are performed related to the scanning of five case study bridges in different light/weather conditions using different equipment. Crack depth detection using photogrammetry and soundwave technology during proofloading of Kalix Brige is done.

Duration: 2021-ongoing

Climate impact on existing snow galleries on the Iron Ore line

Researchers: Gabriel Sas (PL)

Goal: The scope is to measure and assess the impact of changes in snow falls on existing snow galleries between Björkliden and Riksgränsen.

Project Status and Results: In recent years, it was noted several partial collapses of the structures. The cause of these events is hypothesised to be related to a combination of factors such as ageing infrastructure, and heavy short-term snowfalls. The later has created concentrations of snow loads more than the limits allowed by existing building codes, therefore exposing potential damage or collapse and likely traffic stops. The plan is to measure the snow loads in discrete points and compare it with existing prescriptions of the current codes, and to use the data to evaluate the impact on the structural behavior. We will pilot a methodology to monitor the snowloads and to alert the owners when it is time to remove it so that traffic interruptions are avoided. The data can be further used to generate predictive models for structural performance by integrating it in a digital twin of the structure. It is foreseen that the measurement method will be available for further use beyond the lifetime of the project, thus contributing to enriching the pool of data required for training AI algorithms.

Duration: 2021-ongoing

Testbed Railway An infrastructure for test, development and implementation of Railway 4.0

- the Swedish Concept for Future Railway Research and Innovation

Currently, the railway system needs to embrace and get the best out of new technologies, innovations, and implementation of research results in a day-to-day management. However, it is highly important to address and study the implementation of technologies and new innovative solutions at the outset, to avoid lower than expected benefits to the stakeholders in terms of capacity and reliability.

To achieve smooth implementation of new research and innovation, the railway stakeholders, need to develop means for testing of new technology and innovative solutions.

To achieve this, JVTC and the Division of Operation and Maintenance Engineering at Luleå University of Technology have developed a framework called 'Railway 4.0', with a corresponding testbed called 'Testbed Railway'.

The framework and the testbed aim to facilitate establishment of digitalised railway and enable enhanced decision-making through big data analytics. The tools also provide capability to acquire asset-related data such as condition data, failure data, and reliability data, via a service-oriented and cloud-based approach.

Railway 4.0 is the overarching framework that is designed to facilitate the choice of concepts, approaches, technologies and methodologies aimed at the development of the railway system, nationally and internationally. Further, Railway 4.0 focuses on disseminating the experience and knowledge to involved stakeholders (e.g infrastructure owner, entrepreneurs, academia, and consultants). Railway 4.0 provides the railway industry enhanced opportunities to collaborate, cooperate, test, and implement relevant research and development results in the areas of digitalised railway and eMaintenance. This in turn contributes to improved robustness and capacity of the railway transport systems, as well as increased cost efficiency of operation and maintenance.

Testbed Railway is a platform aimed for transparent and replicable testing of scientific theories, computational tools (such as Big Data Analytics) and new technology. The goal of the 'Testbed Railway' is to strengthen the railway industry's adaptability and competitiveness by developing and providing a testbed for research and innovation in the rail industry, nationally and internationally. The purpose of the 'Testbed Railway' is to enable that Sweden should be a leader in research and innovation in railway, which contributes to strengthening the industrial production of rail-related goods and services in Sweden.

The testbed will facilitate continuous monitoring of railway infrastructure and rolling stock in real time using state of the art technology. The corridor which is equipped with state of the art measurement and communication technologies for measurement, monitoring and storage of data is critical for researchers at JVTC with strategic focus to develop maintenance models, tools and methodology to facilitate correct and timely decisions ensuring effective and efficient maintenance processes solutions. The digital part of Testbed Railway is powered and hosted by eMaintenance LAB.

Today, the testbed covers two main track-sections (around 5 000 km railway), i.e. Malmbanan and Haparandabanan. These two track-section are instrumented so that both infrastructure and the rolling stocks can be monitored online and in real-time. The data monitoring data is used for maintenance analytics, i.e. maintenance descriptive, maintenance diagnostics, maintenance prognostics, and maintenance prescriptive.

The testbed includes both the track-sections with wayside and portable measuring equipment and two laboratories at LTU.

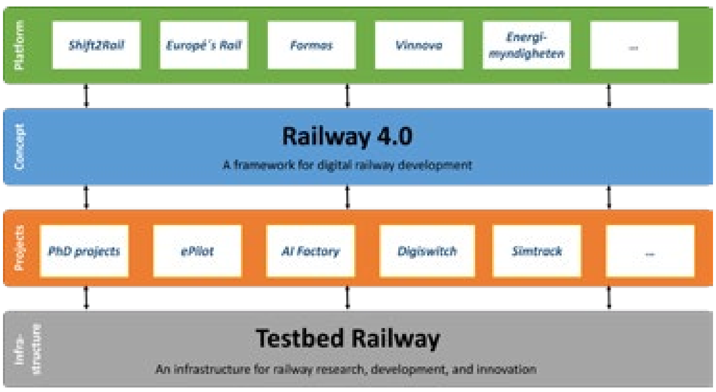


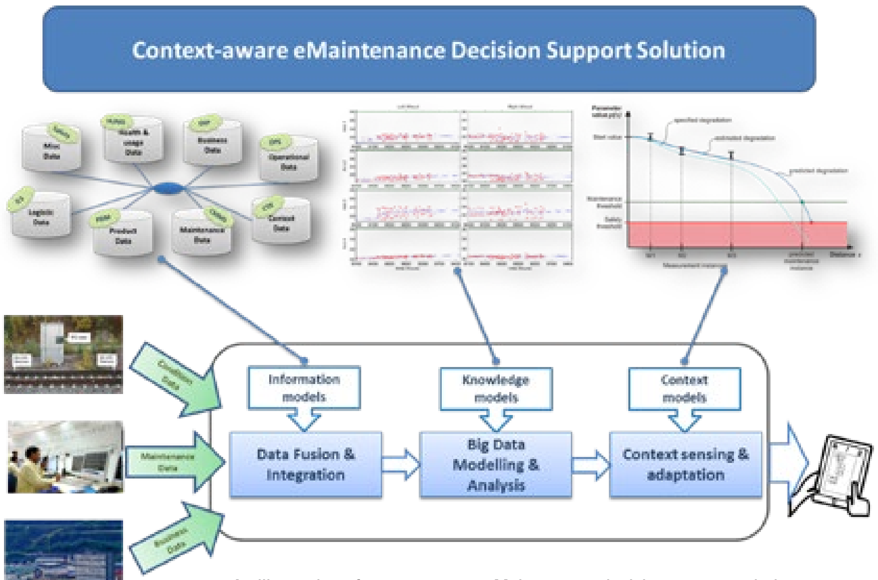
Illustration of the context of the framework called 'Railway 4.0', with the corresponding testbed.

The eMaintenance LAB

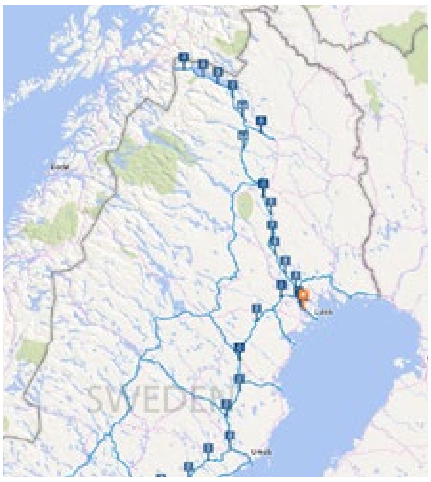
The eMaintenance LAB provides a platform for research and education in eMaintenance to enable enhanced decision-making in maintenance through digitalisation. The lab offers a set of services which can be utilised at various tiers, e.g. Infrastructure as a Services (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). The integrated services can smoothly be adapted to the context of different stakeholders, applications, and industries. Today, the eMaintenance LAB offers artefacts based on technologies, methodologies, and approaches such as Artificial Intelligence, Machine Learning, Big Data, Cloud computing, Edge computing, and cyber security. The lab supports research and innovation (R&I) projects in aviation, mining, railway, energy, and process industry. To support a wide range of R&I projects and initiatives, the lab provides a combination of physical and virtual sites.

eMaintenance LAB, is located at the University in Luleå and a similar site developed for LKAB in Kiruna, Sweden. These sites are designed and developed to facilitate hands-on experiences in eMaintenance research. The lab provides a set of interconnected and integrated services grouped as architectural services, infrastructural services, and platform services. The provided tools are utilised in research, education, and innovation within operation and maintenance. Furthermore, eMaintenance LAB is used to encourage and strengthen the cooperation and collaboration between industrial and academia partners

The Railway Cloud powered by eMaintenance LAB is a platform that enables tools, data, and information aimed for Big Data Analytics related to railway system, including railway infrastructure and rolling stocks. Today, this platform serves railway projects with context-adapted services.



An illustration of context-aware eMaintenance decision support solution.



A map of Malmbanan and connected sensors along the track

At the **Wheel Profile Measurement Station** in Sunderbyn, a wheel profile measurement equipment has been installed. The equipment automatically detects passing wheel sets and fires laser-based units to measure the wheel profiles of trains at operational speed. By combining this information with RFID readings of the wagon identity, the research corridor can provide a unique opportunity for eg. wheel maintenance optimization on an individual wheel level.

A robotic dog and drones are part of tools and services provided eMaintenance LAB, which are aimed for research activities related to topics such as remote maintenance, condition monitoring, remote inspection, safety, and security.

Track Logger is a portable logger to be installed on any railway vehicle and that scans the rail for imperfections by using accelerometers on axle bearings. Equipment owned by Damill AB.

S&C Vision Logger is a camera surveillance system installed in the catenary system above special track components such as switches.

Images in real time for condition monitoring check of snow conditions and to be used by the corrective maintenance personnel before driving out to the site to repair, in order to take the right spare parts, equipment and right personnel with right competence to repair the failure. In collaboration with Damill AB.

A Top-Of-Rail lubrication unit has been installed in the research corridor to perform research in the area of rail contact band friction management. The unit is powered by wind and solar energy and can be programmed to apply different amounts of fric¬tion modifiers to investigate the effect on eg. friction forces, wear and noise & vibrations.

Charlie the robotic dog that carries sensors for monitoring and inspection.

Condition Based Maintenance Lab (CBM Lab)

The Condition Based Maintenance Lab (CBMLAB) at LTU conducts research and training in condition-based maintenance. In the laboratory, which focuses on the condition control of railway and mechanical machines (gears, rolling bearings, etc.), today include the following test rigs and equipment:

- actuation, locking and detection device
- test rig for condition monitoring of cracks in gears
- test rig for condition monitoring of various sizes and types of gearboxes loaded with realistic torque and speed
- test rigs for rolling bearing testing where radial force is controlled via computer and where accelerations and temperatures are to be analysed with smart algorithms
- equipment for measuring friction on rails as well as wear constants
- equipment for measuring rail cracks with ultrasound, phased array and SAFT
- water tank for measuring ultrasonic cracks
- measuring trolley with eddy current technology for detecting rail fasteners
- level gauges for track position measurements
- crack gauge according to the resistance measurement method
- track profile gauges and surface finish gauges
- equipment for wireless transmission of railway measurement data

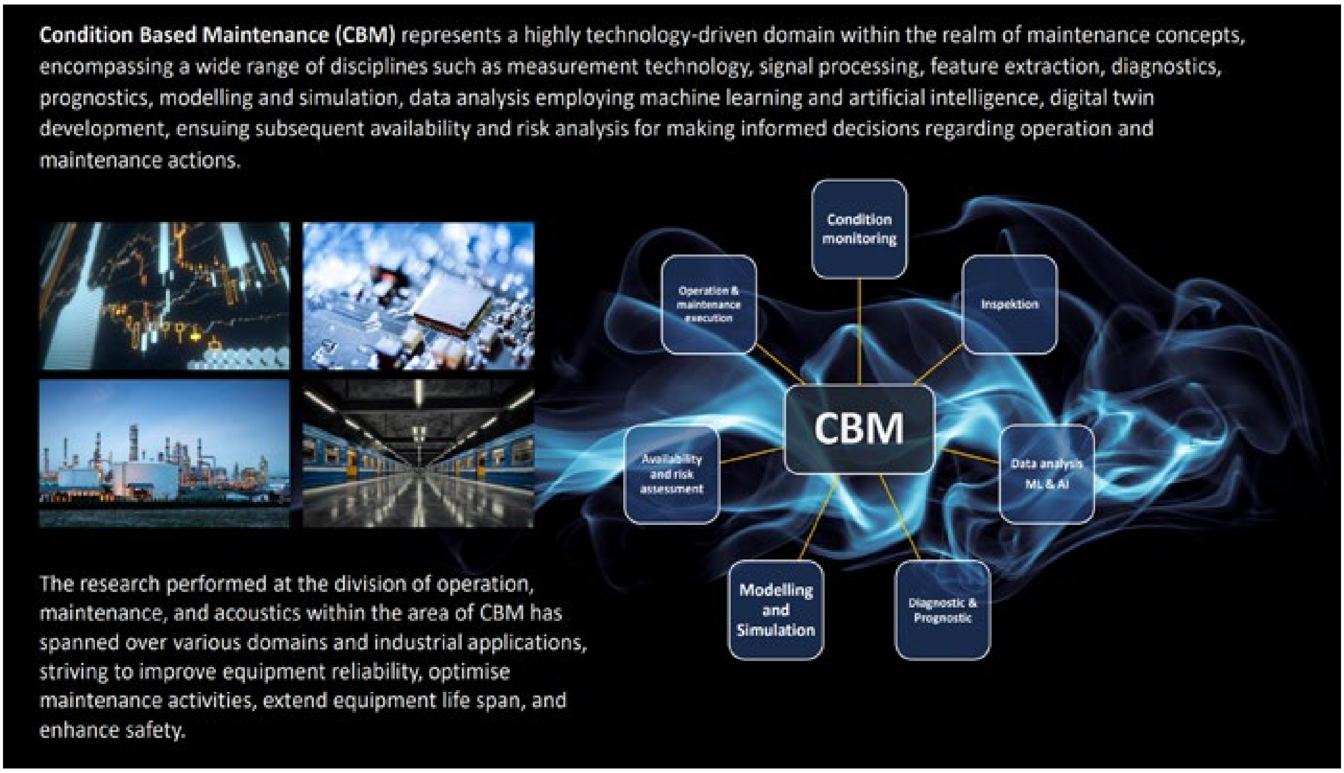
CBMLAB have a top modern Bombardier point machine, ready for digitalisation and smart algorithm adaption to the future railway.

Outside of CBMLAB, a complete, full-scale switch is also installed. It is 30 meters long and has been donated by Trafikverket. The switch will initially be used to study so-called gear drives. Furthermore, there is also a 30 m long railway track for detecting fasteners. In 2019, a boogie, a rotatable undercarriage for trains and rail cars, was delivered to perform tests on the university's full-scale switches and crossings lab.

Bombardier Point machine.

A complete full-scale track switch mounted connected to the CBMLAB.

Condition Based Maintenance (CBM)



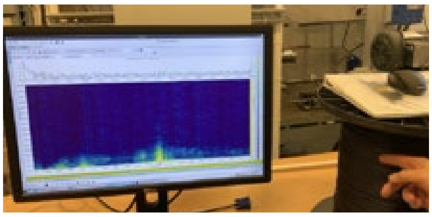
Condition monitoring and inspection

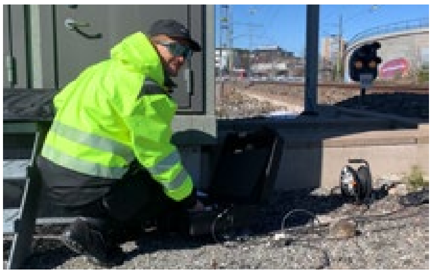
A prerequisite for implementing an effective CBM process is to establish an accurate measure of the functional state of an asset. The division has conducted comprehensive research focused on different facets of measurement technologies and the conversion of measurement signals into meaningful information or features that represent the state of the assets.

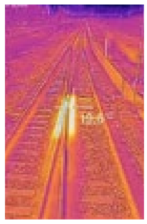
Ultrasonic techniques for inspecting subsurface cracks for different applications has been developed using methods like soft aperture focusing techniques.

Vibration measurement stands out as a widely employed technique in CBM applications for inspection and condition monitoring This has been applied in many research projects at the division dealing with detection of road and railway defects both from wayside and on-board vehicle measurement systems, as well as for monitoring defects in machine elements like bearings, gear boxes and changes in the machine dynamics due to component degradation.

In addition to classical vibration measurements research related to





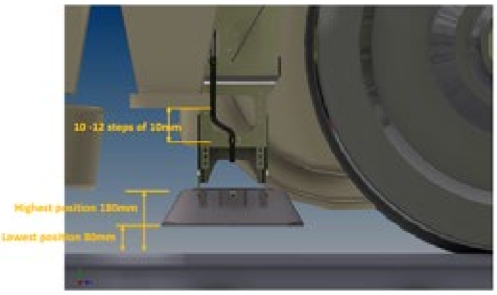


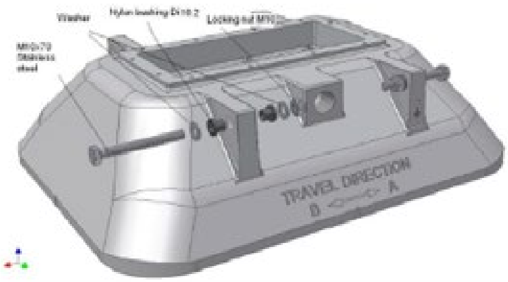
thermal imaging and measurements of temperature, sound, magnetic fields, and ground penetration radar (GPR) has been conducted at the division. For distributed assets like roads and railways research on Distributed Acoustic Senses utilising optical fibres is deployed.

By using magnetic field measurements, the division are performing and has successfully performed numerous research project related to track defect detection from ins service railway vehicles. The latest contribution to this area is the PhD thesis of Praneeth Chandran who defended his thesis focusing on railway fastener detection.

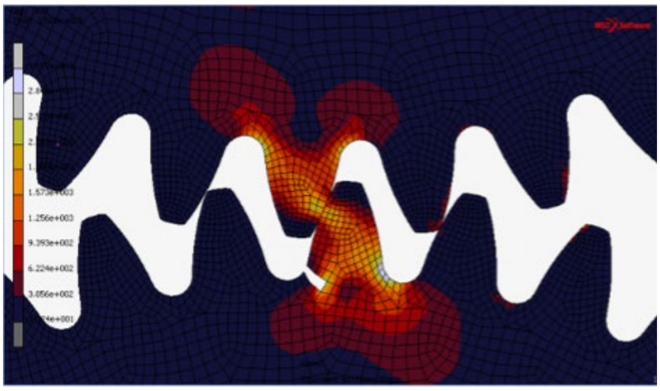
Modelling and simulation

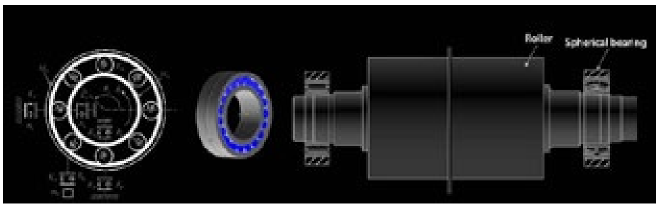
Research in modelling of digital versions (Digital Twins DT) of the asset and simulation of their behaviours are conducted on a regular basis to elevate the performance





of condition monitoring, diagnostic and prognostic solutions. To manage the transition to a sustainable society DT's for smart battery management systems are being developed to improve the energy and resource utilisation for battery based solutions. Multi body dynamic models and simulations using Particle Flow Code (PFC) are also being used for increasing the knowledge of unwanted behaviours and root causes to e.g. railway asset degradation and acoustic contamination. For the paper and mining industry rotor dynamic models are used to extract features for defect detection when analysing different measurement signals from rotating machinery like milling machines or rollers. To enhance the performance of physical models or to solve problems where traditional methods fail, AI and Machine Learning models are used, both cases with labelled or unlabelled data sets.





Data analysis, Diagnostic and prognostic

Most of the research projects within the area of CBM deals with different aspects of data processing and information analysis. Diagnostic solutions often deal with defect detection and root cause analysis. For the railway system wayside detectors for load, temperature and sound are being analysed to ensure the integrity of the detectors. This to increase the accuracy and presession of the detector signals. By addressing and mitigating deviations in the detector signals false positives related to waggon defects can be reduced, hence increasing the capacity of the railway system. Other laser-based measurements for on-line wheel profile measurement currently being used for predicting degradations of the railway system.

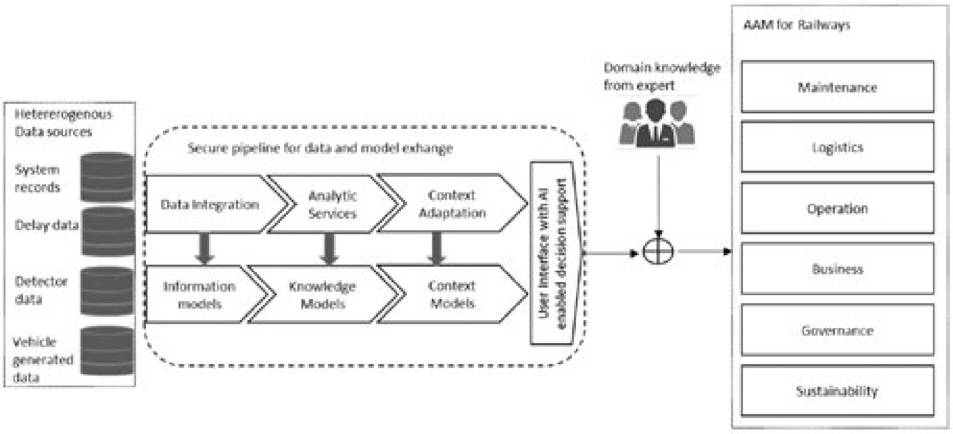
To increase the confidence of a prediction of the state of a function, hybrid modes are often used where a physical model is updated by measures from filed or lab test or from real operational conditions. This approach has been applied to the prediction problem of battery end-of -life (EOL) and end-of-discharge (EOD) where physical models have been combined with measurement-based prediction techniques. Models of predicting railway track geometry degradation has also been developed using the hybrid approach. Within the University technology centre for advanced condition monitoring, research in this area has been performed to improve traditional models for prediction remaining useful life (RUL) of bearings as well as anomaly detection models for machines. Currently the prediction models are being further developed to include machine learning and AI approaches in combination with physical models. These are being tested for prediction of unwanted events like paper breakage in paper mills and for optimal maintenance intervals for railway wagon couplers.

Availability, risk assessment and operation & maintenance execution

The final stage of the CBM process consists of the optimisation phase where different scenarios are evaluated based on availability simulations of the asset functions in combination with risk assessments and life cycle profit (LCP) analysis. The research within this topic is developed for large scale linear assets like the railway systems where the available train slot will be estimated based on the asset conditions. This phase incudes a combination of prognostic algorithms and e.g. classical reliability theory. Research questions related to optimal operation and maintenance actions are also an important aspect of CBM. Railway friction management is such an example as well as risk assessment for automatic train operations, which both are currently being studied.

Augmented asset management in railways

Augmented Asset Management (AAM) refers to the concept of augmenting the decision-making related to asset management processes with the use of Industrial AI and digitalisation.



