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*Frontpage photo: Thomas Nordmark*
Chairman’s Message

The industrial maintenance business is changing. Many initiatives are being taken all over the business and all over the world and new digital solutions, methods, technologies are being developed and applied in order to render the maintenance more effective and add value to the end-user. It is sometimes referred to as Smart maintenance or Maintenance 4.0. The railway business is no exception. JVTC, with its focus on building advanced knowledge within the programs Dependability, Information logistics, Condition monitoring and Effective maintenance execution, is well positioned in the core of this exciting development. Last year was successful and overall JVTC is sticking to its business plan for the period 2016-2018. In particular I would like to highlight JVTC’s combination of domain knowledge within railway, knowledge within analytics and knowledge within management aspects as a key success factor during the last year as well as the years to come. Furthermore, I would like to reinforce JVTC’s focus on delivering research with a high technical readiness level, i.e. solutions and methods that are close to being implementable in real life. We should stick to that.

Finally, I would like to thank the management and staff of JVTC for your devotion to your mission as well as the board and the members for engagement, resources and interesting discussions.

Sven Ödeen, Trafikverket, Chairman
Luleå Railway Research Center,
February 2018
We have revised our strategic road map and have initiated efforts to address the challenges and develop transformative maintenance technologies and solutions for the railway sector.”

Director’s Report

A quick reflection on the news from the railway sector, it is evident that leaders in railway sector have embraced and aligned their strategic thinking towards assets wide application of digital technologies and solutions for achieving excellence in their operations. In that respect, application of Big Data analytics, machine learning, applications of drone technology, robotics, etc. to facilitate implementation of state of the art predictive maintenance technologies has been a dominant theme for board room discussions searching for sustainable solutions for ageing infrastructure and rolling stocks maintenance. There is a spoken need for implementation and exploitation of the new transformative technologies to integrate digital and physical infrastructures to ensure robust and reliable railway assets.

Keeping this in mind, we initiated work to review our research and innovation platform to address the challenges associated with implementation of digital technologies and solutions characterized by increased application of Big data, industrial internet in operation and maintenance of railway systems. Accordingly, after discussion with industry partners, we have revised our strategic road map and have initiated efforts to address the challenges and develop transformative maintenance technologies and solutions for the railway sector. The journey towards this goal seems much easier now with all round effort by railway sector to adopt digital technologies and solutions for transforming operation and maintenance of ageing and new railway assets.

Furthermore, as in the past our efforts are also directed towards creating a strong and responsive framework to secure a sustainable financial platform to allow innovation and basic research activities to continue. This has resulted in establishing us as a leading and attractive partner for the Swedish Transport Administration and EU Framework Programme apart from attracting international companies looking for innovative maintenance solutions.

During 2017 we have signed an agreement with China Railway Rolling Stock Company (CRRC), the world largest train manufacturer to establish a joint research center for Prognostics and Health Management (PHM) at Luleå University of Technology. The Center is expected to develop state of the art technology and innovative solutions for new and existing train fleets. Within the framework of “eMaintenance and Information logistics program of JVTC” the project ePilot has attracted nationwide attention, and we are thankful and take pride that the Swedish Transport Administration has approved the continuation of this project. I am also happy to say that ePilot was awarded Strukton Innovation Award for the year 2017 for the work on the vision of a punctual rail traffic, with proper maintenance measures at the right time. The project was described as an idea catalyst for fast decision support that is both requested and that gives actual results.

We 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 enhance decision-making through big data analytics.

JVTC was established during the year 1998 and we will be celebrating its 20th anniversary this year. Even though JVTC is only 20 years old, it has been successful in establishing itself as a world leading player in maintenance research and innovation offering solutions and new technologies to its partners from Sweden and other countries in Europe.

I would like to thank the management of Luleå University of Technology, my colleagues at the University, and our supporting partners in industry for the successful results accomplished in the year 2017.

Finally, I would like to thank the members of the Board of JVTC, for their guidance and support to the management team throughout the year. I will also take this opportunity to thank the management team especially Veronica Jägare, for their hard work, trust and continuous support. It is with great pleasure that I present the Annual Report of Luleå Railway Research Center, covering the activities, results and important events for the year 2017.

Professor Uday Kumar, Director
February 06, 2018
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 these keywords: Safety, Sustainability, Availability and Capacity.

The center has built up world class competence in the areas of RAMS, Condition Monitoring and eMaintenance. These three research areas bring strategic focus to some critical research topics which have considerable impact on the performance of railway systems. The center has also established Testbed Railway as a living labs test facility.
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, the research stations which provides access to data, and the eMaintenance 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, 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, and procurement. The center operates under the aegis of the chancellor of LTU and the director of JVTC is Prof. Uday Kumar. JVTC has 16 members and is funded by the industry.

Members
- Luleå tekniska universitet
- Bane Nor
- Bombardier Transportation
- Damill
- Duroc Rail
- eMaintenance365
- Infranord
- LKAB
- Omicold
- Outflight
- Norut Teknologi
- SJ
- SWECO
- Trafikverket
- Tyréns AB
- Vossloh Nordic Switch Systems

About JVTC

JVTC is a collaborative research center 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.
A look in the rearview mirror

JVTC was founded by LTU along with a number of interested companies in 1998 with support from Lulea Growth Academy, in order to make the area of heavy rail in a Cold Climate and mixed traffic more efficient. During the autumn of 2000 it was decided to focus the research on the operation and maintenance issues of the railway.

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

Sustainable bridges
A European research project initiated by Construction Technique was a so-called integrated project, submitted in April 2004. The 4-year project started on December 1, 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 the 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 and the 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 satellite company Damill AB, a monitoring station in Sävast on the Ore Line. The placement in Sävast was decided based on a large variance in traffic volume and the proximity of Luleå University of Technology. The measuring station has instruments to measure forces from vehicles on the track and the data is stored in the system. The measurements start automatically when a train passes the sensors on the track. The sensors separate vertical and horizontal forces. An accelerometer is used to measure the vibration of the rails when the train passes. Measurement data are now transferred to the eMaintenance LAB. This was the first step in establishing the Testbed for Railway.
Professor Uday Kumar was conferred a Distinguished Visiting Professorship by Tsinghua University in a simple ceremony on May 17th, 2017 in recognition of his academic contribution to the body of knowledge relevant for railway maintenance technology. In 2017, JVTC were involved in one proposal of Tsinghua University (Department of Industrial Engineering) titled “Big data driven high availability studies on high speed railway” as external consultant. It was approved on August 18th, by National Natural Science Foundation of China.

The theme of the International Heavy Haul Association (IHHA) Conference for 2017 was “Advancing Heavy Haul Technologies and Operations in a Changing World”. This conference specifically focused on research and innovations related to how to advance heavy haul technologies and operations to respond positively to the current market downturn, thereby contributing significantly to the survival of the railways. More than 480 abstracts were received from more than 20 countries across the world, 220 were selected for full technical papers, 188 papers were selected for publication as part of these proceedings. LTU and JVTC contributed with five selected publications:

- Asplund, M, Khan, S.A and Nordmark, T. Improved wheel-rail system of Sweden’s iron ore line.
- Famurewa, S. M, Zhang, L, Kumar, U. and Asplund, M. Data analytics for condition based wheel maintenance.
- Nordmark, T, Khan, S.A, and Domay, C. Use of electro-dynamic braking on locomotives and its effect on rolling contact fatigue.

Professor Uday Kumar, director for JVTC, together with professor Yan-Fu Li, Tsinghua University.

PhD student Thomas Nordmark at the IHHA conference in Cape Town, South Africa.

Ulla Juntti and Ramin Karim receives the award from Catharina Elmsäter-Svärd at Nordic Rail.

MAY
Professor Uday Kumar is conferred a Distinguished Visiting Professorship by Tsinghua University

JUNE
IHHA Conference in Cape Town

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The ePilot project at Luleå University of Technology has been awarded the newly established, Strukton Innovation Award. This for the work with the project ePilot and the vision of a punctual rail traffic, with proper maintenance at the right time.

The ePilot project is a collaboration project run by LTU and funded by Trafikverket, with the aim of improving punctuality and minimizing rail disruptions through decision support for maintenance operations. The jury’s motivation for the award was as follows: ‘With the vision of punctual rail traffic, with proper maintenance measures at the right time. JVTC at Luleå University of Technology runs ePilot, a development and implementation project that fits perfectly well in the future. The society is moving fast and ePilot is the experimental box that can give the industry the right tools to keep up with. An idea catalyst for fast decision support that is both requested and that gives actual results.’
Luleå University of Technology is the only Swedish university that now has a complete 30 meter, full-scale railway switch on campus. The switch, which is a gift from Trafikverket, will initially be used to study the machines that handle the switches on the railroad. The switches are a central part of the railroad, and now Trafikverket and JVTC want to further develop the machines handling the switches to further increase safety and punctuality in rail traffic.

At present, a collaboration project is being planned between professor Jan Lundberg at LTU, Trafikverket and Bombardier, which manufactures rail, locomotive and gearboxes. The railway switch at the university area, will be used to make power measurements and calculations, to improve the specifications for the shift functions.

OCTOBER

The University receives a railway switch as a gift

DECEMBER

The Railway Day

JVTC participated in the annual Järnvägsdagen (The Railway Day) at Stockholm Waterfront Congress Center, arranged by Swedtrain and the industry association Tågoperatörerna. Topics included future of transportation, cybersecurity, big data, Shift2Rail and financing of railway equipment. The Swedish minister for infrastructure, Tomas Eneroth, talked about the railway from a national perspective.
The strategic focus of the railway research and innovation programs is to develop new tools, methods and models that will facilitate innovative solutions in order to improve and strengthen the railway system.

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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 network and rolling stocks.

Strategic Research and Innovation Programs

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

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<th>RAMS</th>
<th>Asset management, Risk and Human Factors</th>
<th>eMaintenance</th>
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<td>Context based diagnostics and prognostics</td>
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<td>Dependability, LCC</td>
<td>Big Data analytics</td>
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<td>Threshold limits</td>
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<td>Risk analysis and modeling</td>
<td>Cloud-computing and data mining</td>
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<tr>
<td>Modeling of track geometry</td>
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<td>Big Data mining, Maintenance optimization and modeling</td>
<td>Distributed computing</td>
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<td>Wear and friction control</td>
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<td>Design for reliability and maintainability</td>
<td>Crowd-computing</td>
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<td>Component improvements</td>
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<td>Information logistics</td>
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<td>Grinding optimization</td>
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<td>Data integration, fusion and processing</td>
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<td>Condition monitoring techniques and strategies</td>
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<td>Data visualization</td>
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<td>Sensor technologies</td>
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<td>Context adaptation</td>
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<td>Demonstrator for testing on rail</td>
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<td>eMaintenance railway demonstrator</td>
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<td>Dependability</td>
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<td>Asset maintenance organization and strategy</td>
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<td>LCC</td>
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<td>Asset Performance Measurements and management</td>
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<td>Risk analysis and modeling</td>
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<td>LCC and LCP for asset management</td>
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<td>Big Data mining</td>
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<td>Maintenance workflow optimization</td>
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<td>Maintenance optimization and modeling</td>
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<td>Maintenance process and procedure analysis</td>
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<td>Design for reliability and maintainability</td>
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<td>Maintenance contracts</td>
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<td>Models for evaluating and implementing new knowledge</td>
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<td>Human, Technology and Organization (HTO)</td>
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<td>Human Factors /Ergonomics for risk management</td>
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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.

RAMS (Reliability, Availability, Maintainability, Safety, Security, Supportability, 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 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, during the last 6–8 years, 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 the framework EU H2020 Program and JVTC is one of the key players for the analysis of RAMS of railway systems.

The importance of the concept and application of human factor 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 ergonomic 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 factor related projects thus 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.
The overarching objective of the eMaintenance Research Programme (eMRP) is to: 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 solutions.

eMRP focuses on topics which reflect issues and challenges within industry and academia. Some of these topics are: Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), Explainable AI (XAI), service-oriented and event-oriented approaches, digitalisation, IoT and IIoT, and information logistics are getting orchestrated to develop solutions which can be utilised during a system’s whole lifecycle (i.e. conceptualisation, design, development, production, utilisation, and retirement). The eMRP aims to various process phases (i.e. maintenance management, maintenance support planning, maintenance planning, maintenance execution, maintenance assessment, and maintenance improvement) on-line and in real-time.