The decision-making related to asset management processes, requires asset-related information and domain expertise. Augmented Asset Management (AAM) is a set of processes, that integrate asset related data from multiple heterogeneous sources and transforms them into information, knowledge, and context models. These models can be combined with domain expertise to enable advanced decision-support with an increased level of automation in the decision-making processes. However, facilitating decision-making in asset management through utilisation of industrial AI and digitalisation is highly dependent on availability of data and appropriate information logistics to enable smooth integration of various data sources between involved stakeholders.

The first step in the concept of AAM process is aimed to receive, store, and pre-process the asset-related data. In an industrial domain such as railway system, this step poses several challenges related to heterogeneity, quality, and quantity of data. Railway system involves multiple stakeholders that require a holistic image of the asset-health and the Key Performance Indicators (KPIs) related to different stakeholders. The information models in the next step are based on integration of asset-related data from different sources that provide such a holistic image of the asset with the state of the KPIs. The state of the KPI needs to be explained from the data.

The application of descriptive, diagnostic, predictive and prescriptive analytic services to information models leads to knowledge models. The knowledge models are intended to identify patterns and hidden relationships in data and make predictions and suggestions based on the observed patterns and relationships. These knowledge models can be further enriched by placing them in context. The adaptation of the information and knowledge models to context specifications such as operational environment, maintenance policy, end-user etc., enable the application of these analytic services to real-world challenges. An effective decision-support for asset management of railway system in real-time requires continuous exchange of data and models between the stakeholders.

A secure pipeline with consideration to cyber-security guidelines within railway system domain ensures a trustworthy platform for data and model sharing between stakeholders. The output of the information, knowledge and the context models are provided through a user interface, adapted to the context of the end-user. This user interface provides information related to asset-health, extracted by advanced analytics services that are enabled by industrial AI and digitalisation.

The end user combines this information with other information sources or domain knowledge from experts that are relevant to the domain such as operation, maintenance, life-cycle costing, logistics, business, governance, sustainability and so on, to augment the decision-making in asset management.

When implementing solutions based on AI and digital technologies to augment asset management in railway system, there are several challenges that need to be addressed. A taxonomy of issues and challenges in the augmented asset management of railway system lays down a foundation for further research in the application of industrial AI and digitalisation for the asset management of railway system. This taxonomy of issues and challenges related to augmented asset

management of rolling stock is structured into three categories i.e.: a) organizational; b) technological; and c) economical.

The concept of augmented asset management (AAM) is based on the underlying thinking that knowledge acquired from domain expertise in complex technical system is key to decision-making. The AAM platform, therefore, does not intend to replace the domain expertise with advanced analytics using IAI and digitalisation. It intends to augment or enhance the domain expertise with fact-based data-driven models for decision-making related to asset management in railway system. The processes related to asset management such as maintenance, logistics, operation, business, governance, and sustainability are not independent of each other. A holistic platform for AAM is expected to consider these interdependencies. The AAM platform can also be applied to industrial systems with similar requirements and constraints.

Metaverse for Intelligent Asset Management

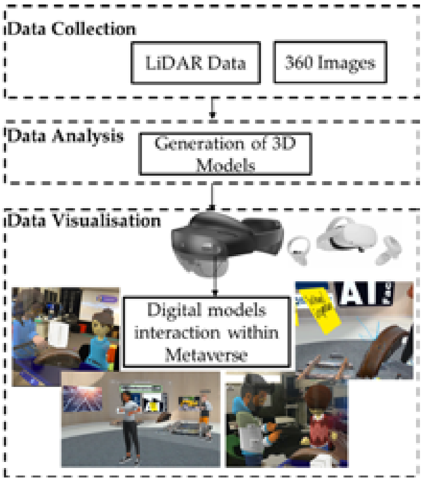
Metaverse is a game-changer in industrial asset management! Metaverse is a multi-space environment, aims to augment the interaction between liveware, software, and hardware.

With the use of advanced digital technologies, industries are increasing their efficiency and productivity with improved quality, lower costs, enhanced safety, and accelerated growth. These new technologies support research in the domain of scientific development such as application of eXtended Reality (XR) and Artificial Intelligence (AI) in various industrial domains.

These technologies help to feel an extraordinary immersive experience where digital world is merged within the physical world. Within these two worlds, people come together to visualise and interact with numerous digital assets by creating a perpetual and persistent multiuser environment merging physical reality with digital virtuality. This environment is the post-reality universe and called as Metaverse (Meta; Greek prefix meaning post, after or beyond+ Universe) based on the convergence of XR technologies like virtual reality (VR), augmented reality (AR), and mixed reality (MR).

The existing Metaverse from Meta company has been used for social interactions and this

concept can be utilised by railway industry to enhance the maintenance activities. Thus, the introduction of the developed Metaverse for Asset Management (AM) to enhance the operation and maintenance processes in the railways utilising AI, digitalisation, and XR technologies is very crucial. The developed platform for the Metaverse consists of number of components like, 3D scanning (LiDAR), 3D modelling, visualisations, and gaming technologies.

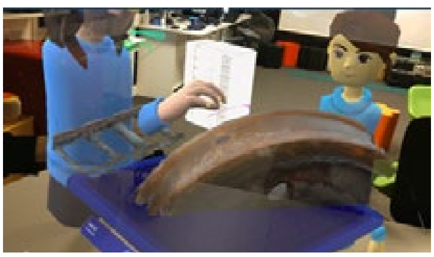


The developed Metaverse aims for inspection of virtual assets which are merged with the physical assets into a real-world context. The virtual assets are the digitalised replica of the physical assets. Metaverse consists of virtual assets, which are operated by the avatars of the real operators and maintainers. This developed Metaverse is expected to enhance the inspection process and facilitate the decision-making processes within the operation and maintenance of railway industries. In addition, by applying this concept, railway stakeholders and maintenance engineers can be in multi-space environment from different locations. Thus, the developed Metaverse can improve immersive experience of assets and facilitate collaborative mechanisms for accessibility, training, education, and visualisation of an Intelligent Asset Management (IAM) within operation and maintenance to enhance the decision-making process.

Generally, in asset management, an asset is considered an item, thing, or entity with potential or actual value to an organisation. Here virtual assets of railway (wheel and track) have been used in the developed Metaverse to show how these assets can be inspected remotely. Thus, Metaverse has shortened or removed the distance between the collaborators/avatars to discuss any railway asset for future maintenance decisions. Metaverse where avatars are visualizing and discussing a kind of wear on the railway wheel and rail can be seen in the figures.

A railway wheel can be represented as a point cloud data with color information. This color information can be used to show where the wear occurred within the railway wheel. Based on this, we can alert the maintenance operators or engineers about the wheels that need to be visualised for maintenance.

The Metaverse for IAM, will help to enhance the inspection process, which will have a positive impact on the decision-making processes within railways. In addition to this, Metaverse for IAM will also help the researchers and students for educational purposes. By integrating engineering models with these technologies to better predict the areas where a well-trained asset management team needs to focus in inspection will lead to significant contribution and a game changer in asset management of remotely placed long life and capital-intensive assets. It has been proven that VR metaverse system is more valid as an educational environment than existing video-based methods. Thus, these technologies can help the students to enhance their learning capabilities through an immersive environment where they can visualise and interact with the digital assets of interest.



Climate-Resilient Infrastructure

- For a more reliable and sustainable future

Division of Operation and Maintenance Engineering at LTU, along with Trafikverket, municipalities, and other stakeholders, are building a new research area "Climate-Resilient Infrastructure" with the aim of promoting a sustainable future.

Infrastructure is the basic physical and organizational structures and facilities (e.g., buildings, transport, water and energy resources, and administrative systems) needed for the operation of a society or enterprise. Resilience means the ability of assets, networks, and systems to anticipate, absorb, adapt to and/or rapidly recover from a disruptive event, for instance, extreme whether events and adaptation to future climate change scenarios.

Climate-resilient infrastructure is distinguished by utilizing climate adaptation measures and options in planning, designing, constructing, and maintaining of the infrastructure life cycle to anticipate, prepare for, and adapt to evolving climate conditions. A climate-resilient infrastructure is capable of withstanding, responding to, and recovering promptly from any disturbances caused by changing climate conditions. Climate resilience is a continual process that spans the entire lifecycle of the asset. Efforts to achieve climate resilience can be mutually reinforcing with efforts to increase resilience to natural hazards and extreme events.

Climate-resilient infrastructure can improve service reliability, increase asset life, and assure asset returns. Building climate resilience can include:

- Management measures such as changing maintenance planning.
- Adaptive management to reduce future uncertainty of reliability, availability, maintainability, and safety measure of asset.
- Structural measures such as updating the current standards related to the snow loads in Nordic countries.

Climate-induced changes in structural behavior due to changes in snow loads and extreme event scenarios. This has created concentrations of snow loads more than the limits allow by existing building codes, therefore exposing critical structures such as railway stations, buildings or avalanche or rock fall shelters to potential damage or collapse.

The resilience of individual infrastructure assets to climate change should be assessed in relation to the overall system's ability will cope with climate-related challenges. Although it is essential to consider the impact of climate change on individual infrastructure assets, such as bridges or railway lines, it is not sufficient to ensure that the system remains functional and resilient against changing climate hazards. To address this challenge, measures to enhance resilience at the system level should be integrated into a strategic approach to infrastructure network planning that considers both the direct and indirect impacts of climate change and climate variability.

Climate Mitigation and Climate Adaptation actions are the main drivers toward building climate resilience infrastructure. Adaptation to climate change means helping the whole society and ecosystems adapt and prepare for future unavoidable impacts of climate change (see the Building Climate Resilience figure). That means the adaptation of infrastructure to climate change cannot be viewed individually by technical infrastructure improvement. A holistic view of sustainable transport not only needs to be robust and resilient in terms of technical and socio-economical aspects but also there is a need to minimize transport-related emissions in the whole value chain to minimize the climate change risks to the infrastructure.

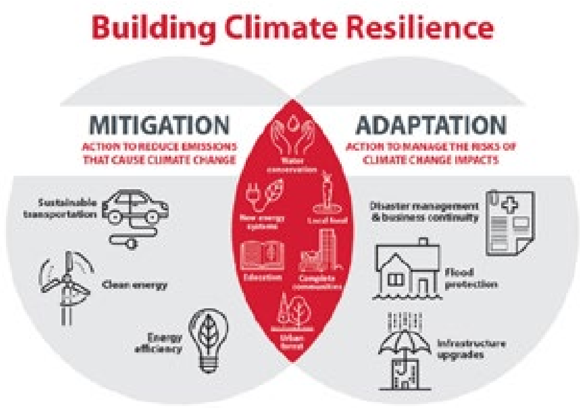


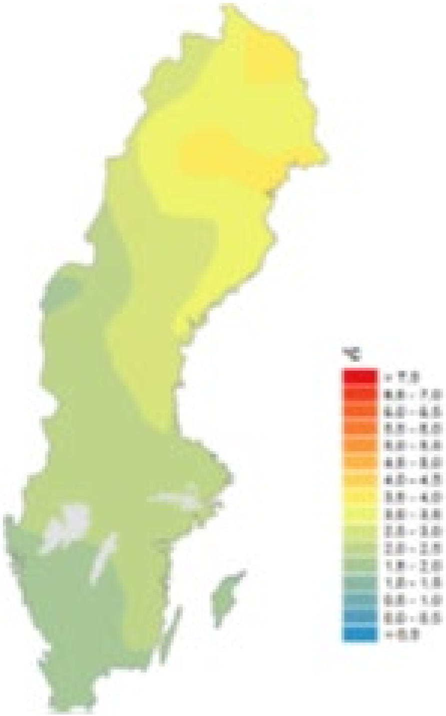
Figure. Building Climate Resilience.

Ensuring that infrastructure is resilient to climate change can support the achievement of the goals of the Paris Agreement, including through increasing the ability to adapt to climate change. Climate-resilient infrastructure can also support efforts to achieve a number of Sustainable Development Goals and the implementation of disaster risk reduction due climate changes.

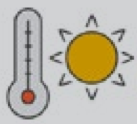
More about climate change in Sweden

According to the climate change model, it is projected that climate change will increase damage to infrastructure from extreme weather events ten-fold by the end of the century in Europe if adaptation measures are not taken. Different regions at Sweden have experienced significant changes to its climate in recent decades. The winter temperature is expected to rise above the annual average temperature, with the largest increase in northern Sweden.

Climate modelling tells us that Sweden will experience more severe and frequent extreme weather events such as heat waves, flooding, and severe snowstorms. Climate change hazards pose risks to the health and wellness of citizens, the economy, public infrastructure and services, homes and private property, and natural ecosystems. Six climate hazards are becoming more likely and/or severe due to climate change. These hazards are as follows:



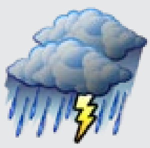
Amir Garmabaki, project leader, Climate resilient infrastructure.



Extreme heat: rising global temperatures cause more intense and frequent heat waves, leading to illness, death, and damage to crops and infrastructure.

Shifting seasons: altering the timing of seasons can disrupt natural events, impacting ecosystems.

Heavy rainfall and flooding: warmer temperatures leading to more evaporation, resulting in more intense precipitation events, causing flooding and water-related disasters.



Severe storms: changing atmospheric circulation patterns leading to more frequent and intense storms, causing severe damage to coastal communities.

Snowfall: warming climate leads to more moisture in the atmosphere, causing more intense snowfall in some regions.

Wildfires: higher temperatures and drier conditions increasing risk of wildfires, which release CO_2 into the atmosphere, exacerbating climate change.

SIMTRACK - Simulation of railway track geometry and intelligent maintenance planning

Researchers: Alireza Ahmadi (PL), Arne Nissen (PL Trafikverket), Adithya Thaduri, Iman Soleimanmeigouni, Hamid Khajei.

Sponsor: Trafikverket, JVTC and Infranord.

Goal: The SIMTRACK project will facilitate simulation-based platform that enables development of tools, methodologies and techniques for optimization of track geometry maintenance planning, scheduling and opportunistic maintenance. The results will enhance safety, maximize capacity utilization, and lead to an efficient and cost effective maintenance program.

Project Status and Results: SIMTRACK is structured into 6 work packages. The details of the work packages and their relations are presented in Figures 1 and 2.

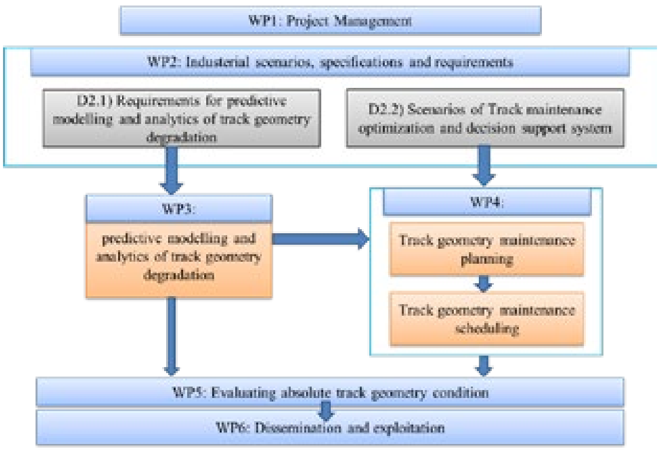


Figure 1. Description of WPs and their relations.

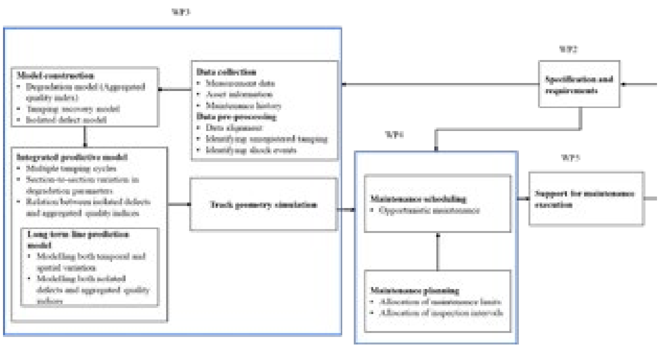


Figure 2. Framework of SIMTRACK project.

A summary of the main outputs of SIMTRACK project is presented here. One of the main prerequisites for prediction of track geometry failures, is to process the data to minimize the positional errors. Figure 3 shows an example of two datasets before and after alignment. Datasets may be shifted, stretched or compressed. Minimizing the positional errors is done by applying an alignment method which is a combination of COW and RAFFT algorithms. The performance of the method is checked considering the precision and the ability of keeping the original shape of measurements. It is concluded that the developed combined alignment method is flexible to address both constant and non-constant shifts between two datasets while keeping the original shape of measurements.

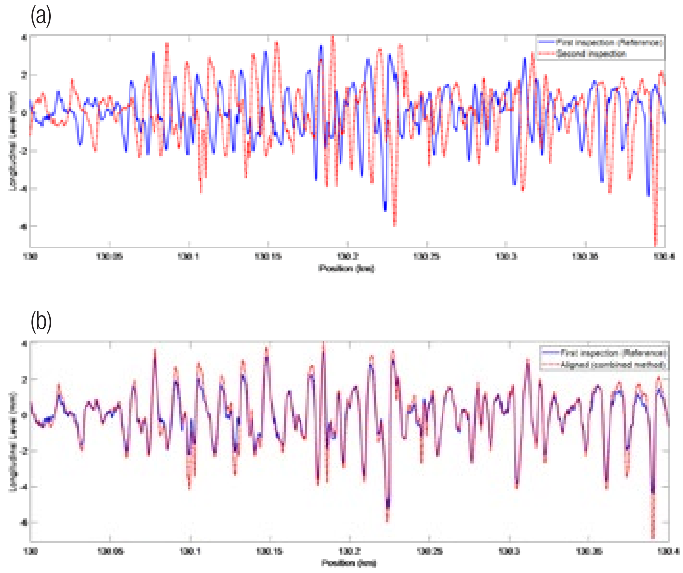


Figure 3. Example measurement before (a) and after (b) data alignment.

After performing data alignment, a main step towards prediction of track geometry condition is to predict the occurrence of isolated defects. Within the project this issue is addressed in both detailed level and section level. The aim of detailed level model is to model the changes in defect's amplitudes over time, see Figure 4.

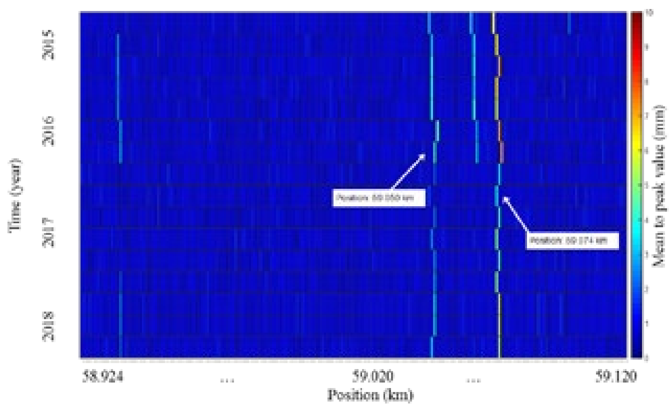


Figure 4. Heat map of longitudinal level at a sampling interval of 25 cm.

It is found that isolated defects of twist and longitudinal level have a linear pattern over time. In addition, within the project, it is found that the first and second order derivatives of defects can properly be used to identify shape and severity of defects, see Figure 5. These results will be used to plan local maintenance activities.

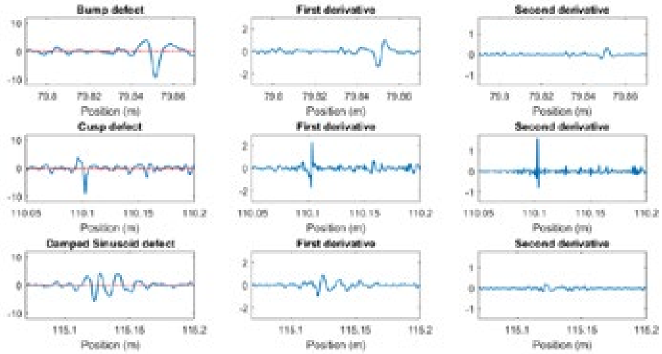


Figure 5. Examples of three types of isolated defects.

In order to predict the probability of the occurrence of isolated defects in a track section, a section level model is developed within the project. The results show that there is a significant relation between the value of standard deviation and kurtosis of geometry parameter and occurrence of isolated defects, see Figure 6. This information can be used to schedule maintenance activities by considering the occurrence of isolated defects.

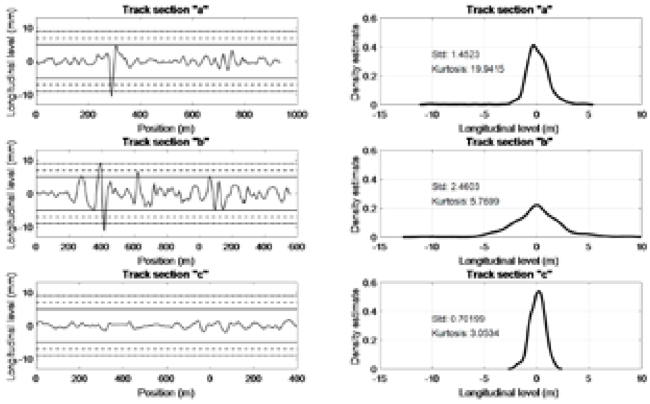


Figure 6. Relation between aggregated quality indices and isolated defects.

In order to model the evolution of standard deviation of longitudinal level, as the main aggregated quality index for planning tamping activities, a two-level piecewise linear model was developed. This model consider the breakpoint after tamping intervention and the possible spatial dependence between adjacent track sections. Figure 7 shows an example of track geometry degradation over a line section.

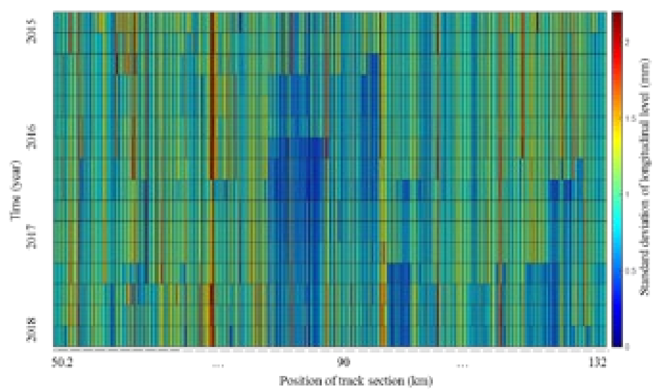


Figure 7. Track geometry degradation over a line section.

Within the project, the occurrence of shock events is analysed. Since the degradation rate dramatically increase after occurrence of shock events (see Figure 8), those track sections must be considered with highest priority for planning maintenance actions.

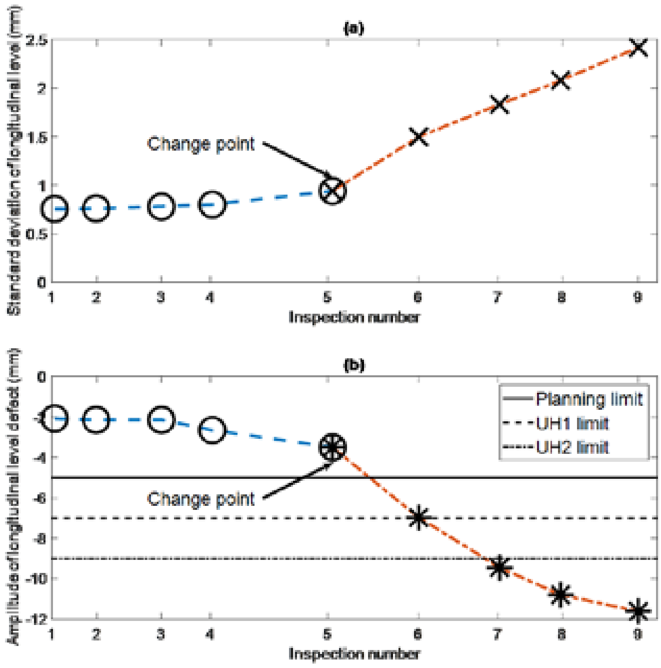


Figure 8. Irregular trend in the track geometry degradation path.