The main goal of the eMaintenance Research Program (eMRP) is to enable Operational Excellence enhance through establishment of effective and efficient operation and maintenance processes. eMRP enables Augmented Decision-Making empowered by Advanced Maintenance Analytics. In eMRP, frameworks, approaches, methodologies, technologies, and tools such as Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), Explainable AI (XAI), service-oriented and event-oriented approaches, digitalisation, IoT and IIoT, and information logistics are getting orchestrated to develop solutions which can be utilised during a system’s whole lifecycle (i.e. conceptualisation, design, development, production, utilisation, and retirement). The eMRP aims to various process phases (i.e. maintenance management, maintenance support planning, maintenance planning, maintenance execution, maintenance assessment, and maintenance improvement) on-line and in real-time.
At present, under the JVTC platform, six H2020 EU-projects within Shift2Rail are running during 2017: IN2RAIL, INFRALET, IN2SMART, IN2TRACK, FR8RAIL and SMArTE. The descriptions of stated EU projects are given below.

**IN2RAIL**

**Sponsors:** EU, H2020, SHIFT2RAIL, Trafikverket

**Researchers:** Matti Rantatalo, Stephen Famurewa, Iman Arasteh Khoy, Johan Odelius, Christer Stenström, Adithya Thaduri, Johan Odelius

**Objective:** The next 20-30 years will see unprecedented demand for growth in transport. European railways have to deliver increased productivity to fulfill the growth demand across all modes in freight and passenger services by 80% and 50% respectively by 2050. IN2RAIL will pave the way for the optimisation of the design of core infrastructure elements as well as improve the management of the railway system by adopting a holistic approach.

IN2RAIL is to set the foundations for a resilient, consistent, cost-efficient, high capacity European network by delivering important building blocks that unlock the innovation potential that exists in the SHIFT²RAIL Innovation Programmes (IP) 2 and 3.

IN2RAIL will make advances towards achieving the overall SHIFT²RAIL objectives:
- enhancing the existing CAPACITY fulfilling user demand of the European rail system;
- increasing the RELIABILITY delivering better and consistent quality of service of the European rail system;
- reducing the LIFE CYCLE COST (LCC) increasing competitiveness of the European rail system and European rail supply industry

**WP2 – Smart Infrastructure - Innovative S&C Solutions:** Improved performance, safety and reduced life cycle of S&C will be investigated through technologies including mechatronics, self inspection/correction/adjustment, embedded sensors, and novel locking mechanisms. The performance and safety critical S&C asset and its reliability will be targeted. Failures associated with S&C currently account for some 25-30% of all infrastructure failures on European railways.

**WP3 – Smart Infrastructure - Innovative Track Solutions:** Fast and efficient railhead repair methods, optimised ballast track system, solutions to decrease noise and vibration, and a radical hybrid track system will be areas of research. The track system has significant safety, efficiency and costs implications for European railways. WP3 will target key aspects to deliver cost effective solutions.

**WP4 – Smart Infrastructure - Bridges & Tunnels:** Improved knowledge on bridge and tunnels asset condition and rates of degradation is required to reduce cost, and improve performance. Better information and intelligence to create predictive capabilities. The challenge is to develop inspection and monitoring methods that can be used with minimal traffic disruption.

**WP6 – Smart Infrastructure - Maintenance Strategies & Execution:** Delivers a consistent and holistic approach to asset maintenance improving the reliability of the railway system reducing recurring maintenance costs. The research will focus on an asset maintenance framework, a dynamic model for track system maintenance, and condition and risk based maintenance planning.

A framework and process for KPI decisions that support infrastructure managers and the supply chain to define and evaluate their own KPIs have been developed. The process is demonstrated by connecting it to In2Smart asset management requirements and by conducting two case studies on Trafikverket maintenance records. The case studies involve KPIs of availability and risk matrices.

**WP9 Intelligent Mobility Management (I2M) – ‘Nowcasting’ and Forecasting:** WP9 will focus on the design and development of an advanced asset information system with the ability to ‘nowcast’ and forecast network asset status with the associated probabilities. This will allow TMS/dispatching systems to seamlessly access heterogeneous data sources.

**Duration:** 2015-2017
INFRALERT

Sponsors: EU, H2020, SHIFT2RAIL, Trafikverket
Researchers: Johan Odelius (PL), Adithya Thaduri, Stephen Famurewa, Amir Garmabaki
Objective: The overall goal of INFRALERT is to improve the operability and functionality of linear asset transport infrastructures based on large-scale automated condition prediction, intervention alert management, maintenance, RAMS & LCC analysis and renewal (M&R) planning to support decision making. INFRALERT will develop, deploy and exploit solutions that enhance the transport network infrastructure performance and adapt its capacity to meet growing needs by:

i. ensuring the transport infrastructure operability by optimising network functionality under traffic disruptions

ii. keeping and increasing the availability of the existing infrastructure by optimising tactical and operational maintenance interventions and assessing strategic long-term decisions on new construction

iii. ensuring infrastructure service reliability and safety by minimising incidences and failures.

An essential advancement to reach this goal is the development and implementation of expert-based Infrastructure Management System (eIMS) to coordinate and integrate all processes from measurement to decision support for maintenance & renewal. The eIMS will integrate various toolkits that are developed for the following functions: Data Management, Asset Condition, Alert Management, RAMS and LCC, and Decision Support (see Figure 1). LTU is leading asset condition toolkit that include the methodologies to assess the current condition (nowcasting) and predict the future condition (forecasting). The key issues addressed are dynamic segmentation, condition uncertainty and hybrid modelling for more accurate forecasting.

Figure 1: INFRALERT eIMS - data to maintenance action coordination

The performance of the eIMS prototype is demonstrated in two case studies: rail and road use cases. The demonstrator for railway infrastructure in INFRALERT is under the responsibility of LTU with close collaboration with Trafikverket. The track sections to be considered in the demonstrator are the northern and southern loops of the Iron Ore Line in the Trafikverket’s network. For an objective evaluation of eIMS performance, a baseline case is defined covering necessary aspects required to evaluate INFRALERT’s goals. External Key Performance Indicator (KPI) such as asset utilisation, service quality and financial effectiveness will be used for comparison of the baseline condition and the asset condition.