In order to model section-to-section variation in degradation rates, Artificial Neural Network (ANN) model is applied, see Figure 9. It is found that the maintenance history, the degradation level after tamping, and the frequency of trains passing along the track have the strongest contributions among the considered set of features in prediction of track geometry degradation rate.

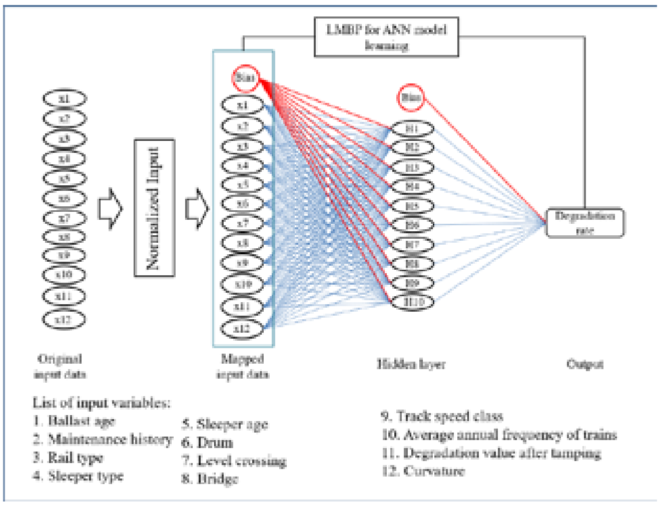


Figure 9. ANN model architecture.

The proposed predictive models within the project are used to simulate long-term track geometry behaviour considering different maintenance and inspection scenarios. One of the key steps in defining maintenance strategy is allocation of a proper maintenance limit so that the total cost of maintenance would be minimized while keeping geometry condition in the acceptable level, see Figure 10.

In addition to setting the planning limit, applying an adequate inspection interval is vital to ensure the availability, safety and quality of the railway track, at the lowest possible cost. Therefore, another simulation framework was developed within the project to investigate the effect of different inspection intervals on the track geometry condition. Figure 11 demonstrates a schematic view of the framework for assessment of inspection plan.

Based on the results obtained, it was observed that varying the length of the inspection intervals has a significant effect on the percentage of time spent by the track in different longitudinal level states.

The final aim of the decision support system is to propose an opportunistic scheduling plan that minimize the total maintenance costs while keep track geometry condition in an acceptable level. To achieve this, the track geometry tamping scheduling problem was defined and formulated as a mixed integer linear programming (MILP) model and a genetic algorithm was used to solve the problem. Figure 12 shows an example of optimal tamping scheduling considering the opportunistic maintenance concept.

Some of the results obtained are as follow: 1) different scenarios for controlling and managing isolated defects will result in optimal scheduling plan 2) to achieve more realistic results, the speed of the tamping machine and the unused life of the track sections should be considered in the model 3) ignoring the destructive effect of tamping in prediction of geometry condition will cause an underestimation of the maintenance needs by about 2%.

Duration: 2017-2022

Alireza Ahmadi, project leader SIMTRACK

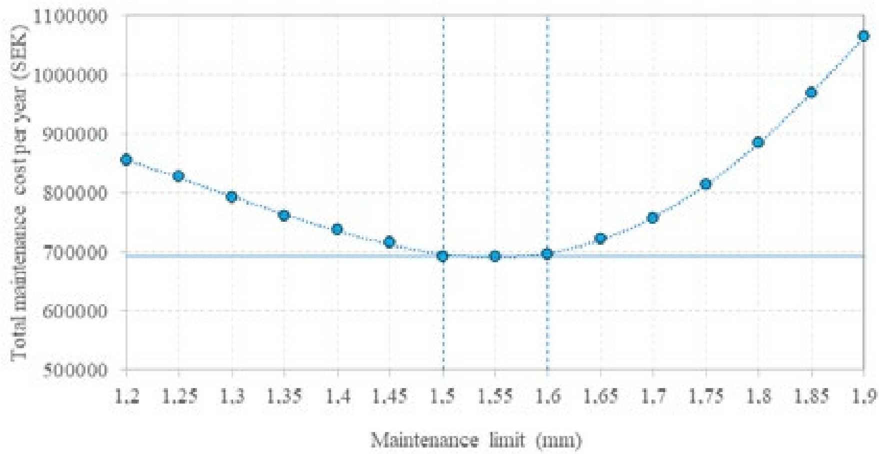


Figure 10. Example of simulation results for comparison of maintenance limits, total expected costs for different maintenance limits.

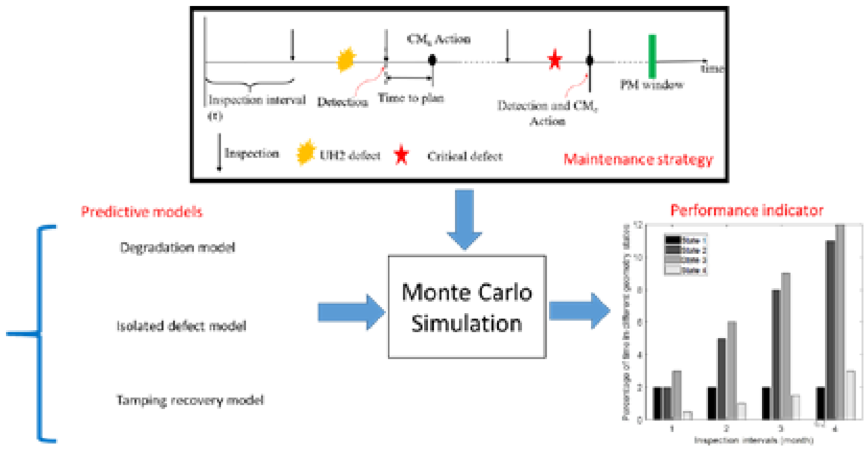


Figure 11. A schematic view of simulation framework.

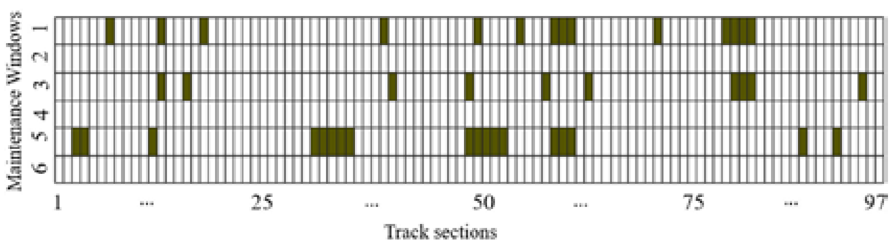


Figure 12. An example pf opportunistic maintenance plan

Digiswitch
- The digital railway switch

Researchers: Jan Lundberg (PL), Taoufik Najeh, Veronica Jägare

Sponsor: Formas, Bombardier, Trafikverket, Infranord

Goal: The overall aim of this project is was to increase the transport capacity in the long term and to indirectly reduce the environmental impact in Sweden by reducing operational disruptions at railway switches and thereby increasing the punctuality of rail traffic. This provides a better utilization of environmental transport infrastructure in Sweden, with a focus on increased accessibility for the interchanges as a whole.

The priority switch components are the ones that cause the most interference, which is the switch blades, crossing and other parts. The goal is to develop new knowledge and skills that can later be developed into a demonstrator in the form of an auxiliary equipment inside the point machine for switches in real traffic. This auxiliary equipment that in real-life traffic should have the ability to, using IoT, AI and smart algorithms with pattern recognition, provide continuous information about the state of the switch to the Swedish Transport Administration and its maintenance contractors (for example Infranord). This means that maintenance can be planned and carried out in a better way to increase the availability of switches and thus reduce traffic disruptions.

The project has developed an AI demonstrator that shows that it is fully possible for pattern-recognition neural networks to correlate measured vibrations in the point machine, against actual wear and tear and damage in different positions in our test switch with test wagon, which also forms part of the demonstrator. This opens up for full-scale trials in real traffic in the future. If this future project is also successful, the last remaining step is that this new technology can be product-adapted by companies to become commercially viable for the Swedish Transport Administration's switches. If this happens, the Swedish Transport Administration and related maintenance contractors will have access to a completely new technology that can effectively reduce the disruptions in train traffic by considerably facilitating the planning of preventive maintenance of the switches. The demonstrator is patent applied.

Project status and results: The project is completed and some of the most important results are shown below:

- Squats: Within a distance of 14 m approximately symmetrically around the point machine, it was quite possible to detect squats with a diameter of 50 mm and with a depth of 0-4 mm, as well as 1-4 mm, over the entire switch.
- Crossing: With a speed of 0.05 m/s in the switch, it was not possible to detect damage in the crossing, either by means of acceleration amplitudes or an FFT. However, with a speed of 0.6 m/s, it was entirely possible to detect and separate levels of wear of the order of 1-7 mm at a distance of 63 mm, 153 mm and 243 mm from the crossing tip. With a speed of 0.6 m/s, it was not possible with an FFT to detect and separate such levels of wear at a distance of 63 mm, 153 mm and 243 mm from the tip.
- Crossing: LSTM algorithm with 7 vibration parameters show 82 % prediction accuracy for 60 % unseen data.
- Middle rail: Levels of side wear of the order of 0.5-8 mm were possible to detect and separate from each other over the entire rails.
- Middle rail: LSTM algorithm with 7 vibration parameters show 89 % prediction accuracy for 50 % unseen data
- Switch blade: Levels of side wear G of the order of 3.5-4.3 mm at a position 200 mm from the tip of the tongue were possible to detect and separate from each other.
- Switch blade: Levels of side wear - H of the order of 3.14–0.48 mm between a position 200 mm from the tip of the tongue and a position 228 cm after the centre of the point machine were possible to detect and separate from each other based on the maximum amplitudes and the number of amplitudes over 0.1 g. The results point to a relatively strong nonlinear dependence.
- Switch blade: Levels of side wear + H of the order of 0.80-3 mm at a position 228 cm after the centre of the point machine were possible to detect and separate from each other. Moreover, levels of heavy rail height wear of the order of 4 mm were possible to detect and separate from other.
- LSTM algorithm with 7 vibration parameters show 85 % prediction accuracy for 60 % unseen data
- Support rail: Levels of rail height wear of the order of 3 mm on support rails were possible to detect and separate from each other.
- Wheel plates: Wheel damage of the order of 12-60 mm was detectable. The results point to an approximately linear dependence.
- Trailed switch: The risk of a trailed switch occurring was possible to detect for all combinations of carriage position and position in the switch blade.
- Tamping error: Tamping errors at the deflection device could be detected by measuring the number of amplitudes above 0.15 g when the relative difference in the height position between rails was of the order of 10 mm.
- The AI demonstrator based on LSTM is capable of predicting wear and damages in the S &, C with probability 41-82 %, dependent on the type of damages and the position of the damages in relation to the point machine.

Duration: 2019-2022

Award: The Digiswitch project was on the Royal Swedish Science Academy 100 list 2022 for Technology in the service of humanity.

Jan Lundberg, project leader Digiswitch

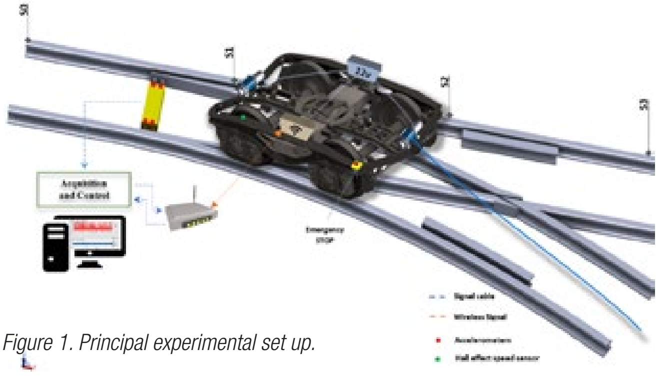


Figure 1. Principal experimental set up.

Figure 2. Point machine with assembled vibration sensors used in the study.

Figure 3. Experimental set-up of test waggon used in the study.

Figure 4. Artificial introduced realistic wear on support rail as input to AI.

Figure 5. Artificial introduced realistic wear on crossing as input to AI.

Figure 6. Artificial introduced realistic squats as input to AI.

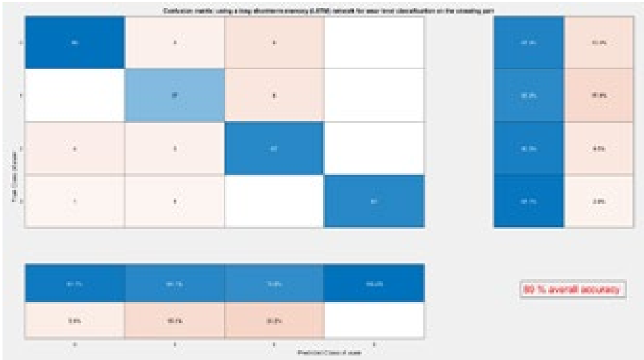


Figure 7. Confusion matrix results based on AI for crossing.

Figure 8. Confusion matrix results based on AI for wear in switch blades.

Figure 9. Test of demonstrator in switch at real traffic.

AI Factory for Railway

A platform for data sharing and analytics

AIF/R's goal is to create value for its stakeholders via establishment of a reliable and resilient platform for data sharing, engineering and business solutions. The platform consists of a set of services and governing structures, which enables railway stakeholders, nationally and internationally, to provide and consume data and services securely.

The ongoing digitalisation and implementation of AI-technologies in railway is highly dependent on availability and accessibility of data for a geographically distributed system. AIF/R is facilitating this by providing a platform for data sharing. AIF/R is a set of smart cloud/edge-based data services that are aimed to accelerate digitalisation in railway. AIF/R's services provide capabilities such as acquisition, integration, transformation, and processing of railway related data across endpoints, e.g. authorities, industries, academia, and SME:s. AIF/R's integrated services can be invoked on-premises or in multiple cloud-based environments. AIF/R architecture is built on loosely coupled storage and computing services, see Figure 1.

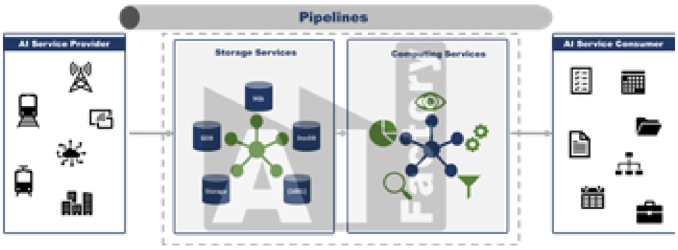


Figure 1. AIF/R's conceptual model (Karim et al., 2020)

AIF/R provides digital pipelines between data providers and data consumers, as illustrated in Figure 1. Each pipeline represents a set of orchestrated activities aimed to extract, transfer, load, and process datasets between the provider and the consumer. AIF/R's pipelines are configurable entities, which can utilise a palette of technologies for e.g. communication, storage, and processing, to enable context-adaptability and fulfil the users' requirements. Selection of appropriate technologies for each pipeline will be based on the context specific requirements such as requirements on scalability, authentication, and authorisation. It is believed that a generic data factory for railway should be hosted as a neutral open platform , which is governed by a body with focus on research and innovation.

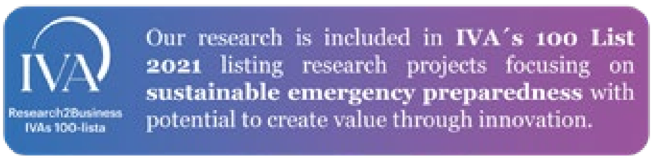
AIFR/R achievements :

- AIF/R team: 16 (researchers, master, coordinators)
- Coordination platform (cloud/edge-based) established
- Development platform (cloud/edge-based) established
- 17 use cases identified
- Integration:
  - Several external data sources integrated
  - Several data lakes and analytics services connected
- Demonstrators: 8 demos in different UC:s
- 34 conducted seminars/workshops (dissemination)
- PhD:s recruited
- A Roadmap for the future
- Special issue in the Journal of Sustainability
- Book proposal: 'AI Factory'
- OECD report on 'Data-Driven Approach' Transport

Use Case	Title
UC01	AI Empowered Fleet Management
UC02	Augmented Decision Support using IAI
UC03	Cloud/edge-enabled AR/VR for Enhanced Asset Management
UC04	Predictive maintenance for railway catenary using IAI
UC05	Prescriptive Maintenance using IAI in Process Mining
UC06	Predictive maintenance for wheel using IAI
UC07	Enhanced track maintenance planning using AI
UC08	Distributed computing, edge/cloud integration
UC09	Enhanced cybersecurity using distributed ledgers
UC10	Predictive Models for Railway Track Geometry Degradation
UC11	AI for improved maintenance planning of track tamping
UC12	Track geometry data alignment
UC13	AI for track anomaly detection from mobile onboard sensors
UC14	Condition monitoring of railway infrastructure using satellite InSAR
UC15	Dynamic decision support tool for data mining based on PetriNet
UC16	Asset management digitized overhead catenary
UC17	MetaAnalyser® - Automated ML

Researchers: *Ramin Karim (PL), Miguel Castano, Veronica Jägare, Jaya Kumari, Adithya Thaduri, Cecilia Glover, Uday Kumar, Amit Patwardhan, Ravdeep Kour, Diego Galar, Kevin Karim, Emil Lindh.*

Sponsors and participating companies: *Vinnova, Trafikverket, Association of Swedish Train Operating Companies, Infranord, Norrtåg, Alstom, Bombardier, Damill, Omicold, Sweco, Transitio.*



Ramin Karim,
project leader AI Factory for Railway.

ePilot

A collaboration platform that enables innovations for the railway ecosystem within eMaintenance and Industrial AI.

ePilot provides a collaboration platform for the development of solutions for maintenance decision-making. The platform is based on the needs and requirements from various stakeholders, in order to enable and transform the Swedish fragmented railway industry to an integrated system. The solutions result in improved punctuality and minimized disruption in railway system and an insurance of improved accessibility and increased quality together with more efficient maintenance.

ePilot has been initiated and developed in close collaboration between Trafikverket, Luleå University of Technology (LTU), and a large number of stakeholders from the railway industry. The concept of ePilot was developed by the Luleå Railway Research Center (JVTC) at LTU as a result from more than 20 years of research, innovation, and implementation in operation and maintenance of railway.

Our mission is to provide a collaborative innovation platform enabling operational excellence for the railway ecosystem through eMaintenance and Industrial AI.

Our vision is to enable a robust, resilient, reliable, and digitalised railway system in Sweden that is attractive, safe and efficient.

Our goal is to incorporate relevant research and development findings into the railway system, thereby contributing to greater reliability, punctuality, and sustainability in railway, and also greater cost-efficiency in operation and maintenance.

Within the ePilot's framework, 38 sub projects have been conducted. The ePilot was ongoing from 2013 to 2020.

Achieved impacts

- ePilot has contributed to greater collaboration where 51 stakeholders have actively participated
- ePilot has established a national platform for the retrieval, storage, integration and analysis of condition and operational data
- ePilot has created a neutral innovation platform
- ePilot has established a process-oriented, crosssectoral working method between organisations
- ePilot has created a greater understanding of the challenges and opportunities that affect the implementation of innovations
- ePilot has increased the industry maturity regarding the opportunities inherent in eMaintenance
- ePilot expect the upshifting of the invested funds to continuously increase
- ePilot collaboration has generated 105 ideas resulting in 38 conducted sub projects
- ePilot won the Strukton Innovation Award 2017
- ePilot has been selected to the The Royal Swedish Academy of Engineering Sciences (IVA) top hundred list 2020
- ePilot contributes to the achievement of the following impacts by utilisation of digital technologies and Industrial AI in operation and maintenance:
  - Improved robustness and punctuality in the railway transport system.
  - Greater cost-efficiency of operation and maintenance.

Between 2013-2020, ePilot received 105 ideas for improvements where 38 of these have been approved and demonstrated in sub projects.

The sub projects can be related to different topics such as:

- Track maintenance
- Vehicle maintenance
- Decision support
- Digitalisation
- eMaintenance
- Information logistics
- Industrial AI
- Prognostics and health management (PHM)
- Augmented reality (AR) /Virtual reality (VR)
- Computer vision
- eCollaboration
- eChange Management
- eGovernance
- Business models
- Cost benefit analysis models
- Test and verification of innovations

ePilot has also contributed to a large number of ongoing works, initiatives and projects within Trafikverket and the industry, including: Shift2Rail, H2020, Horizon Europe, Asset data (ANDA), Maintenance system (GUS) and BanaVäg För Framtiden (BVFF).

ePilot homepage:
https://www.ltu.se/research/subjects/Drift-och-underhall/Forskningsprojekt/ePilot

Veronica Jägare, project leader ePilot.

ePilot on the Royal Swedish Science Academy 100 list 2020

ePilot collaboration partners

EU Research PROJECTS 2022

JVTC researchers have participated in six H2020 projects within Shift2Rail during 2021: IN2SMART2, IN-2TRACK3, FR8RAIL II, FR8RAIL III, FR8RAIL IV and Europe's Rail. The descriptions of the European projects are given below.

IN2TRACK3

- Research into optimised and future railway Infrastructure 3

Researchers: Jaime Gonzalez, Johan Casselgren, Matti Rantatalo, Florian Thiery, Johan Odelius

Sponsors: EU, H2020, SHIFT2RAIL, Trafikverket

Objective: Develop technologies for better assessment and performance of existing railway structures.

The IN2TRACK3 project is a continuation of IN2TRACK and IN2TRACK2, which will develop physical as well as digital technology and methodology demonstrators for the track, switches and crossings and bridge and tunnel assets. IN2TRACK3 will help to further develop and demonstrate solutions from the previous two projects as well as reduce lifecycle costs, improve the reliability and punctuality of tomorrow's railway.

WP3: Wheel/rail interaction and Simulations and track monitoring

Evaluation of wheel tread measures with its limits for reliable wheel/rail system in order to formulate guidelines that increase availability performance. Investigation of methods to predict and mitigate curve squeal for corves with small radii and validate the results in real context. Perform system prototype demonstration in operational environment for detection of Rolling Contact Fatigue (RCF), especially squats, by sensors e.g. axle box accelerometers. Perform field demonstration in collaboration with Trafikverket.

Test of the sensor Rail Eye: The sensor has been tested in real environments but not mounted on a train. Similar sensors have been mounted on road vehicles with good result. There is a difference between road and rail environment and this is why this sensor need to be tested mounted on a train. The main goal of the test was to investigate how the sensor signals were affected by the motion of the railcar, especially with focus on measuring on the contact band of the rail. In the end of November, the first tests of the Rail eye sensor mounted on a railcar, was carried out. The results looks promising, and when the sensor measured on the contact band of the rail the signals was strong, but when the railcar turned the sensor focus was outside the contact band on the rusty part of the rail the sensor signals went down. This was expected and the development of an upgraded sensor has started. Secondly, the environment close to the rail was not a problem for the sensor, although it was wet and slushy, the sensor handled that fine. If this project is successful, it would enable a sensor that could monitor the rail contamination and top of rail lubrication in real time and produce maps of the current state.

WP5: Bridge health monitoring

Due to the age of the existing railway infrastructure in the world, damage and deterioration of railway bridges is a major social and economic concern in many countries. Therefore, there is a strong need to identify new inspection and monitoring techniques for infrastructure. LTU (for TRV) will lead the work, perform ground-based photogrammetry to create digital models of bridges, develop technology to identify and present changes over time. Outcomes of the project will allow railway infrastructure owners to include this technology as part of their bridge management system.

Duration: 2021-2023

In2Track3

IN2SMART 2

- Intelligent Innovative Smart Maintenance of Assets by integRated Technologies 2

Project Leader: Hitachi Ansaldo STS (LTU is a 3rd linked party to TRV)

Researchers: Matti Rantatalo, Praneeth Chandran, Elahe Talebiahooie, Mahdi Khosravi, Hamid Khajehei, Yang Zou, Jaya Kumari

Sponsors: EU, H2020, SHIFT2RAIL, Trafikverket

Goal: The main objective of WP14: Track maintenance decision support tool for a Swedish heavy haul railway line (TRV is the lead) is to develop a decision support tool for railway track maintenance. These objectives can be divided into the following sub-objectives:

- To collect, measure and detect the track status and precursors of track degradation based on work IN2SMART
- To integrate the prediction model of the behaviour of track degradation for segments developed in IN2SMART with predictive models with the possibility to including isolated defects
- To implement and adopt the integrated RAMS, LCC and Risk framework for generating maintenance plans for maintenance schedules, previously developed in IN2SMART
- To define specifications and requirements for an Integrated Maintenance Decision Support Platform and to incorporate the human factor guidelines developed in IN2SMART

The WP is divided into the following subtasks:

- Task 14.1: Monitoring and inspection of track geometry and precursors
- Task 14.2: Diagnostics and Prognostics
- Task 14.3: Decision Support System
- Task 14.4: Demonstrator Development

Projects status and results: Deliverable D14.1 is the first output document of WP14. D14.1 describes specifications and requirements for the decision support tool, data collection and methods of diagnosis, prognosis, planning and scheduling. This includes the inputs, methods, and outputs of track geometry degradation modelling as well as planning and scheduling of maintenance activities. In addition, it provides the readers with the specification and features of the data, which will be used in the development of WP14. It should also be mentioned that this deliverable is linked to the T14.4 "Demonstrator development".

The decision support tool aims to employ data-driven methods to develop an integrated platform to support effective track geometry maintenance planning and scheduling. In order to achieve the aim of the decision support tool, different functions and processes must be implemented in the Integrated Maintenance Decision Support Platform (IMDSP). The main parts of the decision support tool are (1) measurement and asset data management, (2) analysis of current and future track geometry condition, (3) maintenance planning and scheduling, and finally (4) demonstration. This will support the process of track geometry maintenance planning and scheduling by providing a picture of the track geometry condition, the maintenance needs, and the available scenarios for maintenance planning and scheduling. Figure 1 shows the basic building blocks of the decision support tool.

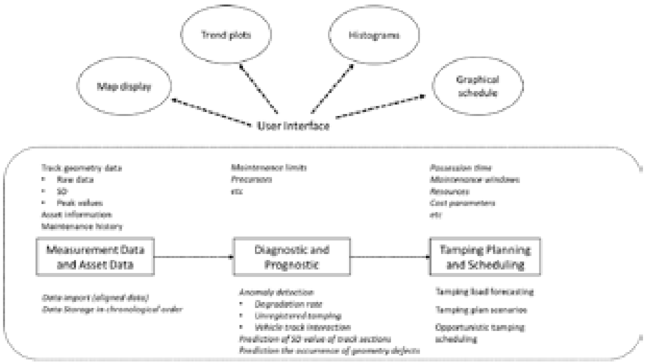


Figure 1: Design of the decision support tool

The main output of the IMDSP is the tamping schedule. Therefore, the demonstrator will provide a graphical view of the optimum tamping schedule with the related information about the KPIs. This will show the users the time and location for performing tamping activities. A schematic view of the information which will be visualized by the demonstrator is provided in figure 2.

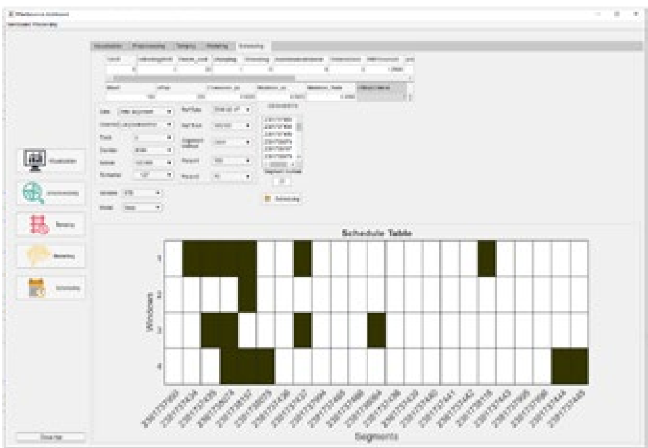


Figure 2 shows a schedule of the demonstrator.

Duration: 2019-2022

FR8RAIL II, III and IV

– Use-centric rail freight innovation for Single European Railway Area

Researchers: Matti Rantatalo (PL), Florian Thiery

Sponsors: EU, H2020, SHIFT2RAIL, Trafikverket

Objective: Maximize the usage of current wayside monitoring systems for CBM related issues.

Projects status and results:

The condition monitoring (CM) of vehicles applied in railway systems is divided into two categories: wayside monitoring systems and on-board monitoring systems. In general, for defects developing rapidly or for defects not possible to detect by wayside equipment, on board systems are more appropriate due to a high number of measurements points up to continuous monitoring of crucial components. For slowly evolving defects, wayside monitoring has the advantage of avoiding large scale installations of measurement equipment in many vehicles, which reduces cost and time. Historically, wayside measurement systems for railway vehicles have been focusing on detecting critical states of the vehicles like failing axle boxes or wheel flats. These wayside systems were traditionally designed in a reactive manner to examine the asset for compliance with respect to important characteristics which could lead to disturbances to the traffic as well as damage to the infrastructure. As a result, the wayside systems are detecting wagons in an already faulty stage, which has implications on both the railway capacity and the probability of inducing wear on the infrastructure.

The main objective within this work is to examine the possibility of moving from the existing reactive approaches to a more proactive approach and hence support a CBM strategy for the vehicles, with the aim of reducing the number of capacity consuming events and the probability of introducing failures or wear to the infrastructure. The study focuses on several key points that should improve the condition monitoring for wheelsets:

- Give a detailed description and analysis of the sensors currently installed on the Swedish railway network, from which gaps and possible improvements have been evaluated. Overall, this part of the project gives a broad overview of various wayside monitoring and its improvements and possible future applications
- Evaluate and ensure the quality of transferred data between the different detectors, since deviations can occur at different locations and manufacturers of similar systems (Figure 1). These deviations could give rise to false alarms, as well as affecting preselected features used for prognostics. It could serve as a baseline of the condition monitoring of the wayside systems on the entire network
- Development of a concept based on extracting time temperature signatures of wagons from the Hot-Box/Hot-Wheel measurements (Figure 2). This concept could help detect anomalies related to a change of condition of the bearings without reaching the current safety limits, and therefore redefine alarm limits related to the condition of the axle-boxes. This concept has preliminarily been tested on case studies based on rolling stocks on the northernmost part of the Swedish railway network known as "Malmbanan"
- Investigate - from the available data - specific wheels or wagons that have slower degrading processes which can be tracked based on the dynamic load or impact factors as the main feature to enable the estimation of the Remaining Useful Life

By combining the quality check of various detectors, a rescaling of the features as function of specific predictors and tracking down appropriate condition indicators from RFID-tagged wagons as function of time (or running distance) enhance the possibilities to transition towards a pro-active approach by utilizing appropriate algorithms. These algorithms will be dependent of the mechanical part of the wagon being examined. Since the case studies focus on data from a specific rail line, further investigation should be performed to evaluate if the proposed methodologies could be applied on a larger scale and implemented into the current Infrastructure Manager's Data Analysis System

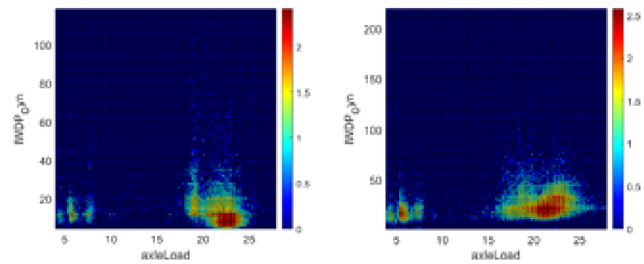


Figure 1. Influence of the axle load on the dynamic load of the WILD system for two detectors. Variations are visible for an axle load greater than 20 tons

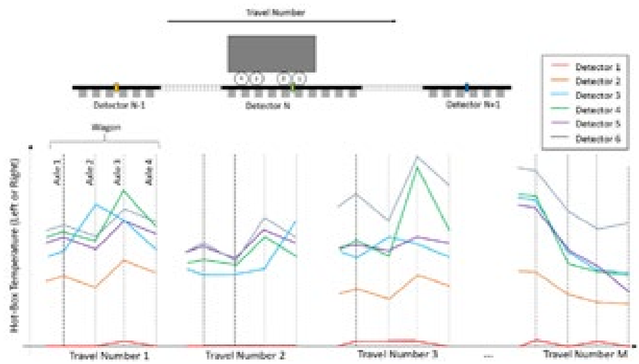


Figure 2. Description of the concept of temperatures signatures for Hot-Box detectors

Duration: 2019-2023

FR8RAIL II

FR8RAIL III

FR8RAIL IV

Europé´s Rail

Researchers: Matti Rantatalo, Amir Garmabaki, Mattias Holmgren, Johan Odelius, Ulla Juntti, Adithya Thaduri, Praneeth Chandran, Florian Thiery, Alireza Ahmadi, Veronica Jägare.

Sponsor/Grant: Horizon Europe

Objective: The objective of Europe's Rail Joint Undertaking is to deliver a high-capacity integrated European railway network by eliminating barriers to interoperability and providing solutions for full integration, covering traffic management, vehicles, infrastructure and services, aiming to achieve faster uptake and deployment of projects and innovations. That should exploit the huge potential for digitalisation and automation to reduce rail's costs, increase its capacity and enhance its flexibility and reliability, and should be based upon a solid reference functional system architecture shared by the sector, in coordination with the European Union Agency for Railways.

In this regard, the general aim of the partnership will be to ensure a fast transition to more attractive, user-friendly, competitive, affordable, easy to maintain, efficient and sustainable European rail system, integrated into the wider mobility system. EU-Rail will support the development of a strong and globally competitive European rail industry while contributing towards the achievement of the Single European Railway Area (SERA).

Projects status and results: The projects in Europé Rail started in the end of 2022. Researchers from JVTC are participating in the following Flagship projects (FP):

- FP2 - Rail to Digital automated up to autonomous train operation (R2DATO)
- FP3 - Holistic and Integrated Asset Management for Europe's RAIL System (IAM4RAIL)
- FP4 - Sustainable and green rail systems (RAIL4EARTH)
- FP5 - Transforming Europe's Rail Freight (TRANS4M-R)
- FP6 - Delivering innovative rail services to revitalise capillary lines and regional rail services (FUTURE)

Duration: 2022-2026

Europe's Rail

Research PROJECTS 2022

R&I projects in progress within JVTC related to maintenance and the railway system.

A physics based framework to predict ballast degradation

Researchers: Elahe Talebiahooie (PhD candidate), Matti Rantatalo (PL)

Sponsor: Trafikverket/JVTC

Goal: Proposing a physics based framework to predict ballast degradation.

Project status and results: Ballast layer has an important role in transmission of stress from train passage on the rail to the formation and its rate of degradation affects the derailment risk which is controlled with maintenance of the track. This degradation is a function of parameters such as properties of the ballast particles, weather condition, sub ballast, subgrade and sub soil condition, loading condition which is a function of speed of the train and the axle load and some other parameters. Both the data driven methods and physics based methods used for prediction of ballast degradation. In this project physics based method selected to simulate ballast degradation.

Finite element method has been widely used to model the ballast domain, but with improves in the computational power, discrete element method is becoming more popular. Ballast is a granular domain and with DEM we can monitor micro-dynamics of the particles and non-homogeneous domain properties such as stiffness, strain and damping ratio.

In this project, PFC software (Itasca Consulting Group, n.d.) used to perform the simulations. In the first step the simulation results from previously published literature improved by changing the contact model from Linear Parallel Bond to Hysteretic model and its parameters. A sensitivity analyses showed us the applicability of 3 different damping formulations that can be found in the PFC software in the simulation. The results from this study soon to be published.

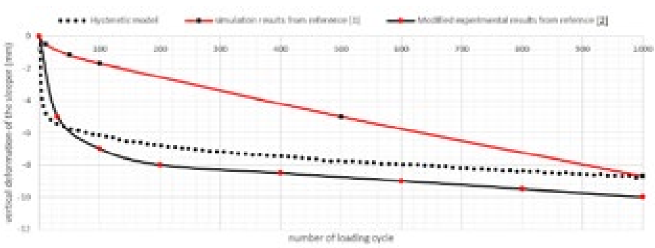


Figure 1. Comparison between the vertical settlement result from Hysteretic contact model and results from simulations performed in (Chen et al. 2015) and modified experimental data from (Indraratna, Hussaini, and Vinod 2013).

In order to improve the knowledge about the physical phenomena of ballast degradation in terms of sleeper settlement and particle breakage, 3 tests ran in the Construction Lab of LTU with the same material, particle size distribution and loading profile in order to be used for the second set of simulations with PFC. In the experimental test the loading frequency set on 8 HZ based on the apparatus characteristics and in order to simulate the degradation during the 100,000 cycles of loading, the 2D simulation chose to perform the parameter study and improve the breakage simulation.

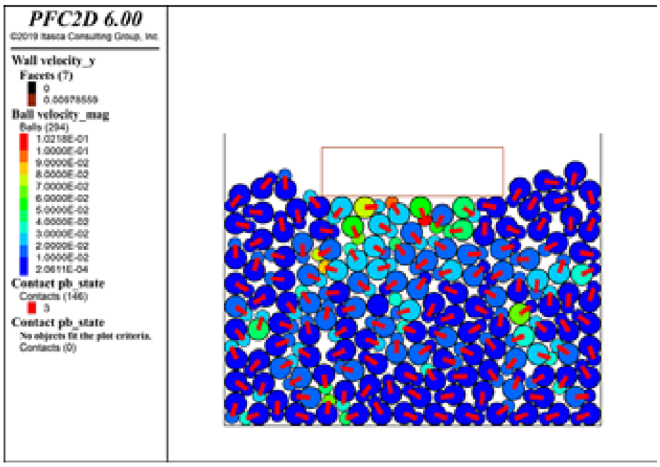


Figure 2. 2D model of the experiments performed in LTU after preloading state with having zero bond breakage in the model.

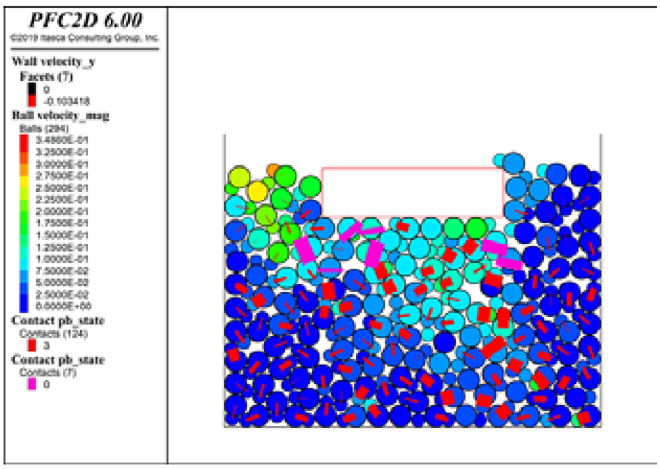


Figure 3. 2D model of the experiments performed in LTU after 800 cycles of loading which led to 7 broken bonds.

Chen, Cheng, Buddhima Indraratna, Glenn McDowell, and Cholachat Rujikiatkamjorn. 2015. “Discrete Element Modelling of Lateral Displacement of a Granular Assembly under Cyclic Loading.” Computers and Geotechnics 69: 474–84. https://doi.org/10.1016/j.compgeo.2015.06.006.

Indraratna, Buddhima, Syed Khaja Karimullah Hussaini, and J. S. Vinod. 2013. “The Lateral Displacement Response of Geogrid-Reinforced Ballast under Cyclic Loading.” Geotextiles and Geomembranes. https://doi.org/10.1016/j.geotexmem.2013.07.007.

Itasca Consulting Group, Inc. n.d. “PFC — Particle Flow Code,.” Minneapolis: Itasca.

Duration: 2017-2022

Detection of track damage in railways - Train-based prototype field tests

Researchers: Matti Rantatalo (PL), Praneeth Chandran, Florian Thiery, Johan Odelius

Sponsor: Vinnova

Goal: The main goal of this project is to develop an automated system for condition monitoring that support efficient maintenance decision for the Swedish railway network and to facilitate optimisation of the assets availability and utilization.

Project status and results: Growth in overall transport demand has led to railways experiencing higher demand on operational capacity, service quality, and safety. A higher operational capacity can lead to an increase in traffic and load subjected on to the existing infrastructure. Increase in load and traffic leads to deterioration of the infrastructure quality and degradation to its components, resulting in a higher number of Maintenance and Renewal(M&R) interventions. The downtime arising from these M&R of networks is responsible for nearly half of all the delays to passengers. Hence the track and its components need to be periodically inspected to decrease interruptions of train operation, reduce cost, and ensure safety. One of the crucial components in rail tracks is the rail fastening system, which acts as a mean to fix the rails onto the sleeper, upholding the track stability and track gauge. Failures of fasteners can increase wheel flange wear, reduce the safety of train operations, and may lead to derailment due to gage widening or wheel climb. In Sweden, the inspection of track fasteners is mainly carried out either manually by trained inspectors or by using measurement cars. Manual inspections are slow, cost-intensive, labour-intensive, pose safety issues for maintenance personal involved, and are prone to human errors. Inspections based on measurement car requires track possession and are cost intensive and thus cannot be utilised frequently without compromising the operational capacity. Further, the adverse weather condition, especially in the north of Sweden for the majority of the year, limit regular fastener inspection that depends on such traditional inspection methods To overcome these challenges, this research aims to develop an automated monitoring system based on an in-service train installation, a robust magnetic field sensor and artificial intelligence using machine learning algorithms to enable continuous monitoring during regular operations.

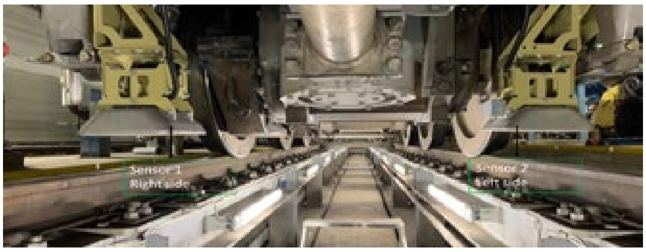


Figure 1. Differential eddy current measurement system mounted on both sides of a freight train.

The purpose of the project is to enable autonomous maintenance of railway fastening systems by enabling the use of in-service trains as the carrier of the condition monitoring system. By using passenger and freight trains as carriers of robust and autonomous sensors, a larger amount of information about the railway asset status will be generated. The aim of the project is to develop and implement a scalable solution of a previously developed sensor for railway fastener inspection. The project will be conducted in three main work packages, where the first part will focus on the installation of the railway fastener measurement system on a railway locomotive. Thereafter, the measuring system shall be tested for a longer period. In parallel with this work package, two other activities will be performed. These activities will address issues concerning the implementation of a measurement system from trains in operation linked to different actors' business arrangements and interests, as well as how information from multiple systems needs to be handled and combined. Figure 1 depicts the differential eddy current sensors mounted on both sides of a freight train. The sensor was successful in capturing all the fastener signature from a distance of 110mm above the railhead, during train measurement. Signal processing techniques and feature extraction methods were used to extract useful information 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 2 and Figure 3 depicts the time signal and anomalies detected during 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.

Duration: 2022-2023

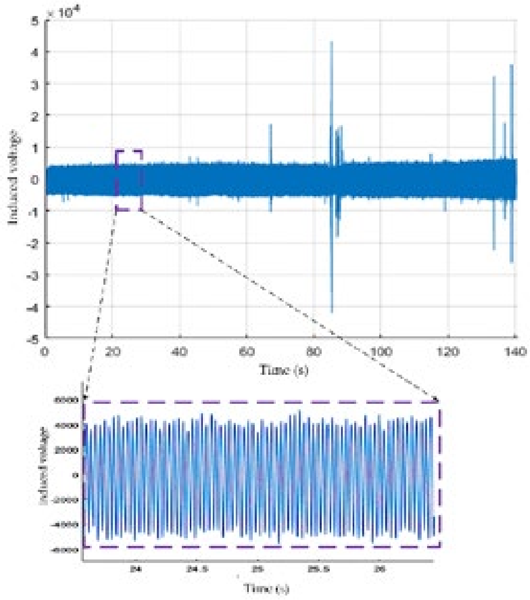


Figure 2. Time signal of the measurement carried out over a track section of 2.5 km. A small window is expanded within the dashed box to depict the fastener signatures.

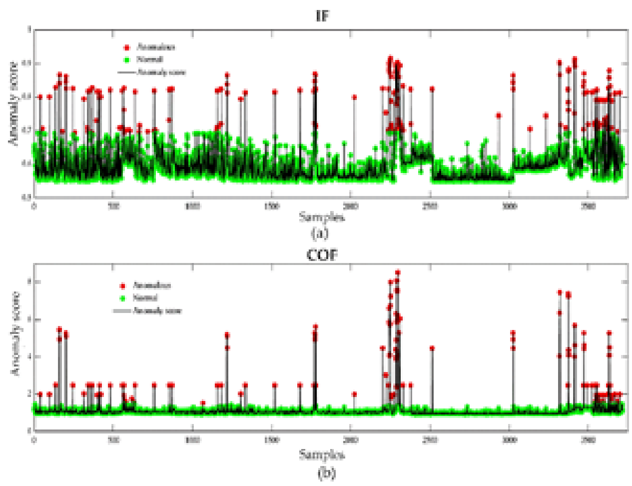


Figure 3. Anomaly score of the detection model. Anomalous points are marked with red indicators and normal/ healthy fasteners with green indicators.

A Challenge-driven Framework for Innovations in Railways

Researchers: Veronica Jägare (PhD candidate), Ramin Karim, Jan Lundberg, Ulla Juntti, Per-Olof Larsson-Kråik

Sponsor: Trafikverket/JVTC

Goal: To develop and provide, a challenge-driven framework that can be used to facilitate implementation of innovations in the Swedish railway.

Projects status and results: The railway is often perceived as an industry where new technology is not utilised to its full potential. However, the future of the railway and its ability to respond to future transportation demands lies in its ability to adopt, adapt, implement, and integrate emerging technology.

These technologies are expected to lead to, e.g. intelligent asset lifecycle management with a whole-life asset approach and digital railway industry supply chain management. The technology transformation and digitalisation affect not only the technical systems, e.g. railway infrastructure and rolling stock, but also regulations, organisations, processes, and individuals.

The railway industry needs to recognise the challenges and define strategies, which enable the successful implementation of innovations in railway. Thus, the purpose of this research work is to study, explore, and investigate how implementation of innovations in a multistakeholder environment such as railway maintenance, can be facilitated through a systematic approach. Further, the main objective of this research is to develop and provide, a challenge-driven framework that can be used to facilitate implementation of innovations in the Swedish railway.