Webpage: http://infralert.eu/
Duration: 2015-2018

IN2SMART

Sponsors: EU, H2020, SHIFT2RAIL, Trafikverket
Researchers: Matti Rantatalo, Johan Odelius, Ramin Karim, Adithya Thaduri, Stephen Famurewa, Christer Stenström, Philip Tretten, Mattias Holmgren, Mustafa Aljumaili, Alireza Ahmadi
Objective: IN2SMART represents the first project of the Shift2Rail members referring to the following Technology Demonstrators (TDs) in the Multi Annual Action Plan:

- TD3.7 Railway Information Measuring and Monitoring System (RIMMS),
- TD3.6 Dynamic Railway Information Management System (DRIMS) and
- TD3.8 Intelligent Asset Management Strategies (IAMS).

In the project, Luleå University of Technology acts as a linked third party to Trafikverket with the responsibility of performing research activities in the TDs. The TDs will deploy an overall concept for Intelligent Asset Management based on the following three main interlinked layers:

- Measuring and Monitoring systems to collect data from the field related to the railway assets status: IN2SMART will develop unmanned systems for “remote” monitoring; track geometry, switches & crossings and signalling monitoring systems; innovative measurement of train parameters and wheel defects combined with rolling stock identifications systems.

- Data management, data mining and data analytics procedures to process data from the field and from other sources: IN2SMART will develop standard open interfaces to access heterogeneous maintenance-related data; analytic tools to automatic detect anomalies, discover and describe maintenance workflow processes and predict railway assets decay towards prescriptive maintenance.

- Degradation models and decision making tools to support maintenance strategies and execution: IN2SMART will lay the foundation of a generic framework for asset management and decision support process. This framework will specify the scope, objectives, workflow and outcomes of the decision-making process for maintenance interventions planning, and will be the enabler for the development of future decision support tools and systems. IN2SMART will also develop an optimised tamping tool and a robot platform for maintenance works.

IN2SMART will complement the work of the IN2RAIL light-house project to reach a homogeneous TRL4/5 demonstrator.

Duration: 2016-2018
IN2TRACK

Sponsors: EU, H2020, SHIFT2RAIL, Trafikverket
Researchers: Cosmin Popescu, Björn Täljsten, Lennart Elfgren
Objective: The main objective of IN2TRACK project is to set the foundations for a resilient, consistent, cost-efficient, high capacity European network by delivering important building blocks that unlock the innovation potential that have been identified as part of the Shift2Rail Innovation Programme 3.

The specific objectives of IN2TRACK are divided into three parts;
- Enhancing and optimising the switch & crossings and track systems in order to ensure the optimal line usage and capacity;
- Investigating novel ways of extending the life of bridges and tunnel assets through new approaches to maintaining, repairing and upgrading these structures;
- Development and adoption of a holistic, whole-system-approach.

A whole-system approach, which is defined as the system boundaries extending from dynamic wheel-rail interaction (loading input) through to degradation of the S&C system, sub-systems, individual components, and underlying track foundation, will also be at the heart of IN2TRACK on how to reach the objectives.

In the project, Luleå University of Technology acts as a linked third party to Trafikverket. The task is to work with inspection methods for bridges and field tests have been done on bridges on the Iron Ore Line.

Duration: 2016-2019

FR8RAIL

Sponsors: EU, H2020, SHIFT2RAIL, Trafikverket
Researchers: Matti Rantatalo
Objective: The main aim of the FR8RAIL project is the development of functional requirements for sustainable and attractive European rail freight.

The objectives of the project are:
- A 10 % reduction in the cost of freight transport measured by tonnes per Km,
- A 20 % reduction in the time variations during dwelling, and
- Increase attractiveness of logistic chains by making available 100 % of the rail freight transport information to logistic chain information systems.

The objectives of the FR8RAIL project will be achieved by developing a number of vital areas within freight rail.

There are six main areas of work that form the backbone of this project’s approach:
1. Business Analytics, KPIs, Top Level Requirements,
2. Condition Based and Predictive Maintenance,
3. Telematics & Electrification,
4. Running Gear, Core and Extended Market Wagon,
5. Automatic Coupling,
6. High level System Architecture and Integration.

In the project, Luleå University of Technology acts as a linked third party to Trafikverket. The task is to work with condition based and predictive maintenance.

Duration: 2016-2019

SMaRTE

Sponsors: EU, H2020, SHIFT2RAIL Joint Undertaking Consortium
Researchers: Alireza Ahmadi (PL), Matti Rantatalo, Hussan Hamoodi
Objective: SMaRTE will provide the methodology for implementation of a Condition Based Maintenance system appropriate for the railway. This will allow maintenance to be tailored around the actual remaining life of key components and will reduce costs and improve reliability and availability. Knowledge and experience from other sectors will be extracted and new scientific methods for handling data and setting up architectures and intelligent systems to process data will be developed; appropriate to the railway system. Case studies will be designed and carried out for two different but typical passenger railways and lessons learned will be used to improve the system definitions. The final result of the SMaRTE project will be a CBM system which works for passenger railways and will result in reduced system costs and improved system reliability. The final result of SMaRTE will be a set of quantified factors influencing rail usability, and recommendations on how to decrease the cognitive effort and onward mobility for rail journeys through a “Smart Journey Vision” and rail map of measures.

Duration: 2017-2019

Diagram:

WP 1: Project management
WP 2 Smart Maintenance for Rolling Stock
WP 3 Human Factors: User centred planning and mobility
WP 4 Impact Assessment
WP 5 Dissemination
There are about 28 R&I projects in progress within the center related to maintenance and the railway system.