To overcome the identified challenges, several artefacts have been developed and provided in this research, i.e. a) A challenge-driven mission-based framework; b) A methodology for evaluating innovations; c) Strategies and guidelines for data governance; d) Strategies and guidelines for innovation in maintenance contracts; and e) Railway domain systemic aspects for the implementation pathway. The findings and artefacts of this study may be used as a framework and a road map in any industry by providing scientific guidance in the implementation of innovations.

Duration: 2014-2022

Intelligent operation and maintenance for traction motor bearings

Researchers: Janet Lin (PL), Diego Galar, Haidong Shao, Dongming Fan, Haizhou Chen

Sponsor: CRRC Yongji Electric Co., Ltd.

Goal: This Project aims to study the context-driven intelligent operation and maintenance technology's capability to perform condition monitoring and hybrid prediction of Remaining Useful life for traction motor bearings.

Projects status and results: In this Project, context investigations and analytics of traction motor bearings will be adopted, Machine learning approaches (incl. Deep learning) will be applied for strategies making and optimization. The purpose is to move forward to the final goal of intelligent maintenance for traction motor.

Duration: 2021-2022

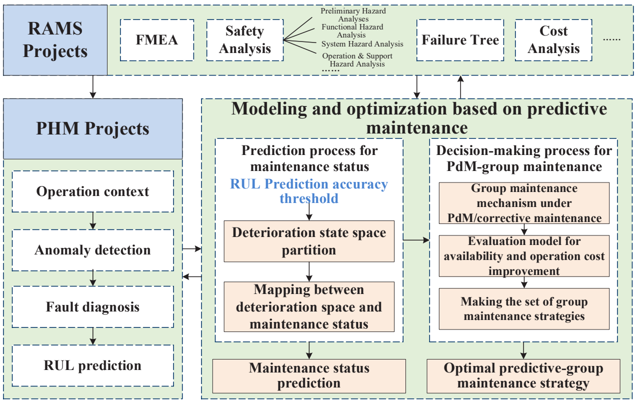


Figure 1. Project roadmap.

Multi and interdisciplinary method to identify the true capacity of concrete bridges (TruBridges)

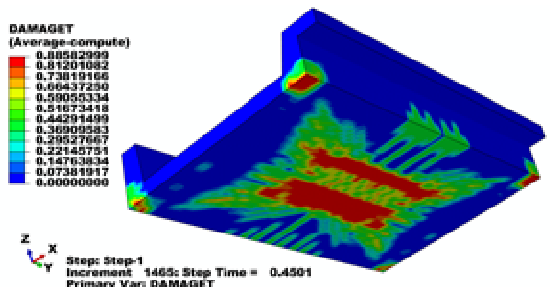
Sponsor: LKAB, Trafikverket

Researchers: Gabriel Sas (PL), Jaime Gonzalez-Libreros

Goal: This project's purpose is to enhance sustainability by reducing costs of strengthening or replacing existing bridges, by improving predictions of their true capacity and remaining life. The aim is to develop a multi-disciplinary procedure for evaluating bridges' capacity using reliability- and probability-based assessments involving non-linear finite element modelling, real and scaled down model tests, and structural health monitoring data.

Projects status and results: A review of the database of existing railway bridges administered by Trafikverket was carried out. This analysis showed that around 20% of the Swedish bridge population corresponds to reinforced concrete trough bridges. Based on this information, a comprehensive experimental campaign including two real scale trough bridges was designed to study the behaviour of these bridges under different loading conditions (ultimate limit state, serviceability limit state, fatigue, and dynamic behaviour) and evaluate their actual capacity. Preliminary finite element models were developed with the aim of having an initial prediction of the expected capacity. The two bridges have already been casted.

Duration: 2021-2022



eMaintenance Solution for Enhanced Asset Management in Railway - Using Industrial AI

Researchers: Jaya Kumari (PhD candidate), Ramin Karim (PL), Miguel Castano

Sponsor: Trafikverket/JVTC

Goal: Develop AI solutions for the maintenance of Railways

Project status and Results: The project aims to streamline and optimize asset management and rail maintenance, with a focus on railway infrastructure. From an academic perspective, the project will explore and investigate how technologies and methodologies in the so-called. 'Industrial Artificial Intelligence (IAI)', incl. deep learning, can be used to develop eMaintenance solutions that help to improve TAK, eng. OEE and streamline the infrastructure management of railway infrastructure.

The project builds on previous research results and obtained research findings carried out in the eMaintenance research area at Luleå University of Technology. The eMaintenance research aims to enable and facilitate complex data analyzes in the operation and maintenance process.

This project will aim to design frameworks, approaches, technologies and methodologies based on 'Industrial AI' that contribute to fact-based decision support in operation and maintenance of railway infrastructure.

The project are performing a state of the art literature survey and state of the art review in the field of Railway infrastructure, Artificial intelligence and Machine Learning methodologies.

Duration: 2019-2023

MOnItoRing of large scale complex technologicAl systems- MOIRA

Researchers: Parul Khanna (PhD candidate) and Ramin Karim (PL)

Sponsor: European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 955681.

Goal: The overall objectives of MOIRA are i) the development of novel signal processing tools for the monitoring of industrial processes based on machine learning methods applied on heterogeneous time series, ii) the application of data mining technologies for the estimation of Key Performance Indicators which determine the operational profit, iii) the conception, development and validation of methodologies for automated monitoring of cyber physical system fleets, iv) the multi sensor machine condition monitoring under variable operating conditions.

For the work specific to LTU as a beneficiary: The main objectives of this work are: a) Determine what physical conditions need to be monitored for autonomous maintenance diagnostics, finding a strategy for autonomous maintenance, b) Develop benchmarks that are an empirical clarification of the role of intuitive cognition in the maintenance context, laying a foundation for different perspectives of intuitive cognition including psychological, philosophical, and engineering stances and c) Develop concepts for collaboration and integrate them into the design of automated systems in such a way that intuitive cognition can be utilized to accomplish the final goals. This will include the design concepts for automated interfaces to assist humans in the intuitive identification of and response to abnormalities.

Projects status and results: Currently the work is in phase 1 where the required pre-study is going on for the expected outcome i.e. to develop a methodology describing how autonomous machines can learn from human experts in a maintenance context and to critically assess the maintenance actions for automated production lines in order to identify factors that contribute to performance and technical efficiency with focus on the identification of the elements that are necessary for machines to conduct maintenance actions. More specifically, implicit situation awareness measurement techniques and state-of-the-art techniques will be taken into consideration in the exploration of cognitive tasks as a platform to develop extended methods and to explore intuitive cognition.

Project Period: 2021-2025

Industrial AI for Secure and resilient data and model sharing in railways

Researchers: Amit Patwardhan (PhD candidate), Ramin Karim (PL)

Sponsors: Trafikverket/JVTC, Infranord, Norrtåg, Alstom, Transitio

Goal: Development of framework for data and information assurance for digitalized railway systems.

The purpose of the architecture is to provide the structure for an end-to-end process pipeline supporting accumulation, storage, processing of 3D point cloud data generated through LiDAR scanning process. The architecture supports creation of a digital twin of railway linear assets from collected data through the utilization of AI (Artificial Intelligence) and ML (Machine Learning) tools based on domain knowledge.

One of the important aspects for creation of digital twins will be support for storing and handling of metadata i.e. providing the information about the data. This can be in the form of source of the data the location where it was collected, the sensor used, the weather information, operator's comments. The purpose of the data, how and where the data can be used, limitations within the data and processing requirements etc. The data itself may be useless without the suitable metadata.

The collected data sets often have their own prescribed formats and may or may not support metadata storage within the file. Some of the data formats such as simple binary storage or CSV formats are not suitable for storage

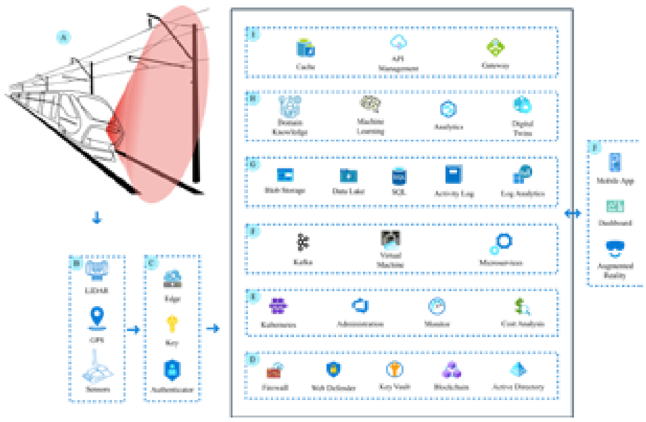


Figure 1. Architecture for 3D point cloud data processing.

of metadata due to the requirements of specialised parsing. Standardised methods for metadata storage such as XML and JSON are extensible, easy to handle and are well supported by many platforms for reading and writing.

Project Status and Results: As a part of development the architecture has been applied to point cloud processing requirements. Various aspects of data processing and interface are being developed individually as microservices.

Duration: 2020-2024

Advanced solutions to Improve Cybersecurity in Railway

Researchers: Ravdeep Kour and Ramin Karim (PL)

Sponsor: Trafikverket

Goal: The main goal of the research undertaken is to minimize the risk of cyber threats and to quantify them.

Projects status and results: Railway maintenance based on information and communications technologies (ICT), generally depends on Internet infrastructure, and this makes it vulnerable to cybersecurity threats. These cyber threats may have negative impact on railway stakeholders e.g., threat to the safety, loss of railway data integrity and confidentiality, reputational damage, monetary loss, service unavailability, loss of dependability, etc. Therefore, there is a need to develop advance cybersecurity solutions for railway to minimize the risk of these cyber threats. This research is using both qualitative and quantitative methods for collecting cybersecurity data. Collecting cybersecurity data is really a challenging task because of its sensitivity due to its safety and security issues.

In the current research, we have identified various issues and challenges that can be faced by railway organizations. We have also estimated the cybersecurity maturity levels of railway organizations and proposed cybersecurity framework for railways. Next, we have conducted a systematic review and outline cybersecurity emerging trends and approaches, and identified possible solutions by querying literature, academic and industrial, for future directions. In addition, we have proposed a methodology on how to deals with OT security in the railway signaling using Failure Mode, Effects and Criticality Analysis (FMECA) and ISA/IEC 62443 security risk assessment methodologies to quantify cyber threats. We have also proposed a systematic approach, based on an enhanced Cyber Kill Chain model, to improve the overall system resilience through monitoring and prediction (Figure below). We have also disseminated the research work in various journals and conferences.

Duration: 2022-2023

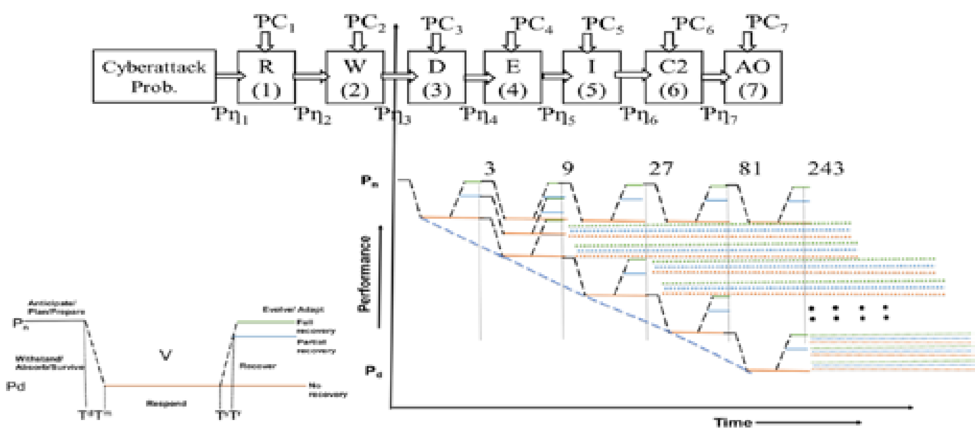


Figure. Resilience curve within each stage of the CKC model with 3 stages of recovery.

RAMS for track

Researchers: Mahdi Khosravi (PhD candidate), Alireza Ahmadi (PL)

Sponsor: Trafikverket/JVTC

Goal: The main aim of the project is to develop an approach, to assist track geometry maintenance decision making by improving the quality of the measurement data and prediction of the degradation.

Project status and Results: It is crucial for railway infrastructure managers to ensure that the RAMS parameters of the railway system remain within acceptable thresholds while minimizing costs. Any deterioration in the track geometry can have adverse effects on safety, availability, and travel quality. To address this issue, an effective maintenance strategy must be employed to restore track geometry parameters to their design values. The key to implementing an efficient and effective maintenance plan is the availability of reliable and complete track geometry data. Traditional methods for evaluating track geometry condition involve the use of aggregated quality indices, such as the standard deviation of a track section. However, these indices are not sufficient to provide precise information on the location of single defects. Therefore, recent studies have focused on predicting the occurrence of single defects, which is a critical prerequisite for developing predictive models and maintenance planning. It is important to note that predicting the occurrence of defects requires information on both the position and time of occurrence of these defects.

Typically, track geometry measurement data are prone to positional inaccuracies. Therefore, before modeling track geometry degradation and implementing a condition-based maintenance strategy, the collected track geometry measurements from different inspection runs must undergo pre-processing. To accurately determine the location of the measurement data, it is necessary to precisely estimate the distance traveled by the measurement car from a milepost. However, various factors, such as wheel wear condition, wheel slip and slide on the rail, environmental conditions, and calibration of the wheelset and optical encoders equipped on the wheelset, can affect the accuracy of these distance estimations. Furthermore, during the collection of track geometry measurements, the sampling positions are not uniformly spaced across different inspection runs. As a result, these influential factors can cause the measurement data to shift, stretch, or compress with non-uniform and random distances between any two successive sampling points (refer to Fig 1 and Fig 2). Additionally, maintenance operations and track geometry degradation can also distort the inspection measurement data. Accordingly, the accurate alignment of the inspection measurement data can reduce positional errors and improve the quality of the measured data.

Thus, there is a crucial need to employ an alignment method that accurately aligns different inspection measurement data while maintaining the original shape of the datasets. It is also desirable that the alignment method is fast and requires minimal memory usage.

The objective of this study is to identify an accurate and efficient method for aligning track geometry measurements and reducing their positional errors. To achieve this, six alignment methods, namely Correlation Optimized Warping (COW), Modified COW (MCOW), Recursive Alignment by Fast Fourier Transform (RAFFT), a combined method using RAFFT and COW, Dynamic Time Warping, and Cross Correlation Function (CCF), are evaluated for their efficacy in aligning railway track geometry measurement data. The first four methods divide the datasets into smaller segments and align them, while the other two methods align the entire dataset. The results indicate that COW, MCOW, DTW, RAFFT, and the combined method can align datasets when one dataset is stretched or compressed relative to the others. Moreover, CCF is suitable for datasets with a fixed shift between them and is inefficient when one dataset is stretched or compressed relative to the other. DTW has high precision in aligning measurements at the cost of warping the aligned dataset, while COW is inefficient in finding shifts at the start and end of datasets. RAFFT achieves precise alignment without changing the shape of the aligned dataset, although some sporadic warping may occur in some sections. Overall, MCOW and the combined method are highly efficient in aligning track geometry measurements, with MCOW being faster. These methods can effectively reduce the positional errors in track geometry measurement data, leading to improved accuracy of the inspection measurement data and strengthening the analysis and prediction of track geometry degradation.

Duration: 2019-2023

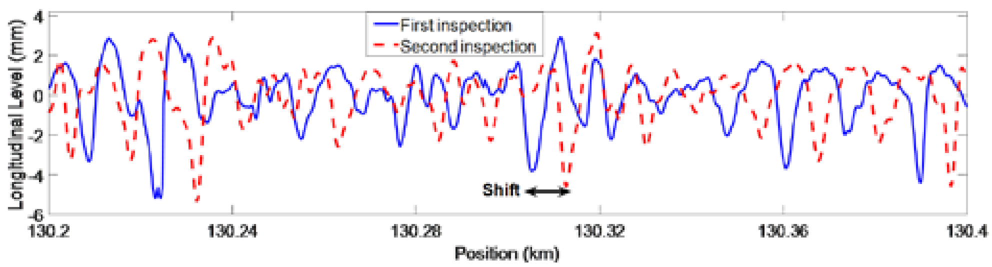


Fig 1. A constant shift between the two datasets

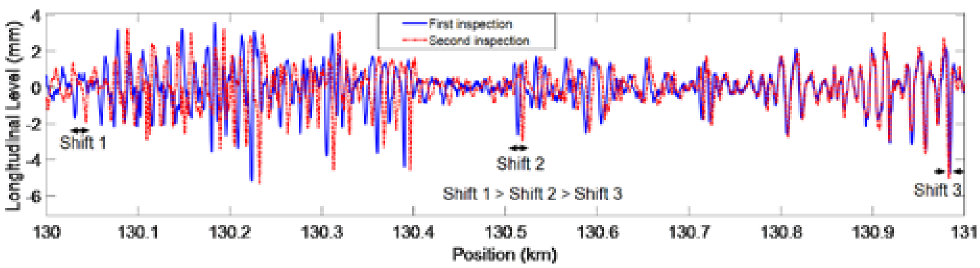


Fig 2. Compression of the second dataset with respect to the first one

Robust infrastructure – Adapting railway maintenance to climate change (CliMaint)

Researchers: Amir Garmabaki (PL), Uday Kumar, Adithya Thaduri, Johan Odelius, Stephen Famurewa, Veronica Jägare, Ahmad Kasraei, Khosro Soleimani Chamkhorami, Ulla Juntti

Sponsors: Vinnova, TRV, SMHI, Infranord, Sweco, Transportstyrelsen, JVTC

Goal: The aim of CliMaint is to ensure robust and reliable railway infrastructure by maintenance adaptation to climate change. The objective of the project is to reduce future disturbances due to extreme climate conditions by an effective maintenance program. The aim will be achieved by utilizing RAMS (reliability, availability, maintainability, and safety) methodology and integrating infrastructure degradation modelling with metrological and satellite information. The methodology implemented in CliMaint can have significant impacts of 5-10% reduction in traffic disruptions and maintenance costs.

Project status and results: To assess the risk of high and low temperature to the railway infrastructure asset, questionnaire and interview studies have been conducted. The following images represent the temperature-related failure modes which calculated based on exposure time from the year 2001 till 2022. Based on the methodology develop in CliMaint, Transport manager are capable to assess the risks associated with 1) High Temperature, 2) Low Temperature, 3) Snow and Ice, 4) Flooding/Landslide and 5) High Wind for an individual asset located in different geographical location.

The following figure illustrates the risk matrix for high and low-temperature hazards. Temperature above 27 and below -20 have been identified according to the predefined scenarios for the asset located at Luleå.

More detailed information in the CliMaint webpage: www.ltu.se\climaint.

Duration: 2019-2022

	C1	C2	C3	C4	C5
Freq Category 1 – Less than 0.1 times per month					
Freq Category 2 between 0.1 - 1 per month		Supportability losses	Vegetation fire Track buckling		
Freq Category 3 – between 1 – 3 times per month					
Freq Category 4 – more than 3 times per month		Rail defect and breakage-low temperature	Supportability losses- low temperature		

Figure. A risk matrix for high and low-temperature hazards.

Lidar-based catenary data processing

Researchers: Amit Patwardhan, Miguel Castano, Ramin Karim (PL)

Sponsor: Trafikverket

Goal: Condition monitoring of equipment during operation is an important part of inspection and an unavoidable part of overall maintenance regime. Inspection of railway overhead catenary is required to keep the catenary system in operation and since the catenary is responsible for providing the power to the locomotive. The railway catenary is categorized as linear asset, i.e. the kind of asset that is spread over a large area. Including railway catenary, railway tracks, pipelines, electric lines, roads, water canals are examples of linear assets.

Linear assets due to the spread over a large area can be difficult to inspect at high frequency, in case of railway catenary an inspection is performed every three years, this may be justified due to the high reliability of the catenary. However, the failures in railway catenary can have high impact due to the overall time required to perform the repair due to remote location, difficult terrain and extreme weather. Additionally, current methods of inspection require presence of specialized equipment on rail tracks due to inaccessibility of catenary and dangerous voltage levels. This is not only costly but also effects the scheduled traffic.

Light Detection And Ranging (LiDAR) works on the principle of measuring the time of flight of a LASER beam reflected from the surrounding region. The result of a LiDAR scan is a point cloud, formed by merging scans from multiple location giving a 360˚ x 360˚ depth image from the point of view of the scanning location. Analysis of this point cloud allows extraction of assets such as rail track, masts, catenary wires as well as vegetation in the vicinity of the track.

One of the main goals of this project is to measure the distance between two wires namely the reinforcement wire and the tension wire. Various data analysis steps such as filtering, clustering, feature extraction etc. are used to extract the assets from the point cloud.

Project status and results: Till now the project has focused on detection and extraction of assets from the point cloud. This resulted in extraction of masts and provides the location of individual masts in Latitude and Longitude. The wires are extracted individually and exported as parameterized equations (catenary equation and second order polynomial in 3D space). Different techniques for identification of wires have also been explored. Currently the focus is on developing techniques to measure the distance between the wires hence, numerical and analytical methods are being explored.

Duration: 2021-2023

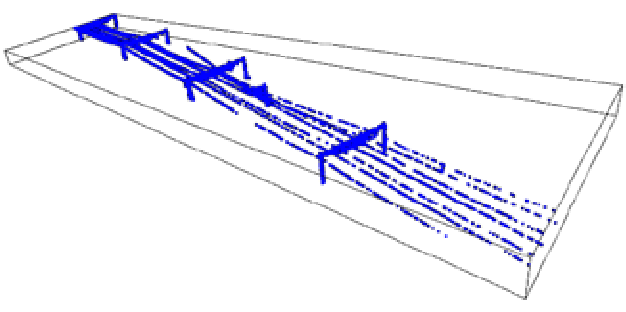


Figure. Railway catenary point cloud with bounding box.

Climate Adaptation and Risk Mitigation of Swedish Railway Infrastructure (AdaptRail)

Researchers: Amir Garmabaki (PL), Johan Odelius, Ulla Juntti, Ahmad Kasraei, Khosro Soleimani Chamkhorami, Stephen Famurewa.

Sponsors: Formas, Trafikverket, SMHI, Infranord, JVTC

Goal: Improve the resilience of railway infrastructure from adverse weather conditions through the implementation of a climate adaptation strategy in design, operation, and maintenance. Develop a decision support system for infrastructure management that integrates climate change models, AI-based tools and techniques, and meteorological data with operation and maintenance data of rail infrastructure.

Projects status and results: Creation of new pathways towards designing, operating, and maintaining climate-resilient rail infrastructure, as well as an expected reduction of 8-10% in disruptions and a 5-10% decrease in operation and maintenance costs through the implementation of a smart alert management system. The objectives are: 1) Integrate climate change models with decision-making processes for railway infrastructure management; 2) Develop AI-based tools and techniques to leverage climate change data, meteorological data, and operation and maintenance data for railway infrastructure management; 3) Implement a smart alert management system to reduce disruptions and operation and maintenance costs.