**Maintenance Decision Support Models for Railway Infrastructure using RAMS**

**Sponsor:** Trafikverket/JVTC  
**Researchers:** Alireza Ahmadi (PL), Iman Soleimanmeigouni  
**Goal:** The goal of railway infrastructure managers is to keep the RAMS parameters of railway system within acceptable thresholds at lowest possible cost. An efficient an effective way of achieving this goal is to employ applicable and effective maintenance and renewal strategy.  
**Project status and results:** The aim of this project is to develop an integrated data driven methodology to support maintenance decision making. Obviously, prediction of track geometry degradation and effectiveness of tamping recovery are the key inputs for RAMS assessment of track (see Fig. 1). In addition, isolated defects must be considered as they are the driving factors for safety of railway operation (see Fig 2). In this regard, track geometry degradation, isolated defect, and tamping effectiveness are modelled and integrated for long term prediction of track geometry condition over a track line. The developed model will be used to predict and simulate track geometry behaviour and to evaluate RAMS parameters by adopting different maintenance plans. This will enable infrastructure managers to compare different maintenance plans with respect to the RAMS and LCC parameters and to find the optimal maintenance plan (see Fig. 3).  
**Duration:** 2014 - 2018

**MaintTrain**

**Sponsor:** LKAB  
**Researchers:** Thomas Nordmark, Jan Lundberg (PL), Christer Stenström, Matti Rantatalo  
**Goal:** To investigate and understand the consequences for increasing the axle load on LKAB:s ore trains from 30 to 32.5 tons.  
**Project status and results:** The mining company LKAB uses IORE electrical locomotives to haul their iron ore trains. During 2001 – 2005, the technical wheel life length was found to be 917,000 km. From around 2006, the wheel life started to decrease because of increased rolling contact fatigue (RCF), dropping to around 300,000 km. A serious of actions was undertaken to restore the wheel life up to present date. These actions include field tests with revised wheel profile, a new better wheel steel grade and a combination of new steel grade and revised profile, limitation of electro dynamic breaking, lower axle load and use of top of wheel thread lubrication. This case study will present and analyse the results from the different actions tested in the field on the Iron Ore Line. The most important finding is that a better steel grade will not give any benefit if not the wheel profile is optimized first. The present wheel life length has increased to 594,704 km for four of the locomotives with revised wheel profile and a better steel grade.  
**Duration:** 2014 – 2020

**Derailment risk assessment**

**Researchers:** Elahe Talebishooie, Alireza Ahmadi, Uday Kumar (PL)  
**Sponsor:** Trafikverket/JVTC  
**Goal:** Proposing a practical framework for derailment risk indexing  
**Project status and results:** Derailment is one of the potential risks in railway transportation, which is rare but its social, economic and environmental consequences is catastrophic. practically, intervention levels and track quality indices are used to determine time for maintenance actions which intended to control derailment risk. To efficiently control susceptibility of track sections to derailment, maintenance and inspection schedules should be optimized. The aim of this project is to develop decision support and methodologies for assessment of derailment risk of track under uncertainty. The proposed method should index derailment risk as a function of age, usage, maintenance actions and environmental properties regards to the dynamic characteristics of track quality. It should be easily applicable in maintenance scheduling, also capable of using nonhomogeneous data. Regards to these circumstances, a combination of rating approach and artificial neural network is selected for indexing. on this way, we will confront with three challenges: a) defining rating factors based on operability, clarity, non-redundancy and compatibility; b) appropriate track segmentation; c) appropriate data combination from nonhomogeneous sources to overcome these challenges a vast classification and review should be done on expert judgments and published researches.  
**Duration:** 2017-2021
RAMS modeling and simulation at system level

Researchers: Hamid Khajehei, Alireza Ahmadi (PL), Uday Kumar (PL)  
Duration: 2017-2021  
Sponsor: Trafikverket/JVTC  
Objective: Track geometry degrades with age and usage, and it affects performance and safety of train operation. Whenever track geometry quality reaches a predetermined limit, maintenance actions are performed on track geometry to restore its quality to an acceptable level (see figure 1). In this regard, identification of an optimal inspection frequency is crucial for infrastructure managers to take appropriate maintenance decisions at right time. Track geometry maintenance threshold is also one of the crucial factors affecting track availability, reliability, and trains safety as setting an inappropriate maintenance threshold may result in over or under maintenance activities. Hence, setting an applicable and effective threshold level arise as another challenge. Therefore, after several track maintenance actions, it will end up with renewal actions. The act of renewal restores the condition of track to the original state. A wide number of strategies may be followed for renewal of the track geometry such as renewal in terms of age and usage, renewal after a special number of track maintenance actions, etc. Identification of applicable and effective renewal strategy is another key issue for infrastructure manager.  
In order to rectify all the mentioned issues, this research takes advantage of RAMS modelling and simulation. In this research work, the ultimate goal is to provide a railway track maintenance planning framework which assist infrastructure managers in decision making. The proposed framework will consider maintenance planning of track geometry inspection frequency, maintenance threshold and renewal period. For this purpose, simulation method is used to evaluate the long term behavior of track geometry and determination of an optimal maintenance plan respect to the desired criteria of interest.

Predictive analytics for degrading infrastructure

Researchers: Ramin Karim (PL), Ravdeep Kour  
Sponsor: Trafikverket/JVTC  
Goal: Formulation of cybersecurity framework for railway infrastructure  
Project status and results: The convergence of IT and OT and the paradigm shift toward Industry 4.0 in modern railway system has brought significant benefits in reliability, operational efficiency, capacity as well as improving passenger experience. However, with the adoption of new ICT technologies in railway system, the vulnerability of cyber threats in railways has also inevitably increased. Therefore, it becomes mandatory for such establishments to move towards security analytics and automation to improve and prevent security breaches, and to quickly identify and respond to security events. The objective of this research is to develop a holistic cybersecurity framework for Railway Infrastructure to ensure security of railway critical infrastructure system, data confidentiality, integrity and availability of information. The proposed framework will assist the Railway industry in minimizing losses in terms of cascading effects, resulting in adverse impacts on railway facility, services, sensitive information, economy, decision making, productive time, reliability, and continuity (Figure 1).  
Duration: 2017-2019

Optimal rail grinding

Researchers: Rayendra Anandika, Jan Lundberg (PL), Christer Sterenström, Matti Rantatalo  
Sponsor: Trafikverket/JVTC, Speno  
Goal: To develop an optimal rail LCC grinding strategy which are for instance considering grinding costs and crack/flaw propagation.  
Project status and results: The optimal amount and frequency of grinding is investigated by a combination of condition monitoring methods, field tests and simulations. So far Phased array technology and 20 MHz sensors seems to be useful for detecting cracks in the rail close to the surface. A field test on a test rail in commercial traffic where a spectrum of grinding depth and grinding frequencies and measurement of remaining cracks by using eddy current and UL methods is planned. The eddy current measurements will be performed by Speno grinding trains and the UL measurement will be performed by LTU on specified spots at the test rail. Also the first steps regarding simulation of cracks has been undertaken.

Duration: 2017-2021

Methods for effective implementation of maintenance related innovations

Researchers: Veronica Jägare, Jan Lundberg  
Sponsor: Trafikverket/JVTC  
Objective: To contribute to a greater understanding of the challenges that implementation of innovation within operation and maintenance of the railway system offers, the factors affecting implementation and provide a knowledge based decision support model, taking into account multiple stakeholders. An effective method for evaluating and implementing new ways of working that will make use of maintenance-related innovations will be developed.

Duration: 2014-2021
Collaborating human cognition and intelligent maintenance systems

Researchers: Prasanna Illankoon, Uday Kumar (PL), Phillip Tretten (PL)
Sponsor: Trafikverket/JVTC
Goal: The overall aim is to develop methodologies for collaborating two-way cognition between intelligent maintenance systems and human operators.
Project Status and Results: The overall aim is to develop methodologies for collaborating two-way cognition between intelligent maintenance systems and human operators. First phase of the project critically assessed the significance of different types of human cognition in the maintenance domain. Critical Decision Method is used to categorize cognitive involvement and their effectiveness at different phases of anomaly detection, cause diagnosis, prediction and identifying prescriptions. Second phase investigates various sources for human cognition about machine behavior. Role of human sensors, experience, environmental signals and their combinations to produce both explicit and implicit knowledge about machines are investigated using simulation studies. Final phase develops a model to represent how intelligent maintenance systems can be designed to facilitate human cognition about unique machine behaviors and how intelligent maintenance systems can learn from what human are able to learn. It is expected to assess the design concepts using psychophysical measures. The model for collaboration has been developed and published.
Duration: 2017-2018

Anomaly detection and system diagnostics

Researchers: Praneeth Chandran, Matti Rantatalo (PL)
Sponsor: Trafikverket/JVTC
Objective: The project is focusing on detecting anomalies related to railway fasteners and rail defects. The main research question: How will different conductive track components affect the modulation of an oscillating magnetic field during the life length of the track?
Duration: 2017-2021

Condition monitoring, prediction and management of railway track assets

Sponsor: Vinnova InfraSweden2030
Researchers: Matti Rantatalo
Objective: Infrastructure managers needs to make well informed operation and maintenance decisions. The decisions should be based on the asset condition or preferably predictions of future conditions and different maintenance scenarios. In this project WSP, LTU and the traffic management of Stockholm county will address the challenges of making an optimum maintenance decision. The aim of the project is to develop a predictive maintenance approach for the Stockholm subway and commuter train traffic. The project is divided into three parts: Investigation into the causes of defects, development of strategic measurement tools to allow predictions as well as statistical analysis of measurement data. The work will be aligned with the asset management standard ISO55000.
Duration: 2016-2018

Simulation of railway track geometry and intelligent maintenance planning SIMTRACK

Researchers: Alireza Ahmadi (PL), Arne Nissen (PL Trafikverket), Adilithya Thaduri, Iman Soleimanmeigouni, Hamid Khajei
Sponsor: Trafikverket
Goal: To develop decision support methodologies and tools for the simulation of track geometry maintenance planning and scheduling.
Project Status and Results: Railways are currently experiencing higher demands on infrastructure performance, capacity and service quality. As a result, higher level of resilience against failure, robustness and availability at reduced cost of the infrastructure are expected. This necessitates development and implementation of an applicable and effective maintenance program to control the degradation of track and to restore the damaged track to an operational state, at lowest possible risk and life cycle cost. SIMTRACK will facilitate a simulation-based platform that enables development of tools, methodologies and techniques for the optimization of track geometry maintenance planning and scheduling and realization of efficient and effective execution of geometry interventions e.g. tamping. These will provide a basis to predict track geometry evolution, analyse the risk of failures and forecast maintenance activities as well as renewal investment requirements. The results will enhance safety, maximize capacity utilization, and lead to an efficient and cost effective maintenance program. SIMTRACK is structured into 7 work packages. WP1 deals with the project management. WP2 presents the industrial scenarios, specifications and requirements that provide inputs to WP3 to WP6 respectively defined as predictive modelling and analytics, track maintenance optimization and decision support system, evaluation of maintenance efficiency and cloud-based predictive analytics platform. WP7 deals with dissemination and exploitation, is devoted for formulating comprehensive plans for results assimilation by the partners and set the ground for the exploitation.
Duration: 2017-2020

Statistically based maintenance planning for railway

Sponsor: Trafikverket/JVTC
Researchers: Bjarne Bergquist, Peter Söderholm
Objective: For corrective and preventive time-based maintenance to be replaced by condition-based maintenance, methods of analysis and modeling that are suitable for the collected condition data and the quality of the data have to be adequate. However, research shows that statistical assumptions are rarely fulfilled and analytical methods are dubious, which may lead to bad and directly wrong decision making. The project aims to analyze methods for condition monitoring and condition based maintenance planning of the railway facility from a statistical perspective. Studies on the versatility and precision of different models should be performed. The aim of the project is to design a system for assessing data from a quality perspective that helps to enable statistically based decision-making criteria for maintenance planning.
Duration: 2017-2021
Optimal methods for innovative product development and decision support (OptiKrea)

**Researchers:** Anna Malou Petersson, Matti Rantatalo & Jan Lundberg (PL)

**Sponsors:** Vossloh Nordic Switch Systems, Trafikverket/JVTC, Infranord

**Objective:** To generate a collaboration between managers, suppliers and maintenance contractors so that it drives the technical development of railway products, and especially turnouts, forward to achieve lower maintenance and life cycle costs as well as increased punctuality. The goal is to develop working methods facilitating innovation that are tailor made for the railway sector.

**Duration:** 2012-2017

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Top of rail—Reduction of damages in wheel/rail interaction

**Sponsor:** Trafikverket/JVTC

**Researchers:** Saad Ahmed Khan, Jan Lundberg (PL), Christer Stenström, Matti Rantatalo

**Goal:** To simulate and measure the effect of TOR friction modifier on the Swedish Railway regarding wear cracks and LCC.