Project web page: www.ltu.se/AdaptRail

Duration: 2023-2025

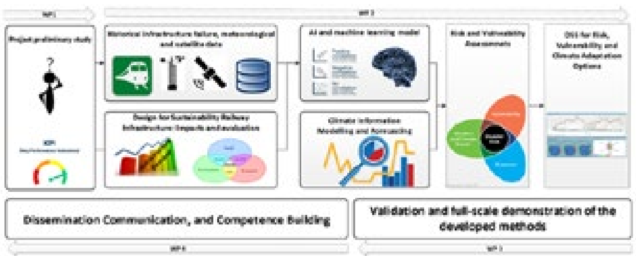


Figure. Research Methodology of AdaptRail.

Climate Resilient Railway Infrastructure: A System Innovation Approach (CliMaint2Innovate)

Researchers: Amir Garmabaki (PL), Veronica Jägare, Ulla Juntti, Sabina Tabares, Vinit Parida

Sponsors: Vinnova, Trafikverket, SMHI, InfraNord, WSP, BnearIT

Goal: This project aims to develop a system-level innovation roadmap and implementation plan for the CliMaint project. To achieve the project objective, a system innovation framework has been explored to identify and analyze obstacles, shortcomings and suggest appropriate measures to accelerate the implementation, upscaling, and dissemination of innovation solutions of the CliMaint project.

Projects status and results: To better understand the key feature of the CliMaint decision support system, we have mapped the CliMaint innovation components and its interrelationship with the five system innovation pillars (see Y-axes) illustrated in Figure 1. Different colors have been used to show the level of innovation plan to be achieved during CliMaint projects. The system innovation approach will demonstrate barriers and enablers for implementing the innovation, by addressing five system pillars: i) Technology, products, and processes; ii) Business models, investments, and procurement; iii) Policy and regulations; iv) Behaviour, culture, and values; and v) Infrastructure.

Business model and procurement process have been identified as one of the main challenges while investigating system innovation perspective for CliMaint. Following the results and inputs retrieved throughout this research, compared with the intervention of the respondents and the supporting literature, figure 2 presents an alternative procurement process for Infrastructure managers to make the tendering procedure more circular.

In addition, a mission-based innovation roadmap and plan for implementation action have been proposed. By following the proposed framework, the CliMaint innovation will receive support toward successful implementation.

Duration: 2022-2023

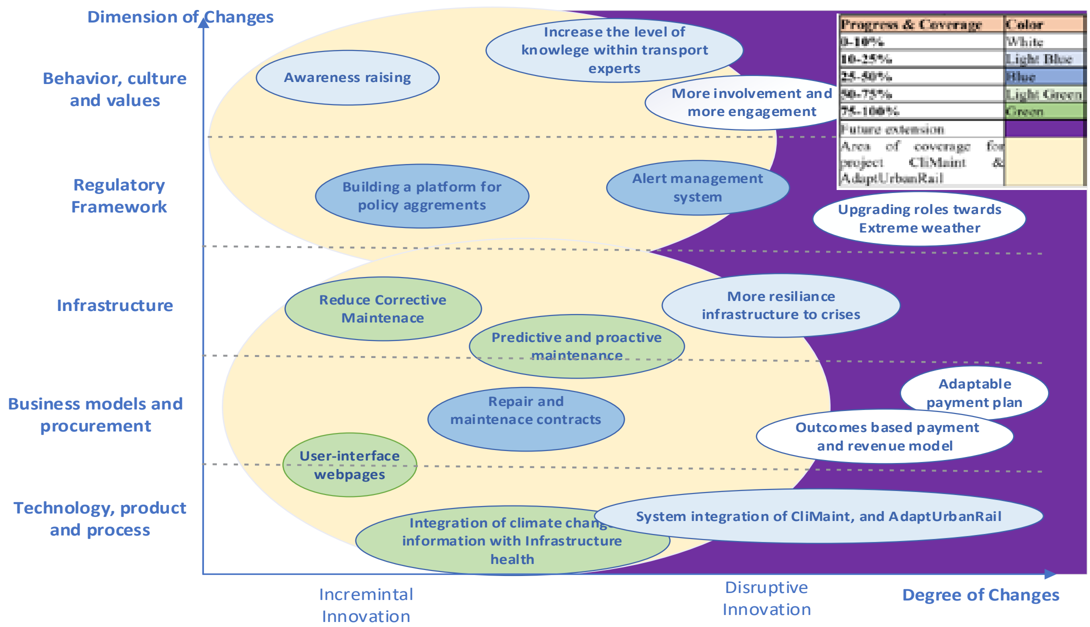


Figure 1. Mapping of the project components in relation to the five pillars of System Innovation.

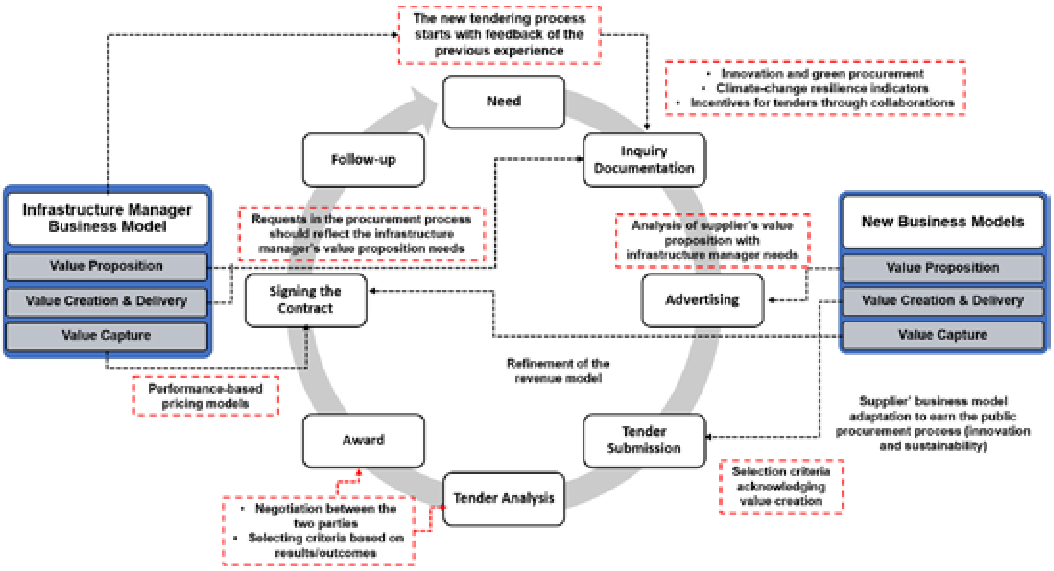


Figure 2. Procurement Process for introducing New Business Models for more Climate-change Resilient Infrastructures in the Railway Industry.

Snow galleries between Björkliden – Riksgränsen. Assessment of capacity and plans for structural health monitoring.

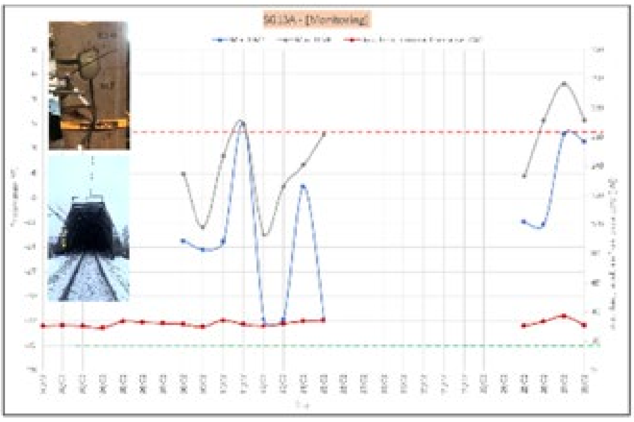
Researchers: Gabriel Sas (coordinator), Cosmin Daescu (project manager), Daphne Pantousa (researcher), Erik Andersson (lab engineer), Karin Björnlinger (MSc student)

Sponsors: Trafikverket, Vinnova

Goal: Evaluate the current loading conditions of the snow galleries and make a real-time measurement of the snow loads, in order to prevent the failure of the structures and the traffic interruptions.

Project Status and Results: Initial static analysis was done, based on original design plans. Critical sections were identified and limit loading conditions were defined. We have implemented the monitoring system for SG9 and SG13A, for snow loads and temperature variations.

Duration: 2021-2022



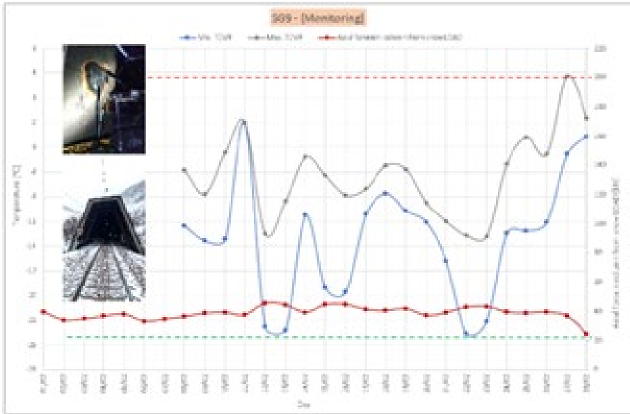


Figure 1 and 2. Snow loads and temperature variations.

Fleet of sensors for autonomous railway condition monitoring

Researchers: Matti Rantatalo (PL), Johan Odelius, Praneeth Chandran, Florian Thiery, Veronica Jägare

Sponsors: Vinnova, Eloptik, LKAB, ALSTOM, Trafikverket

Goal: The purpose of the project is to enable autonomous maintenance of railway fastening systems and other components with the help of condition monitoring via trains in operation. By using passenger and freight trains as carriers of robust and autonomous sensors, a larger amount of information about the railway asset status will be generated. The aim of the project is to develop and implement a scalable solution of a previously developed sensor for railway fastener inspection.

Projects status and results: The project is expected to result in a developed method for how the information from a previously developed measurement sensor is to be analysed and handled in a context where a fleet of sensors are installed on different trains and where different actors with different business plans are involved. The main effect of the project is the enabling of a large-scale implementation of an inspection system for railway fasteners, which will contribute to the future autonomous maintenance.

The project will be conducted in three main work packages, where the first will focus on the installation of the railway fastener measurement system on a railway locomotive. Thereafter, the measuring system shall be tested for a longer period. In parallel with this work package, two other activities will be performed. These activities will address issues concerning the implementation of a measurement system from trains in operation linked to different actors´ business arrangements and interests, as well as how information from multiple systems is to be handled and combined.

Duration: 2022-

Squat Detection in Railway Switches & Crossings Using Point Machine Vibration

Researchers: Matti Rantatalo (PL), Yang Zou (PhD candidate), Jan Lundberg, Johan Odelius, Taoufik Najeh

Sponsors: JVTC/LTU

Goal: Railway switches and crossings (S&Cs) are among the most important high-value components in a railway network and a single failure of such an asset could result in severe network disturbance, huge economical loss, and even severe accidents. Therefore, potential defects need to be detected at an early stage and the status of the S&C must be monitored to prevent such consequences. One type of defect that can occur is called a squat. A squat is a local defect like a dent or an open pit in the rail surface. In this thesis, a testbed including a full-scale S&C and a bogie wagon was studied.

Projects status and results: Vibrations were measured for different squat sizes by an accelerometer mounted at the point machine, while a boggy was travelling along the S&C. A method of processing the vibration data and the speed data is proposed to investigate the feasibility of detecting and quantifying the severity of a squat. A group of features were extracted to apply isolation forest to generate anomaly scores to estimate the health status of the S&C. One key technology applied is wavelet denoising. The study shows that it is possible to monitor the development of the squat size introduced in the test bed by measuring point machine vibrations. The relationships between the normalised peak-to-peak amplitude of the vibration signal and the squat depth were estimated. The results also show that the proposed method is effective and can produce anomaly scores that can indicate the general health status of an S&C regarding squat defects.

Duration: 2019-2022

Adapting Urban Rail Infrastructure to Climate Change (AdaptUrbanRail)

Researchers: Amir Garmabaki (PL), Matti Rantatalo, Adithya Thaduri, Johan Odelius, Stephen Famurewa, Ulla Juntti, Matthias Asplund, Veronica Jägare, Ahmad Kasraei, Abdolrasoul Habibipour, Gabriel Sas, Matthias Asplund.

Sponsors: Vinnova, TRV, SMHI, Infranord, WSP, BnearIT, JVTC

Goal: The AdaptUrbanRail 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.

This project addresses the following short-term 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.

The long-term effects of the project outcomes are:

- Facilitate awareness of climate change impacts and integrate developed solutions to facilitate finance and business models,
- Strengthen the research in sustainable built environment at national and EU level,
- Strengthen collaboration among various urban planner, transport experts, and communities interested climate change impacts on citizen life,
- Improve the resilience of urban railway networks by climate adaptation.
- Facilitate modification and development of national policies and regulation.

The methodology implemented in the project can have significant impacts of more than 10% reduction in disruptions due to climate and 5-10 % operation and maintenance costs due to the early alarm system (exc. the second-hand societal cost).

Project status and results: There is a need to study impacts of climate change on urban railway infrastructure with higher resolution and accuracy considering urban complexities. Figure 1 depicts increase in different failure modes of urban railway infrastructure connected to Stockholm, Göteborg and Skåne's urban areas for the last 10 years extracted from TRV databases.

Project web page: www.ltu.se/AdaptUrbanRail

Duration: 2021-2023

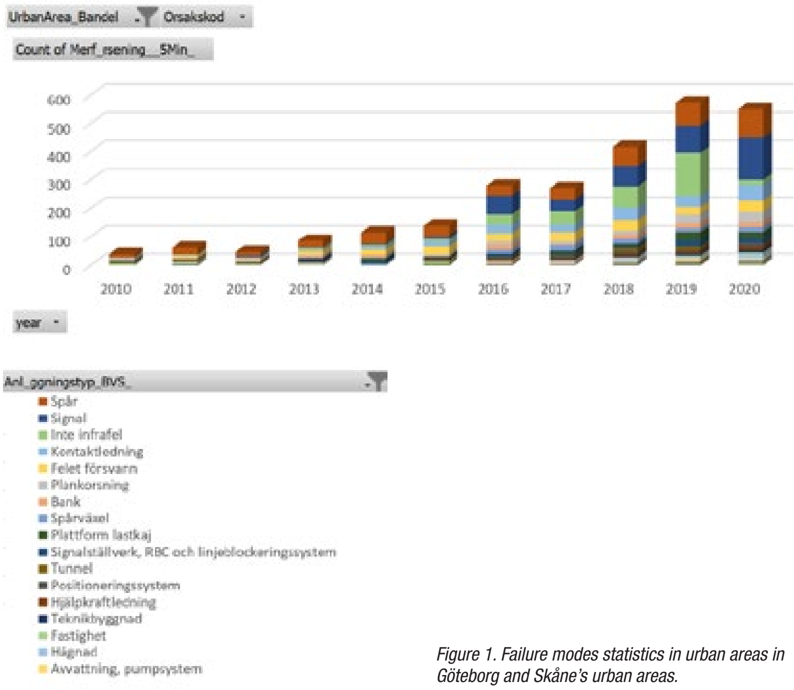


Figure 1. Failure modes statistics in urban areas in Göteborg and Skåne's urban areas.

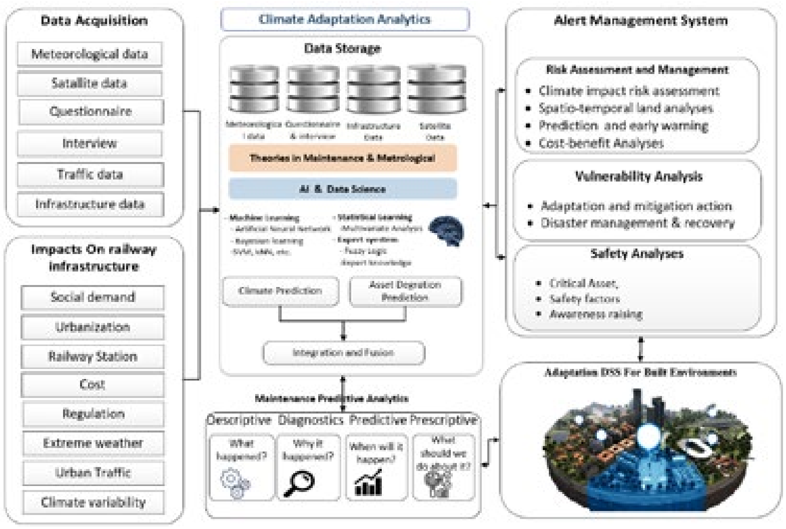


Figure 2. Overall methodology and process.

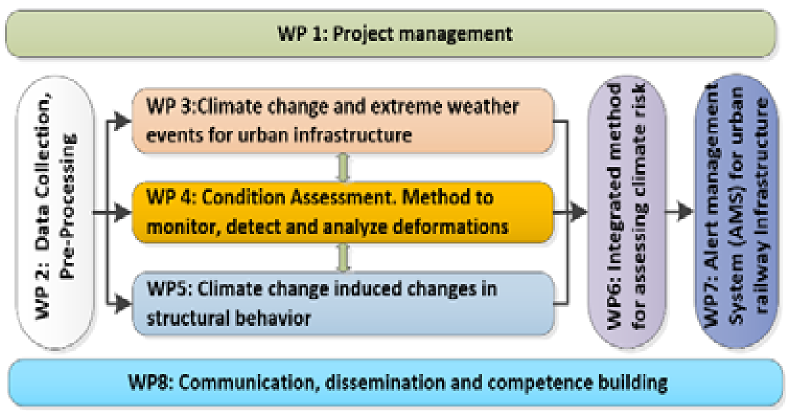


Figure 3. Working Packages and its interrelationships to achieve the project goal.

International Railway
Research Collaboration & Network

To strengthen research and education stance and quality, a strong network with all related and active research groups, nationally and internationally is essential. Keeping this in view, we have created formal and informal networking and collaboration with research groups in the following universities and industries outside Sweden.

The universities and research institutes are: Aalto University, Finland; Birmingham University, UK; Central Queensland University at Gladstone, Australia; Indian Institute of Technology (IIT) Bombay and Kharagpur, India; Queensland University of Technology, Brisbane, Australia; Tromsö University, Norway; University of Cincinnati, USA; University of Queensland, Australia; University of Stavanger, Norway; VTT, Helsinki, Finland; University of Valencia, Spain; Imperial Collage, UK; Delft University, University of Twente, NL; Tsinghua University, Beijing Jiaotong University, Beihang University, China; China Academy of Railway Sciences (CARS); Hongkong City University; Huddersfield, UK.

JVTC is an active member of EURNEX, a European platform where researchers interact and influence the EU's R&D focus. EURNEX also provides the possibility to create networks for EU project applications.

The division and JVTC collaborates with PARC in the area of Prognostics and Health Management (PHM) through Dr. Kai Goebel who is principal researcher at PARC and an Adjunct Professor at the Division of Operation and Maintenance Engineering at Luleå University of Technology.

Dr Pierre Dersin, previously from Alstom in France, is an Adjunct professor at the division of Operation and Maintenance and at JVTC.

Professor Uday Kumar is an Honorary Professor at the Beijing Jiaotong University (BJTU), which is involved in Research and Innovation work for the railway industry especially for the high-speed trains and is equipped with railway laboratories.

JVTC also has a close collaboration and participates in research projects with the Technology Mission for Indian Railways (TMIR). We are engaged with the Indian Railways and involved in defining research projects.

Doctorate Degree Awardees

Praneeth Chandran

Title Doctorate Thesis: Train Based Automated Inspection for Railway Fastening System

ABSTRACT

Rail transportation is a sustainable mode of transportation and is a key enabler of the socio-economic development of modern society through passenger and freight services. Growth in overall transport demand has led to railways experiencing higher demand on operational capacity, service quality, and safety. However, an increase in traffic and load can lead to an increase in degradation of the components and thus cause a reduction in the infrastructure quality. Such degradation leads to failures of components, consequently resulting in a higher frequency of interventions for maintenance and renewal activities. The downtime arising from such maintenance and renewal of networks is a significant contributor to the delays incurred to the passengers. A plausible solution to attain higher operational capacity and quality of service with the existing infrastructure and minimise delays due to failure would be to inspect the track and its components frequently using in-service trains, operating in regular traffic.

One of the crucial components in rail tracks is the rail fastening system, which acts as a means to fix the rails onto the sleeper, upholding the track stability and track gauge. Failures of fasteners can increase wheel flange wear, reduce the safety of train operations, and may lead to derailment due to gage widening or wheel climb. In Sweden, the inspection of track fasteners is mainly carried out either manually by trained inspectors or by using measurement cars. Manual inspections are slow, cost-intensive, labour-intensive, pose safety issues for maintenance personal involved, and are prone to human errors. Inspections based on measurement cars are cost intensive and requires track possession and thus cannot be utilised frequently without compromising the operational capacity. Further, the adverse weather condition, especially in the north of Sweden for the majority of the year, limit regular fastener inspection that depends on such traditional inspection methods. The research presented in this thesis has aimed to find an automated method for fastener inspection that can be carried out using vehicle-mounted measuring equipment operating in regular traffic.

Firstly, a study was carried out to determine the effectiveness of automated visual-based solutions for fastener state detection. An anomaly detection model combining image processing techniques and deep learning algorithms was developed to detect the fastener state from rail images captured during the vision-based inspection. The model had a high capability of detecting the fastener state from the rail images. However, the model had difficulties detecting the fastener when there were instances of occlusions of fasteners due to the presence of snow and ballast stones and when the image brightness was low. In Sweden, specifically the northern part of it, the fastening systems are covered under snow for up to six months and thus can inhibit regular fastener inspections that rely on such automated visual inspection methods.

To overcome the challenges associated with automated visual inspection systems for fastener state detection, an alternative inspection method using a differential eddy current measurement system was investigated. Controlled field measurements were carried out along a heavy haul railway line in the north of Sweden to determine the effectiveness of the proposed measurement system. An anomaly detection model based on a supervised machine learning algorithm was developed to detect the fastener state from the controlled eddy current measurements. Further, to test the effectiveness of the eddy current sensor during real-time measurements, the proposed sensor system was mounted on an in-service freight train, and measurements were carried out along the iron ore line of Sweden. An anomaly detection model using unsupervised machine learning algorithms was developed to facilitate fastener state detection and detect other anomalies from the real-time measurement data.

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Dr. Praneeth Chandran with opponent, scientific committee, supervisors, colleagues and family at the dissertation. Photo: Per Pettersson.

Antonio Galvez

Title Doctorate Thesis: Hybrid digital twins: A co-creation of data science and physics

ABSTRACT

Safety is more important than reliability or efficiency in railway, aerospace, oil & gas, and chemical industries. Regulations are very restrictive in sectors where safety is paramount. This makes maintainers replace critical components in initial stages of degradation, which implies a loss of useful life and a lack of information about advanced stages of degradation for those components. Nevertheless, this lack of data can be overcome using hybrid digital twins, also known as hybrid-model based approaches (HyMAs), which combine data-driven models with physics-based models. This fusion minimizes the occurrence of undesirable failures that may interrupt the functionality of critical systems in a safe or cost-efficient manner.

HyMAs have been studied at Luleå University of Technology by other Ph.D. students who found promising direction for future research in prognostics and health management (PHM) applications. Thus, this research work continues the direction defined in previous research with the proposal of HyMAs for a heating, ventilation, and air conditioning (HVAC) system installed in a passenger train carriage orientated to diagnostics and prognostics processes. The proposed hybrid modelling consists of the fusion of data obtained from two sources: data obtained from the real system and synthetic data generated by a developed physics-based model of the HVAC.