**Project status and results:** The influence of Top of Rail lubricant on rail wear and fatigue are investigated by using simulations and field tests. The simulations are showing a huge potential regarding reduction of the wear and the fatigue but the field test showed that the effective lubricated distances is much lower than the distances promised by the friction modifier suppliers. This means that more way side lubricating machines than expected has to be used, resulting in too high maintenance costs of these apparatus compared with the savings due to less wear and cracks on the rail by using the friction modifier. A suitable solution seems to install the lubricating machines on the locomotives rather than using way side equipment.

**Duration:** 2015-2019

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Big data analytics for fault detection and its application in maintenance

**Sponsor:** Trafikverket/JVTC

**Researchers:** Liangwei Zhang, Janet Lin & Ramin Karim

**Objective:** This study aims to develop fault detection models and validate them using railway data. It will address the following challenges associated with the emerging Big Data in railway industry: high-dimensional data stream and nonlinearity. The study is based upon previous proposed model: the Angle-Based Subspace Anomaly Detection (ABSAD) approach. The scope of this research is to study unsupervised fault detection techniques and develop models for fault detection from high-dimensional data streams, and nonlinear data. The validation of these models will be mainly based on synthetic datasets, and the data generating mechanisms of these synthetic datasets would have been used in similar studies.

**Duration:** 2013-2017

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Harmonisation of asset management definitions and data quality assurance in rail transport

**Researcher:** Christer Stenström (PL)

**Sponsor:** Trafikverket

**Goal:** The objective is to harmonise Swedish-English asset management definitions and to apply SCB’s (Statistics Sweden) data quality framework on maintenance records of the Swedish rail infrastructure.

**Project status and results:** The project aims to harmonise Swedish-English asset management definitions and to assess operation and maintenance data quality within rail transportation. A prestudy was carried out on maintenance records of Trafikverket, to assess the benefit of maintenance inspections in terms of avoided failures in rail infrastructure. Results were positive, but due to uncertainties in data quality, the proposed method could not be recommended for implementation. Data quality issues concerned data bases, terminology usage and work order processes. With improved data quality control, data analysis and decision making processes can become more effective, which brings us to the project aim as stated above. The work includes SCB and Eurostat data quality frameworks.

**Duration:** 2016 – 2019

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Illustration of asset management.
Modelling and assessing the factors that affect human performance in railway maintenance

**Sponsor:** Lloyds Register Foundation

**Researchers:** Dr Arnab Majumdar, Imperial College; Dr Maria Mikela Chatzimichailidou, Prof. Leo van Dongen and Dr Alberto Martinetti, University of Twente and Ned Train, The Netherlands, Prasanna Illankoon, LTU

**Objective:** In the wheel crack detection process, improving human factors is of great importance because maintenance inspections are mainly based on operators’ experience especially in maintenance depots where there is no wayside detection system (e.g. Gotcha) or other monitoring systems to support humans in their decision-making. Therefore, there is a need to determine the factors that, either directly or indirectly, result in a decline in human performance, which in turn may lead to errors in wheel maintenance tasks (LTU).

In the Netherlands, the project partners from Imperial College (IC) will have access to a maintenance depot of Ned Train in Utrecht. In conjunction with the University of Twente, interviews with managerial personnel and maintenance technicians will also be conducted in order to verify the completeness of the process shown in Figure 1. At LTU the partners will collaborate with key research personnel to investigate the maintenance process for wheel cracks in Sweden, as well as the role of human factors.

Bayesian reliability modeling for railway infrastructure

**Sponsor:** Trafikverket/JVTC

**Researchers:** Janet Lin

**Objective:** This project aims to address the challenge in prolonging lifetime of railway assets by developing new context driven Bayesian maintenance approaches for prognostics and health management (PHM). The major drawback in current railway PHM is most studies are focusing on components’ level but not on system’s level or system of system’s level, which means valuable information can be lost; in particular, as maintenance context has changed. This new context driven Bayesian maintenance scenario will promote sustainable and cost-effective asset efficiency optimization in railway PHM and it will help us move closer to the ultimate goal of intelligent maintenance.

**Duration:** 2016-2018

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**Life length estimation of rolling stock**

**Sponsor:** Trafikverket/JVTC

**Researchers:** Behzad Ghodrati

**Objective:** Estimating the Remaining Useful Life of railway rolling stock.

**Project Description:** The term rolling stock originally referred to any vehicles that move on a railway. It usually includes both powered and unpowered vehicles, for example locomotives, railroad cars, coaches, and wagons. The rolling stock health condition is important for both passenger and freight trains in terms of safety, availability, punctuality and efficiency. The estimation and knowing the Remaining Useful Life (RUL) of rolling stock equipment is important and helps/leads to design, plan and perform various inspection and maintenance methodologies on these systems to fulfill the planned performance measures.

In this project different methods for RUL estimation are studied and classified in groups (e.g. Knowledge-based models, Life expectancy models, Artificial neural networks (ANN), and Physical models). Thereafter the best and applicable methods are selected and used in estimation of RUL of rolling stock used in Sweden railway.

The output of this project will be useful and used in the maintenance planning of rolling stock.

**Duration:** 2016-2018

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**ReRail the environmentally friendly rail:**

**Ultrasonic testing**

**Sponsor:** ReRail and Energimyndigheten (Swedish Energy Agency)

**Researchers:** Christer Stenstrom

**Objective:** The goal is to prove that ultrasonic inspection of rail with ReRail is feasible. ReRail replaces railway rails with a two part divided ditto, by milling the head on the worn-out or new rail and snapping on a new race plate in high-tensile steel on the milled rail. The objective of the ultrasonic testing of ReRail is to study the feasibility of inspecting the rail through the interface of the two components. The challenge is essentially a matter of finding a durable ReRail–rail-interface set-up that allows a sufficient large share of ultrasound energy to be transmitted through the interface.

**Duration:** 2017-2019

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Overall wheel crack detection process; adaptation from Palo et al (2013). (proposed by University of Twente & NedTrain).

The best network architecture for RUL prediction of the wheel set subsystem.