The HVAC system is considered a system of systems (SoS). Therefore, the physics-based model of the HVAC system is divided into four main systems: heating subsystem, cooling subsystem, ventilation subsystem, and cabin thermal networking subsystem. These subsystems are modelled considering the sensors installed in the real system and soft sensors, also known as virtual sensors, which provide crucial information for fault detection, diagnostics, and prognostics. These sensors defined in the physics-based model generate synthetic data which reproduce the behaviour of the system while a failure mode (FM) is simulated. Verification and validation are key processes to synchronise the response of the physics-based model with the signals obtained from the real system. Hence, the physics-based model is synchronised, verified, and validated using data collected by sensors located in the real system. These steps are conducted following guidelines suggested in the literature.

Different datasets containing real data and synthetic data while the HVAC system works in faulty and healthy states are used to train data-driven models for fault detection and diagnostics and to train data-driven models for prognostics.

Statistical features, such as shape factor, kurtosis, skewness, and sum square error, among others, are calculated from the selected signals. These features are labelled according to the related FMs and are merged with the features calculated from the data obtained from the real system. The data fusion is classified according to the condition indicators of the system in terms of FMs and level of degradation. The merged features are used to train data-driven models for fault detection and diagnostics. In addition, the real data can be loaded to the physics-based model to predict the degradation of the air filter.

Then, the prediction data are loaded to an exponential model that provides an estimation of the remaining useful life (RUL) of the air filter. To improve the prognostics model, the physics-based model is used to generate run-to-failure data which are used to train and test a deep convolutional neural network (CNN) which accurately estimates the RUL of the air filter.

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Dr. Antonio Galvez with opponent, scientific committee, supervisors, and colleagues at the dissertation. Photo: Per Pettersson.

Veronica Jägare

Title Doctorate Thesis: A Challenge-driven Framework for Innovations in Railways

ABSTRACT

The railway is often perceived as an industry where new technology is not utilised to its full potential. However, the future of the railway and its ability to respond to future transportation demands lies in its ability to adopt, adapt, implement, and integrate emerging technology. These technologies are expected to lead to, e.g. intelligent asset lifecycle management with a whole-life asset approach and digital railway industry supply chain management. The technology transformation and digitalisation affect not only the technical systems, e.g. railway infrastructure and rolling stock, but also regulations, organisations, processes, and individuals. The railway industry needs to recognise the challenges and define strategies, which enable the successful implementation of innovations in railway. Thus, the purpose of this research work is to study, explore, and investigate how implementation of innovations in a multi-stakeholder environment such as railway maintenance, can be facilitated through a systematic approach. Further, the main objective of this research is to develop and provide, a challenge-driven framework that can be used to facilitate implementation of innovations in the Swedish railway. To achieve the purpose of this research, nine (9) descriptive and exploratory case studies have been carried out. In these case studies, issues and challenges have been identified, related to: a) Lead times; b) Complex multi-stakeholder environment; c) Business incentives; d) Governance for data sharing; e) Regulations and maintenance; f) Technology; g) Assessment of innovations; h) Business models; i) Responsibilities, and j) Implementation.

To overcome the identified challenges, several artefacts have been developed and provided in this research, i.e. a) A challenge-driven mission-based framework; b) A methodology for evaluating innovations; c) Strategies and guidelines for data governance; d) Strategies and guidelines for innovation in maintenance contracts; and e) Railway domain systemic aspects for the implementation pathway. The findings and artefacts of this study may be used as a framework and a road map in any industry by providing scientific guidance in the implementation of innovations. Some of the expected benefits for organisations are: a) Reduced development and production costs; b) Increased efficiency in testing, implementing, and utilising existing innovations; c) Increased awareness in data sharing; and d) Increased implementation support. Furthermore, in the context of railway maintenance, the artefacts from this study are expected to improve the overall effectiveness and efficiency through facilitating the implementation of innovations that support digitalisation of railway maintenance. The digitalisation of railway maintenance enables fact-based decision support utilising enhanced analytics aimed for nowcasting and forecasting. These capabilities will lead to: a) Improved knowledge and information exchange between railway stakeholders to enable efficient asset management; b) Enhanced condition monitoring; c) Improved risk management; and d) Improved sustainability.

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Dr. Veronica Jägare with opponent, scientific committee, supervisors, colleagues and family at the dissertation. Photo: Per Pettersson.

Education in Operation and Maintenance Engineering

Undergraduate Program (Bachelor of Engineering in Maintenance)

The Bachelor program in Maintenance Engineering is designed to provide on students with a broad engineering foundation with a focus on Maintenance Engineering and Asset Management.

The courses deal with subjects such as maintenance strategy, system reliability, human factors and maintenance management systems.

Master Program in Maintenance Engineering

Courses in Industrial AI and eMaintenance provide skills in advanced data analysis and knowledge how digitization and AI can be implemented to solve the maintenance challenges in a digitized, automated and connected infrastructures and plants. Courses in Condition Based Maintenance, Reliability Engineering, and Operation Research provide broad competence, which is important components in future work as a maintenance engineer and asset manager. The program also includes courses in Human Factors that gives you knowledge and understanding of how to improve maintainability and safety, but also how organizational aspects affect the safety and quality of maintenance activities.

Professional Education

The division of Operation and Maintenance is a natural partner for your organization's skill enhancement and career development in the increasingly important field of Maintenance engineering. The division has conducted executive programs related to recruitment activities and employee skills development.

Fast Track Maintenance Engineers

The division has developed a program to reskill engineers in maintenance engineering so that they become employable and can contribute to the development of Swedish industry, so-called Fast Track Maintenance Engineers.

The division started a Fast track program in Maintenance engineering in December 2020, where the program consists of four courses with a total of 30 higher education credits within:

- Introduction to operation and maintenance engineering
- Maintenance strategies
- Life Cycle Cost Analysis and Maintenance Management
- Condition Monitoring and Predictive Maintenance

The teaching is conducted via lectures, seminars, group assignments and laboratory work. All activities can be given at a distance since participants can be located throughout Sweden.

After completing the Fast track, the participants have the competence to work as a maintenance engineer or maintenance specialist.

Maintenance upskilling and reskilling

Many companies have identified a need for improved maintenance knowledge. The division can offer several tailor-made courses and executive program in the area of maintenance engineering, e.g. Maintenance management, Reliability engineering, Human factors and ergonomics, Predictive Maintenance, and Industrial AI.

Publications

Journals Papers

1. Galvez, A., Galar, D., & Seneviratne, D. (2022). A Hybrid Model-Based Approach on Prognostics for Railway HVAC. IEEE Access, 10, 108117–108127. https://doi.org/10.1109/ACCESS.2022.3211258.
2. Kumari, J., Karim, R., Thaduri, A., & Dersin, P. (2022). A framework for now-casting and forecasting in augmented asset management. International Journal of Systems Assurance Engineering and Management, 13(5), 2640–2655. https://doi.org/10.1007/s13198-022-01721-2.
3. Kour, R., Arranz, M. C., Karim, R., Patwardhan, A., Kumar, M., & Granström, R. (2022). A Human-Centric Model for Sustainable Asset Management in Railway: A Case Study. Sustainability, 14(2). https://doi.org/10.3390/su14020936.
4. Kour, R., Patwardhan, A., Thaduri, A., & Karim, R. (2022a). A Methodology for Cybersecurity Risk Assessment – A Case-study in Railway. International Journal of COMADEM, 25(2), 5–12. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-92981.
5. Kour, R., Patwardhan, A., Thaduri, A., & Karim, R. (2022b). A review on cybersecurity in railways. Proceedings of the Institution of mechanical engineers. Part F, journal of rail and rapid transit. Published. https://doi.org/10.1177/09544097221089389.
6. Kumari, J., Karim, R., Thaduri, A., & Castano, M. (2022). Augmented asset management in railways - Issues and challenges in rolling stock. Proceedings of the Institution of Mechanical Engineers. Part F, Journal of Rail and Rapid Transit, 236(7), 850–862. https://doi.org/10.1177/09544097211045782.
7. Patwardhan, A., Thaduri, A., Karim, R., & Arranz, M. C. (2022). Federated Learning for Enablement of Digital Twin. IFAC-PapersOnLine, 55(2), 114–119. https://doi.org/10.1016/j.ifacol.2022.04.179.
8. Arias Chao, M., Kulkarni, C., Goebel, K., & Fink, O. (2022). Fusing physics-based and deep learning models for prognostics. Reliability Engineering & System Safety, 217. Published. https://doi.org/10.1016/j.ress.2021.107961.
9. Zhang, L., Zhang, J., Peng, Y., & Lin, J. (2022). Intra-Domain Transfer Learning for Fault Diagnosis with Small Samples. Applied Sciences, 12(14). https://doi.org/10.3390/app12147032.
10. Anandika, R., & Lundberg, J. (2022). Limitations of eddy current inspection for the characterization of near-surface cracks in railheads. Proceedings of the Institution of Mechanical Engineers. Part F, Journal of Rail and Rapid Transit, 236(5), 532–544. https://doi.org/10.1177/09544097211029534.
11. Kumari, J., Karim, R., Karim, K., & Arenbro, M. (2022). MetaAnalyser - A Concept and Toolkit for Enablement of Digital Twin. IFAC-PapersOnLine, 55(2), 199–204. https://doi.org/10.1016/j.ifacol.2022.04.193.
12. Khosravi, M., Soleimanmeigouni, I., Ahmadi, A., Nissen, A., & Xiao, X. (2022). Modification of correlation optimized warping method for position alignment of condition measurements of linear assets. Measurement, 201. Published. https://doi.org/10.1016/j.measurement.2022.111707.
13. Khajehei, H., Ahmadi, A., Soleimanmeigouni, I., Haddadzade, M., Nissen, A., & Latifi Jebelli, M. J. (2022). Prediction of track geometry degradation using artificial neural network: a case study. International Journal of Rail Transportation, 10(1), 24–43. https://doi.org/10.1080/23248378.2021.1875065.
14. Compierchio, A., & Tretten, P. (2022b). Quantum Reality Perspectives in Dyadic Interactions. Human Interaction and Emerging Technologies (IHIET 2022): Artificial Intelligence & Future Applications, 68, 510–517. https://doi.org/10.54941/ahfe1002771.
15. Marchetta, V., Di Graziano, A., Soleimanmeigouni, I., & Ahmadi, A. (2022). Railway degradation behaviour analysis in narrow-gauge railways: A local-railway case study. Proceedings of the Institution of Mechanical Engineers. Part F, Journal of Rail and Rapid Transit. Epub ahead of print. https://doi.org/10.1177/09544097221136912.
16. Murua, M., Galar, D., & Santana, R. (2022). Solving the multi-objective Hamiltonian cycle problem using a Branch-and-Fix based algorithm. Journal of Computational Science, 60. Published. https://doi.org/10.1016/j.jocs.2022.101578.
17. Zuo, Y., Thiery, F., Chandran, P., Odelius, J., & Rantatalo, M. (2022). Squat Detection of Railway Switches and Crossings Using Wavelets and Isolation Forest. Sensors, 22(17). https://doi.org/10.3390/s22176357.
18. Khan, S. A., Lundberg, J., & Stenström, C. (2022). The effect of third bodies on wear and friction at the wheel-rail interface. Proceedings of the Institution of Mechanical Engineers. Part F, Journal of Rail and Rapid Transit, 236(6), 662–671. https://doi.org/10.1177/09544097211034688.
19. Xin, T., Yang, Y., Zheng, X., Lin, J., Wang, S., & Wang, P. (2022). Time Series Recovery Using Adjacent Channel Data Based on LSTM: A Case Study of Subway Vibrations. Applied Sciences, 12(22). https://doi.org/10.3390/app122211497.
20. Chandran, P., Thiery, F., Odelius, J., Lind, H., & Rantatalo, M. (2022). Unsupervised Machine Learning for Missing Clamp Detection from an In-Service Train Using Differential Eddy Current Sensor. Sustainability, 14(2), 1035–1035. https://doi.org/10.3390/su14021035.

Conference papers and Invited speeches:

1. Karim, R., Ahmadi, A., Soleimanmeigouni, I., Kour, R., & Rao, R. (Eds.). (2022). International Congress and Workshop on Industrial AI 2021. https://doi.org/10.1007/978-3-030-93639-6.
2. Kour, R., Patwardhan, A., Karim, R., Dersin, P., & Kumari, J. (2022). A cybersecurity approach for improved system resilience. Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022), 2514–2521. https://doi.org/10.3850/978-981-18-5183-4_S13-03-586-cd.
3. Patwardhan, A., Thaduri, A., Karim, R., & Castano, M. (2022). An Architecture for Predictive Maintenance using 3D Imaging: A Case Study on Railway Overhead Catenary. Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022), 3103–3110. https://doi.org/10.3850/978-981-18-5183-4_S30-04-588-cd.
4. Talebiahooie, E., Thiery, F., Mattsson, H., & Rantatalo, M. (2022). An Experimental Study on Railway Ballast Degradation Under Cyclic Loading. International Congress and Workshop on Industrial AI 2021, 1, 424–433. https://doi.org/10.1007/978-3-030-93639-6_37.
5. Garmabaki, A. H., Odelius, J., Thaduri, A., Famurewa, S. M., Kumar, U., Strandberg, G., & Barabady, J. (2022). Climate Change Impact Assessment on Railway Maintenance. Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022). Presented at the 32nd European Safety and Reliability Conference (ESREL 2022), Dublin, Ireland, August 28 - September 1, 2022. https://doi.org/10.3850/978-981-18-5183-4_S25-01-126-cd.
6. Compierchio, A., & Tretten, P. (2022a). Human Factors Evaluation of Shared Real and Virtual Environments. Human Interaction, Emerging Technologies and Future Systems V : Proceedings of the 5th International Virtual Conference on Human Interaction and Emerging Technologies, IHIET 2021, August 27-29, 2021 and the 6th IHIET: Future Systems (IHIET-FS 2021), October 28-30, 2021, France, 745–751. https://doi.org/10.1007/978-3-030-85540-6_94.
7. Kour, R., Thaduri, A., & Karim, R. (2022). Operational Security in the Railway - The Challenge. International Congress and Workshop on Industrial AI 2021, 1, 266–277. https://doi.org/10.1007/978-3-030-93639-6_22.
8. Söderholm, P., Jägare, V., & Karim, R. (2022). Reality Lab Digital Railway – Digitalisation for Sustainable Development. International Congress and Workshop on Industrial AI 2021, 1, 240–255. https://doi.org/10.1007/978-3-030-93639-6_20.
9. Dersin, P. (2022) Resilience and Capacity in Networks: a comparative Investigation of Rail Transport Networks and Electric Power Grids. In Advances in Modelling to Improve Network Resilience, Proceedings of the 60th ESReDA seminar (Grenoble, France, May 2022), Publications Office of the European Union, Luxembourg, ISSISSN.
10. Pierre Dersin, K. Saiah, A. Péronne, A. Staino, D.Moszkowicz, “Achieving and predicting Resilience and Capacity in Urban Rail and Multimodal Transportation Systems”, ESREL 2022, Dublin, August 2022.
11. Kour, R. et al. (2022). Metaverse for Intelligent Asset Management, International Conference on Maintenance and Intelligent Asset Management in ICMIAM 2022, India.
12. Kour, R., Patwardhan, A., & Karim, R. Cyber Resilient approach for Railways. In 21st Nordic Seminar on Railway Technology (p. 59).
13. Kumari, J. (2022). Bayesian Statistics for Fleet Management of Rolling Stock in 21st Nordic Seminar on Railway Technology, 2022.
14. Patwardhan, A. (2022). Railway catenary digital twin: structure, representation and analytics in 21st Nordic Seminar on Railway Technology, 2022.
15. Juntti, U. (2022). Installationsföreläsning, ny adjungerad professor. Vetenskapens hus.
16. Kumar, U. (2022). Transformative Maintenance Technology for Railway Assets. Keynote and Proceedings. The Fifth International Conference on Railway Technology: Research, Development and Maintenance, Montpellier, France, 22-25 August 2022.
17. Kumar, U. (2022). Keynote: RAMS for performance management for railway sector, IIT Kharagpour, August 27, 2022.
18. Kumar, U. (2022). Keynote. Safety and Reliability Society of India.
19. Galar, D. (2022). Drones: how can railways promptly restore operations after an incident? organized by the International Railway Summit and UIC. November 21, 2022 (webinar).
20. Galar, D. (2022). Opening speech in conference Quo Vadis CBM, by Railgrup. October 20, 2022.

Licentiate thesis

1. Kumari, J. (2022). Augmented Asset Management of Railway System Empowered by Industrial AI (Licentiate dissertation, Luleå University of Technology). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-90416
2. Patwardhan, A. (2022). Enablement of digital twins for railway overhead catenary system (Licentiate dissertation, Luleå University of Technology). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-92656
3. Zuo, Y. (2022). Squat Detection in Railway Switches and Crossings Using Point Machine Vibration (Licentiate dissertation, Luleå University of Technology). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-93191

Master thesis

1. Voorwald, D. (2022). Lidar data processing for railway catenary systems. Master thesis from Luleå University of Technology.
2. Björnlinger, K. (2022). The impact of snow loads on snow galleries. An initial evaluation of the snow galleries on the Iron Ore Line in Northern Sweden Master thesis from Luleå University of Technology.

Book Chapters

1. Galar, D., Seneviratne, D., & Kumar, U. (2022). Big Data in Railway O&M: A Dependability Approach. In Research Anthology on Big Data Analytics, Architectures, and Applications (Vol. 1, pp. 391–416). https://doi.org/10.4018/978-1-6684-3662-2.ch019
2. Submitted to Taylor & Francis /CRC manuscript of: Dersin, P. Modelling Remaining Useful Life Dynamics in Reliability Engineering, ISBN 9781032168593, publication scheduled for 6/6/ 2023.

2022 - News and highlights

APRIL

Trafikverket's trainee group visits JVTC

On April 24, Trafikverket´s trainee group visited JVTC to learn more about research and innovation at Luleå University of Technology.

Trafikverket´s trainees are testing AR and VR tools to work with maintenance in the metaverse.

AI Factory demonstrates Charlie the robot dog in the eMaintenance lab.

Dr Matti Rantatalo talks about condition based maintenance in the CBM LAB.

MAY

The Digital S&C is on IVA's 100 list 2022

The digitalized point machines for the future (Digital S&C) research project has been designated by the Royal Swedish Academy of Engineering, IVA, as IVA's 100 list in 2022. The purpose is to show researchers and research teams who want to achieve increased contacts with companies and the surrounding society. The focus of IVA's 100 list 2022 was technology in the service of humanity. The research must be ready to be utilized within the near future and create value for Swedish business and society.

Large and complex rail networks are vulnerable to adverse weather events and major shocks. There is no way to eliminate disruptions, but we can improve passengers' and goods' resilience, provide redundancy to rail networks, and implement digital monitoring solutions that keep the trains safe and a more sustainable public means of transport. The project's goal is to strengthen the reliability and punctuality of train transport by implementing a digital condition monitoring solution.

Dr Taoufik Najeh and professor Jan Lundberg are the project leaders for the Digital S&C.

JUNE

The technical areas management group from Trafikverket visits JVTC on June 14.

In the picture from the left: Jonas Larsson, Trafikverket, Matti Rantatalo, JVTC, Björn Dellås, Trafikverket, Christer Holmberg, Trafikverket and Ulla Juntti, JVTC.

JUNE

Nordic Railway Seminar on Railway Technology

Researchers from JVTC participated as presenters and session chairs at the Nordic Railway Seminar on Railway Technology in Tampere, Finland on June 21-22.

Ravdeep Kour presents Cyber resilient approach for railways.

Amit Patwardhan presents Railway catenary digital twin: structure, representation and analytics

Closing session where the Swedish railway centers from LTU, KTH and Chalmers expresses their appreciation to the conference chair Dr Heikki Luomala from Research Centre Terra, Tampere University. In the picture from the left: Heikki Luomala, Anders Ekberg, Sebastian Stichel and Veronica Jägare.

OCTOBER

TRAVISIONS 2022 Young Researcher competition

Ravdeep Kour, JVTC researcher, took 6th place in the competition for Cybersecurity in Railways. In the TRAVISIONS 2022 Young Researcher competition.

Dr Ravdeep Kour.

NOVEMBER

Ulla Juntti´s docent lecture

Ulla Juntti, JVTC, presented her docent lecture at Teknikens Hus in Luleå on November 7. The topic was “How can we extend the life length of the railway”?

Professor Ulla Juntti at Teknikens Hus.

2022 - News and highlights

DECEMBER

JVTC members study visit at LKAB

On December 1-2, JVTC arranged a study visit hosted by LKABs. The JVTC member companies and researchers visited the train workshop and mines.

In the picture from the left: Gaurav Sharma, LTU, Niklas Johansson, Transitio, Khosro Soleimani Chamkhorami, LTU, Ahmad Kasraei, LTU, Mahdi Khosravi, LTU, Amit Patwardhan, LTU, Margareta Groth, LTU, Uday Kumar, LTU, Fredric Bonnevier, Alstom, Björn Dellås, Trafikverket and Robert Pallari, LKAB.

DECEMBER

Researcher from LTU elected vice president of the IEEE Reliability Society

Janet Lin, associate professor in operation and maintenance engineering was elected to be vice president of the IEEE Reliability Society. Established in 1884, the IEEE is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity. The IEEE Reliability Society has over 30 chapters and members in 60 countries worldwide. The IEEE Reliability Society promotes recognition of the reliability profession, develops, and disseminates reliability best practices, and is a resource for collaboration among reliability professionals.

Dr Janet Lin.

JVTC railway seminars

JVTC arranged four railway seminars during 2022. All seminars were well attended and presented topics such as:

- Europe's Rail: Flagships
- Development of catenary digital twin through LiDAR
- Climate change impacts assessment on railway maintenance
- Augmented asset management for rolling stock in railways
- Position alignment of single defects in track geometry measurements
- Human factor/Ergonomics in railway

Project	Project members	Sponsor	Status
Department of Civil, Environmental and Natural resources engineering/ Division of Operation and Maintenance			
Framework Railway asset maintenance management and info logistics	Dr Matti Rantatalo, +46 920-492124 PhD candidate: Elahe Talebiahooie, +46 920-4936880	Trafikverket/JVTC	Active
eMaintenance Solution for Enhanced Smart Asset Management in Railway - Using Industrial AI	Prof Ramin Karim, +46 920-492344 PhD candidate:Jaya Kumari +46 920-492427	Trafikverket/JVTC	Active
Secure and resilient data and model sharing in railways	Prof Ramin Karim, +46 920-492344 PhD candidate: Amit Patwardhan +46 920-493871	Trafikverket/JVTC	Active
Predictive models för railway maintenance planning and scheduling (RAMS)	Prof Alireza Ahmadi, +46 920-49 3047 PhD candidate:Mahdi Khosravi +46 920-492814	Trafikverket/JVTC	Active
Autonomt underhåll av infrastruktur, rullande materiel och gränssnitt - Digital switches	Dr Matti Rantatalo +46 920-492124 PhD candidate:Yang Zuo +46 920-491632	Trafikverket/JVTC	Active
AI factory for Railway	Prof Ramin Karim, +46 920-492344	Vinnova	Active
Asset management digitalised overhead catenary	Prof Ramin Karim, +46 920-492344 PhD candidate: Amit Patwardhan +46 920-493871	Trafikverket	Active
Adapting Urban Rail Infrastructure to Climate Change (AdaptUrbanRail)	Dr Amir Garabaki +46 920-49 3429	Vinnova	Active
AI Factory for Railway Operation and Maintenance (Exc THP2 8U1.1)	Prof Ramin Karim, +46 920-492344	Trafikverket/JVTC	Active
AI factory for Railway	Prof Ramin Karim, +46 920-492344	Vinnova	Active
Asset management digitalised overhead catenary	Prof Ramin Karim, +46 920-492344 PhD candidate: Amit Patwardhan +46 920-493871	Trafikverket	Active
Adapting Urban Rail Infrastructure to Climate Change (AdaptUrbanRail)	Dr Amir Garabaki +46 920-49 3429	Vinnova	Active
AI Factory for Railway Operation and Maintenance (Exc THP2 8U1.1)	Prof Ramin Karim, +46 920-492344	Trafikverket/JVTC	Active
Livslängdsförlängning av järnvägssystemet (Exc THP3 8U1.2)	Prof Alireza Ahmadi, +46 920-493047	Trafikverket/JVTC	Active
Cybersecurity (Exc 8U3.1)	Dr Ravdeep Kour, +46 920-492898	Trafikverket/JVTC	Active
In2Track3	Dr Matti Rantatalo +46 920-492124	EU/Trafikverket	Active
Fr8Rail III	Dr Matti Rantatalo +46 920-492124	EU/Trafikverket	Active
Fr8Rail IV	Dr Matti Rantatalo +46 920-492124	EU/Trafikverket	Active
In2Smart II	Dr Matti Rantatalo +46 920-492124	EU/Trafikverket	Active
Sensorflotta för autonom tillståndsövervakning av järnväg	Dr Matti Rantatalo +46 920-492124	Vinnova	Active
Climate resilient infrastructure: A system innovation approach (CliMaint2Innovate)	Dr Amir Garabaki +46 920-49 3429	Vinnova	Active
Railway college (Exc)	Dr Matti Rantatalo +46 920-492124	Trafikverket	Completed
Fr8Rail II	Dr Matti Rantatalo +46 920-492124	EU/Trafikverket	Completed
Robust infrastructure – Adapting railway maintenance to climate change (CliMaint)	Dr Amir Garabaki +46 920-49 3429	Vinnova	Completed
Förstudie Human AI Interface, AR, VR, UX (Exc 8U1.3)	Prof Ramin Karim, +46 920-492344	Trafikverket/JVTC	Completed
A Challenge-driven Framework for Innovations in Railways	Prof Ramin Karim, +46 920-492344 Veronica Jägare, +46 920-491629 2022- doctoral thesis	Trafikverket/JVTC	Completed
Anomaly detection and system diagnostics	Dr Matti Rantatalo, +46 920-492124 PhD candidate: Praneeth Chandran, +46 920-493689	Trafikverket/JVTC	Completed
Effects on increased axle load for heavy freight trains	Prof Jan Lundberg, +46 920-491748 PhD candidate: Thomas Nordmark	LKAB	Completed
In2Track II	Dr Matti Rantatalo +46 920-492124	EU/Trafikverket	Completed

Research

Project	Project members	Sponsor	Status
RAMS modeling and simulation at system level	Dr Alireza Ahmadi, +46 9203047 PhD candidate: Hamid Khajehei, +46 920-493687 2021 – doctoral thesis	Trafikverket/JVTC	Completed
Rail grinding decision support: Non-destructive evaluation (NDE) of near-surface cracks in rail heads	Prof Jan Lundberg, +46 920-491748 PhD candidate: Rayendra Anandika +46 920-492151 2021 – doctoral thesis	Trafikverket/JVTC	Completed
Soft Issues of Industry 4.0: A study on human-machine interactions (Maintenance Ergonomics)	Prof Phillip Tretten, +46 920-492855 Dr Prasanna Ilankoon +46 920-493957 2020 - doctoral thesis	Trafikverket/JVTC	Completed
ePilot 2.0	Veronica Jägare, +46 920-491629 Prof Ramin Karim, +46 920-492344	Trafikverket/JVTC	Completed
Testbed Railway	Veronica Jägare, +46 920-491629	Trafikverket/JVTC	Completed
Verklighetslabb Digital Järnväg (VDJ)	Dr Peter Söderholm	Vinnova	Completed
Predictive analytics for degrading infrastructure	Prof Ramin Karim, +46 920-492344 Dr Ravdeep Khour +46 920-492898 2020 - doctoral thesis	Trafikverket/JVTC	Completed
Statistiskt baserad underhållsplanering inom järnväg	Prof Bjarne Bergquist +46-920-49 2137 PhD candidate: Mahdieh Sedghi 2021 – licentiate thesis	Trafikverket/JVTC	Completed
Simtrack	Prof Alireza Ahmadi, +46 920-49 3047	BVFF	Completed
Digitala spårväxeln, DigiSwitch	Prof Jan Lundberg, +46 920-491748	FORMAS	Completed
Insulation joints	Prof Jan Lundberg, +46 920-491748	Trafikverket	Completed
Impacts of climate changes on maintenance needs of railway and road infrastructure (CliMaint) Reliability improvement of railway infrastructure in climatic context	Dr Amir Garabaki +46 920-49 3429	Vinnova	Completed
RAMS krav för banöverbyggnad	Dr Stephen Famurewa, +46 920-49 2375	Trafikverket	Completed
Detektion av spårskador i järnvägen	Dr Matti Rantatalo +46 920-492124	Vinnova InfraSweden2030	Completed
ARINKA - Arctic Railway Infrastructure in Kolarctic	Dr Matti Rantatalo +46 920-492124	EU/Kolarctic CBC	Completed
Analysis of rail wear for maintenance evaluation and improvement	Dr Stephen Famurewa, +46 920-49 2375	Trafikverket	Completed
Underground pipelines and railway infrastructure - Failure consequences and restrictions	Dr Amir Garabaki +46 920-49	Vinnova InfraSweden 2030	Completed
Condition based maintenance of rail infrastructure using Internet if Things loggers	Dr Christer Stenström +46 920-491476	Vinnova InfraSweden 2030	Completed
Automatic detection of railway fasteners and track defects	Dr Matti Rantatalo +46 920-492124	Vinnova InfraSweden 2030	Competed
Condition monitoring, prediction and management of railway track assets	Dr Matti Rantatalo +46 920-492124	Vinnova InfraSweden 2030	Completed
In2Rail	Prof Uday Kumar, +46 920-491826 Dr Matti Rantatalo +46 920-492124	EU/Trafikverket	Completed
In2Smart	Prof Uday Kumar, +46 920-491826 Dr Matti Rantatalo +46 920-492124	EU/Trafikverket	Completed
SMaRTE	Prof Alireza Ahmadi, +46 920-493047	EU	Completed
Reduction of damages in wheel/rail interaction - Top of rail (ToR)	Prof Jan Lundberg, +46 920-491748 Dr Christer Stenström Dr Matti Rantatalo +46 920-492124 Dr Saad Ahmed Khan +46 920-491402 2019 – Doctoral thesis	Trafikverket/JVTC	Completed
Maintenance decision support models for railway infrastructure using RAMS	Dr Alireza Ahmadi +46 920 493047 Dr Iman Soleimanmeigouni +46 920 493258 2019 – Doctoral thesis	Trafikverket/JVTC	Completed
Improve availability and reduced life cycle cost of track switches	Prof Jan Lundberg, +46 920-491748	Trafikverket	Completed
Baysian reliability modeling for railway infrastructure	Dr Janet Lin, +46 920-49 1564	Trafikverket/JVTC	Completed

Project	Project members	Sponsor	Status
Life length estimation of rolling stock	Dr Behzad Ghodrati, +46 920-491456	Trafikverket/JVTC	Completed
Prognostic for railway S&C geometry degradation	Dr Matti Rantatalo +46 920-492124 Dr Madhav Mishra +46 920-49 2325 2018 – Doctoral thesis	SKF-UTC	Completed
ReRail den miljövänliga rälsen - test	Dr Christer Stenström	Trafikverket	Completed
Harmonisation of asset management definitions and data quality assurance in rail transport	Dr Christer Stenström, +46 920-49 1476	Trafikverket/JVTC	Completed
Infralert	Prof Uday Kumar, +46 920-491826 Dr Johan Odelius +46 920-492124	EU/Trafikverket	Completed
Sustrail	Prof Uday Kumar, +46 920-491826 Dr Matti Rantatalo +46 920-492124	EU/Trafikverket	Completed
TREND	Prof Diego Galar +46 920-2437	EU/JVTC	Completed
Optirail	Prof Diego Galar +46 920-2437	EU/JVTC	Completed
SAFT Inspect	Dr Matti Rantatalo +46 920-492124	EU	Completed
Increased railway infrastructure capacity through improved maintenance practices	Prof Uday Kumar, +46 920-491826 Dr Matti Rantatalo +46 920-492124 Dr Stephen Famurewa +46 920-492375 2015 – Doctoral thesis Dr Matthias Asplund +46 920-491062 2016 –Doctoral thesis	Trafikverket/JVTC	Completed
ePilot119	Veronica Jägare, +46 920-491629 Prof Ramin Karim, +46 920-492344	Trafikverket/JVTC	Completed
Big data analytics for fault detection and its application in maintenance	Prof Ramin Karim, +46 920-492344 Dr Janet Lin, +46 920-491564Dr Liangwei Zhang 2017 –Doctoral thesis	Trafikverket/JVTC	Completed
Link and effect model application through life cycle cost and return of investment analysis	Dr Christer Stenström	Trafikverket	Completed
Maintenance Thresholds	Prof Uday Kumar, +46 920-491826 Dr P-O Larsson-Kråik +46 10-231884 Dr Iman Arastehkhouy +46 920-2071	Trafikverket/JVTC	Completed
OptiKrea - Optimala metoder för innovative produktutveckling och beslutsstöd	Prof Jan Lundberg, +46 920-491748 Dr Anna Malou Petersson 2017 –Doctoral thesis	Trafikverket/JVTC/ Vossloh/Infranord	Completed
Solstormars påverkan på transportsystemet	Prof Uday Kumar +46 920-2437	JVTC	Completed
Winter preparation switches – failure consequences and restrictions	Per Norrbin +46 70-630 5248	Trafikverket/JVTC	Completed
Railway infrastructure robustness, attributes, evaluation, assurance, and improvement	Dr Aditya Parida, +46 920-491437 Per Norrbin +46 70-630 5248 2016 – Licentiate thesis	Trafikverket/SWECO	Completed
DeCoTrack, Track degradation modelling and analysis related to change in railway traffic	Prof Uday Kumar, +46 920-491826 Dan Larsson (Damill AB) 2004 - Licentiate Thesis	Trafikverket	Completed
Maintenance human factors ergonomics	Dr Rupesh Kumar, +46 920-492812	Trafikverket/JVTC	Completed
Investigation of end-user needs for eMaintenance on railway	Dr Ramin Karim, +46 920-492344	Trafikverket/JVTC	Completed
RAMS in signalling	Prof Uday Kumar, +46 920-491826 Dr Amparo Morant 2015 – Doctoral Thesis	Trafikverket/JVTC	Completed
ReRail	Anders Sundgren +46 703-076647	Vinnova	Completed
Automain	Prof Uday Kumar, +46 920-491826 Dr Ulla Juntti	EU/Trafikverket	Completed
Bothnian Logistics Green Corridor, BGLC	Dr Ulla Juntti	Trafikverket/JVTC	Completed
NoRRTeC establish a Swedish-Norwegian research platform	Veronica Jägare, +46 920-491629 Dr Matti Rantatalo +46 920-492124	Interreg/Länsstyrelsen	Completed
Link and effect models of railway infrastructure	Dr Aditya Parida Christer Stenström 2014-Doctoral Thesis	Trafikverket/JVTC	Completed
Integrated reliability analysis for maintenance optimization	Dr Janet Lin, +46 920-491564	Trafikverket/JVTC/LKAB	Completed

Research

Project	Project members	Sponsor	Status
Condition based maintenance for Vehicles	Prof Uday Kumar, +46 920-491826 Dr P-O Larsson-Kråik +46 10 231884 Dr Mikael Palo 2012 – Licentiate Thesis 2014 – Doctoral Thesis	Trafikverket/JVTC/LKAB	Completed
Optimization of track geometry inspection interval (Maintenance limits)	Prof Uday Kumar, +46 920-491826 Dr P-O Larsson-Kråik +46 10-231884 Dr Iman Arastehkhouy 2011 – Licentiate Thesis 2013 – Doctoral Thesis	Trafikverket/JVTC	Completed
From measurement to maintenance decision	Dr Håkan Schunnesson Dr Mikael Palo Dr Iman Arastehkhouy	LTU, LKAB	Completed
Ergonomic analysis for railway vehicle maintenance and workshop facilities	Dr Rupesh Kumar	Trafikverket/JVTC/ LKAB/ Euromaint	Completed
Dynamic maintenance programme	Prof Ramin Karim, +46 920-492344	Trafikverket/JVTC	Completed
Reliability analysis of switches and crossings	Prof Behzad Ghodrati, +46 920-491456	ALSTOM / Trafikverket	Completed
Development of a demonstrator for eMaintenance on railway	Prof Ramin Karim, +46 920-492344	Trafikverket/JVTC	Completed
Developing a method for the specification and selection criteria for technical systems and equipment	Prof Jan Lundberg, +46 920-491748	Trafikverket	Completed
RAMS and LCC in the planning phase	Dr Ulla Juntti	Trafikverket/JVTC	Completed
Support vector machine (Demonstrator)	Dr Yuan Fuqing	Trafikverket/JVTC	Completed
Detection of internal flaws in railway manganese crossings by using Synthetic Aperture Focus Technology (SAFT)	Dr Jan Lundberg, +46 920-491748	Trafikverket	Completed
LCC and RAMS for railway vehicles	Prof Uday Kumar, +46 920-491826 Dr Ambika Patra 2007 - Licentiate Thesis	Trafikverket/JVTC	Completed
Maintenance decision support models for railway infrastructure using RAMS &LCC Analyses	Prof Uday Kumar, +46 920-491826 Dr Ambika Patra 2009 - Doctoral Thesis	Trafikverket/ALSTOM Transport	Completed
Risk based inspection intervals	Prof Uday Kumar, +46 920-491826 Prof Alireza Ahmadi, +46 920-493047	Trafikverket/LTU	Completed
Support Vector Machine (data mining) and demonstrator	Prof Uday Kumar, +46 920-491826 Dr Yuan Fuqing 2011 - Doctoral Thesis	Trafikverket/JVTC	Completed
Wear in crossings	Prof Jan Lundberg, +46 920-491748	Trafikverket	Completed
Technical specifications for crossings	Prof Jan Lundberg, +46 920-491748	Trafikverket	Completed
Ultrasonic measurements of internal cracks in manganese crossings	Prof Jan Lundberg, +46 920-491748	Trafikverket	Completed
Infrastructure winter ability analysis	Dr Ulla Juntti	UIC	Completed
Maintenance performance indicators (MPIs) for Swedish Rail Administration	Prof Uday Kumar, +46 920-491826 Dr Ambika Patra 2009 - Doctoral Thesis	Trafikverket	Completed
Design for/out maintenance	Prof Uday Kumar, +46 920-491826 Dr Håkan Schunnesson Dr Stefan Niska 2008 – Doctoral Thesis	Trafikverket	Completed
LCC analysis of railway switches and crossings (S&C).	Prof Uday Kumar, +46 920-491826 Dr Arne Nissen2009 – Doctoral Thesis	Trafikverket	Completed
Maintenance strategy for railway infrastructure	Prof Uday Kumar, +46 920-491826 Dr Ulla Espling (Juntti) 2007 – Doctoral Thesis	Trafikverket	Completed
Condition based maintenance strategy for railway systems	Prof Uday Kumar, +46 920-491826 Dr Robert Lagnebäck 2007 – Licentiate Thesis	Trafikverket, LKAB	Completed
Reliability analysis and cost modelling of degrading systems	Prof Uday Kumar, +46 920-491826 Dr Saurabh Kumar 2008 – Doctoral Thesis	Trafikverket/JVTC	Completed
Improved train punctuality through improvement in engineering systems	Prof Uday Kumar, +46 920-491826 Dr Rikard Granström 2008 – Doctoral Thesis	Trafikverket, EU-structural funds	Completed

Project	Project members	Sponsor	Status
Improved punctuality through effective maintenance management	Prof Uday Kumar, +46 920-491826 Per-Anders Åkersten Dr Birre Nyström, 2008 – Doctoral Thesis	Trafikverket, EU-structural funds	Completed
Development of a multi-criteria hierarchical framework for maintenance performance measurement: concepts, issues and challenges	Dr Aditya Parida 2006 – Doctoral Thesis	Trafikverket	Completed
Maintenance-related incidents and accidents: aspects of hazard identification	Dr Mattias Holmgren 2006 – Doctoral Thesis	Trafikverket	Completed
Maintenance and continuous improvement of complex systems: linking stakeholder requirements to the use of built-in test systems	Dr Peter Söderholm 2005 – Doctoral Thesis		Completed

Department of Civil, Environmental and Natural resources engineering / Division of Structural and Fire Engineering			
Increased axle loads on railway bridges	Dr Thomas Blanksvärd, +46 920-491642	LKAB/HLRC	Active
Full-scale test trough bridges	Prof Gabriel Sas, +46 920-493835,	Trafikverket	Active
Snow galleries between Björkliden – Riksgränsen . Assessment of capacity and plans for structural health monitoring	Prof Gabriel Sas, +46 920-493835,	Trafikverket	Active
Design performance	Dr Björn Täljsten, +46 920-493360	Formas	Active
In2Track III	Dr Jaime Gonzalez, +46 920-492970	EU/Trafikverket	Active
Condition and capacity assessment of railway bridges (Exc)	Prof Gabriel Sas, +46 920-493835	Trafikverket	Active
Kalix bridge	Prof Gabriel Sas, +46 920-493835	Trafikverket	Completed
In2Track II	Dr Thomas Blanksvärd, +46 920-491642	EU/Trafikverket	Completed
Fr8Rail	Prof Lennart Elfgren, +46 920-491360	EU/Trafikverket	Completed
In2Rail/In2Track	Cosmin Popescu/Jonny Nilimaa/Björn Täljsten/ Thomas Blanksvärd/Lennart Elfgren	Shift2Rail/Horizon 2020	Completed
Sustainable Bridges	Prof Lennart Elfgren, +46 920-491360	EU/UIC	Completed
Mainline	Prof Lennart Elfgren, +46 920-491360	EU	Completed
Assessment of bridge condition	Prof Lennart Elfgren, +46 920-491360 Ulf Ohlsson/Natalia Sabourova	Formas	Completed
Assessment of Vindelälven bridge	Martin Nilsson, +46 920-492533	Trafikverket	Completed
Assessment of Långforsen bridge	Martin Nilsson, +46 920-492533	Trafikverket	Completed
Assessment of Byskeälv bridge	Lennart Elfgren, +46 920-491360	Trafikverket	Completed
Sustainable renovation	Björn Täljsten/Jonny Nilimaa, +46 920-493360	Formas/Trafikverket	Completed
Kiruna mine bridge	Mats Emborg, +46 920-491348	LKAB	Completed

Department of Civil, Environmental and Natural resources engineering / Division of Mining and Geotechnical Engineering			
Rock mechanics consequences of fire in tunnels	Prof Erling Nordlund, +46 920-491335 Kristina Larsson	Trafikverket	Completed
Structural sound	Prof Erling Nordlund, +46 920-491335 Andreas Eitzenberger + 46 920-492267 2013 – Doctoral thesis	Trafikverket	Completed
Deformation and failure of hard rock	Prof Erling Nordlund, +46 920-491335 David Saiang, + 46 920-491053 2008 - Doctoral thesis Perez, Kelvis 2013 - Doctoral thesis	Trafikverket	Completed

Research

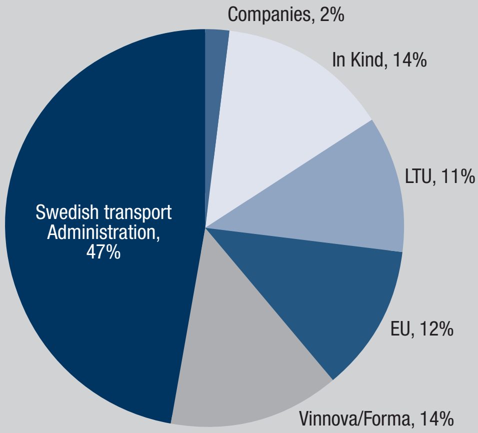
Project	Project members	Sponsor	Status
Department of Engineering Sciences and Mathematics/Division of Machine Elements			
A pre-study on wheel/rail interface friction management	Dr Braham Prakash Dr Jens Hardell +46 920-491774	Trafikverket/JVTC/LKAB	Completed
Surface roughness and rail grinding	Dr Jens Hardell +46 920-491774	Trafikverket	Completed
Rail Grinding and its impact on the wear of Wheels and Rails	Dr Braham Prakash Jonas Lundmark Licentiate Thesis	Trafikverket	Completed
Lubricants influence on wear in sharp rail curves	Dr Patric Waara 2000 – Licentiate Thesis 2006 - Doctoral Thesis	Trafikverket	Completed
Curving performance and nonlinear dynamic behaviour of freight cars with three-piece bogies	Prof Annika Stensson Dr Anselm Berghuvud 1999 – Licentiate Thesis 2001 - Doctoral Thesis	Trafikverket	Completed
Department of Business Administration, Technology and Social Sciences/Division of Business Administration and Industrial Engineering			
Improved condition assessment through statistical analysis	Prof Bjarne Bergquist, +46 920-492137	Trafikverket/JVTC/ LKAB/ Infranord	Active
Statistically based maintenance planning for railway	Prof Bjarne Bergquist, +46 920-492137	Trafikverket/JVTC	Completed
Alternativa system för tågstyrning på Malmbanan	Prof Anders Segerstedt Kristina Nilsson Licentiate Thesis	Trafikverket	Completed
Department of Business Administration, Technology and Social Sciences/Division of Social Sciences			
Status och utvecklingsmöjligheter avseende jämställdhet och integration inom järnvägsbranschen	Dr Kristina Johansson	Nordic Infracenter	Completed
Teknikhistoria elektrifiering av Malmbanan	Dr Roine Wiklund	Trafikverket	Completed

2022 Results

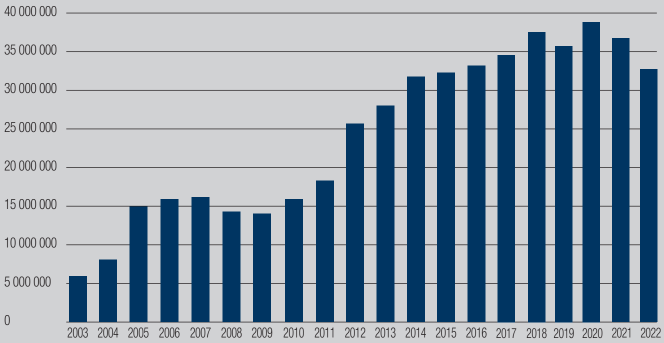
The financial turnover for 2022 was 32,3 MSEK.

JVTC Management and Administration 2022	SEK
Ingoing balance	67 074
Membership fees	995 000
Funding from JVTC framework	500 000
TOTAL INCOME	**1 562 074**
Salaries personnel	610 472
Other personnel costs	45 202
Facilities	68 285
IT/Computers	52 034
Materials	21 400
Travel	96 0400
Consultants	38 420
Other operating costs	31 152
OH	364 189
TOTAL EXPENSES	**1 627 205**
RESULTS JVTC	**-65 131**
Total Turnover JVTC area of interest 2022	
JVTC projects LTU	**32 321 961**

JVTC Contribution 2022



Turnover JVTC Year 2003-2022



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