Flat-bottom echo amplitude as a function of ReRail interface clamping force.
Data processing method based on Genetic Algorithm for assuring maintenance

Researchers: Yamur Aldouri, Jan Lundberg (PL), Hussan Hamodi, Uday Kumar
Sponsor: JVTC
Goal: To investigate the prognostic capacity of Genetic Algorithms
Project status and results: Prognostics of maintenance costs for electrical fans owned by Trafikverket is performed by using Genetic algorithms. Comparisons of the prognostic accuracy with traditional trend equations based on historical cost data have been executed. So far the prognostic accuracy of the Genetic algorithms is in some cases outperforming the traditional methods. Other type of data will also be used as input to the Genetic Algorithms.
Duration: 2012-2022

Underground pipelines and railway infrastructure – Failure consequences and restrictions (PipeXrail)

Sponsor: Vinnova InfraSweden2030, JVTC
Researchers: Amir Garabaki (PL), Annelie Hedström, Jan Laue, Matti Rantatalo, Johan Odelius, Stefan Marklund, Adithya Thaduri
Goal: Understanding failure correlation between Pipeline and railway.
Project status and results: Swedish railway infrastructure has long been forced continuously to increase axial load and the total transported tonnage is expected to increase by 47% from year 2006 until 2050. Therefore, infrastructure health monitoring and upgrading is a necessary to have of robust transport infrastructure. PipeXrail study the interaction of underground pipelines and railway infrastructure and aim is to identify failure mode and failure consequences to the railway infrastructure and other related stakeholders. For data collection, a questionnaire has been distributed to the 291 municipalities and result 64% of expert have rail-pipe cross and 75% have road-pipe cross section failure experience in last 10 years. The results show the need for a tools/technique to support infrastructure manager to mitigate disruption.
Duration: 2015-2018

Condition Based Maintenance of Rail Infrastructure Using Internet of Things Loggers

Sponsor: Vinnova InfraSweden2030
Researchers: Christer Stenström (PL), Veronica Jägare, Matti Rantatalo
Goal: The goal of the project is to develop and demonstrate open source IoT data loggers for condition based maintenance of rail infrastructure.
Project status and results: Open source hardware and software means open innovation, as well as faster, cheaper and tailored designs. In addition, governments and companies can procure customized products from a large number of suppliers to a small product cost. Together with IoT cellular networks, those factors are key enablers for cost effective rail asset management. Hardware are based on for example MEMS (microelectromechanical systems) accelerometers. Field tests are carried out on in common crossings and on rail sleepers. The focus is on IoT solutions, usability, reliability and cost. The stakeholder group consist of LTU, Luleå Railway Research Center (JVTC), Trafikverket, Infranord, Vossloh, Sweco Rail, eMaintenance365 and Damill. Trafikverket hired student Jonas Lindqvist after doing thesis work within the project for continuation.
Duration: 2016-2018

Automatic detection of railway fasteners and track defects

Sponsor: Vinnova InfraSweden2030
Researchers: Matti Rantatalo
Objective: This project aims to automate the inspection of rail fasteners, defect insulation joints and other rail defects, using a robust system based on magnetic field variations measurement. The project will create value in the form of reduced time for maintenance inspections and increased information for maintenance decisions. The value mainly lies in: Fewer manual inspections, freeing capacity in the track; Increased number of automated inspections (also in winter time), providing increased security and better maintenance decisions. The project will develop algorithms to detect the anomalies or defects. The measurements will be performed on a specially built test track at LTU.
Duration: 2016-2018
Innovation projects

FricWear 2017
Sponsor: Trafikverket
Researcher: Jan Lundberg
Goal: To develop a measurement apparatus which can measure real friction and material wear on real rails for accurate rail life time simulation
Project status and results: The FricWear 2017 Tribometer is designed for measuring friction coefficients and wear constants both in the real field and in the laboratory. It is designed by Professor Jan Lundberg at the Division of Operation and Maintenance, Luleå University of Technology, Sweden, for pure research and basic education. It is specially designed for measuring friction coefficients and wear properties in railway applications but can also by advantage be used also for many other applications on wear and friction. By measuring in the real field, the important influence of the third body (moisture, dirt, water, snow, lubricant deposits, brake pad deposits, cargo deposits, and pollutions), etc., will be considered. For laboratory use it is also suitable for basic education regarding friction and wear. A patent on FricWear 2017 is accepted.

New breakthrough railway switch concept
Sponsor: Trafikverket
Researcher: Jan Lundberg
Jan Lundberg has in a project funded by Trafikverket developed a breakthrough concept of new switches. Four different approaches take care of a variation of possible root causes regarding the behavior of the turnout, resulting in 14 new turnout concepts and 7 new concepts for mechanical adjustment position in this perspective and a systematical method to achieve these concepts has been developed. Some of the new concepts are based on wishes of modularized thinking. The most promising concept is based on a stiff modularized system consisting of steel sleepers and a steel latticework.

ReRail
Sponsor: Vinnova, ePilot119, Energimyndigheten (Swedish Energy Agency)
Researcher: Anders Sundgren
The project ReRail previously sponsored by VINNOVA, has developed a new innovative concept to prolong the life of the existing worn out rail. The outcome from the project can help transport companies to meet CO2 emission target. The innovator is Anders Sundgren owner of Rerail AB. ReRail consists of a rolling format, modern hardened steel, which forms a wear surface. The hardened steel in ReRail is nearly twice as hard as normal rail steel. ReRail tread is about 10 mm thick and is mounted around the head of the original rail which is milled down when it is worn out and adapted to the tread of the internal form. Trafikverket together with LTU are testing and evaluating ReRail during 2015-19 in an operating and lab environment.
Duration: 2010 – 2019
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 is based on cross-organisational collaboration based on information logistics which ensures that maintenance is carried out in line with both the customers’ and the suppliers’ business objectives during the system’s whole lifecycle. There is a strong link between the infrastructure and the vehicles that use it. By using condition based data from across the railway sector and its stakeholders, a good basis is established, to make the right decision at the right time, and based on facts.

ePilot is based on an industry collaboration between infrastructure owners, railway companies, contractors, maintenance service providers, suppliers, consultants, innovators, and the Luleå Railway Research Center (JVTC). The Swedish Transport Administration (Trafikverket) initiated and funded the framework of ePilot, and supported the sub-projects. The purpose of creating a collaborative project was to get all stakeholders to jointly control the maintenance of the railway system to improve the reliability, robustness, and resilience of the railway system. The project ran between 2014-16 on track section 119 between Boden and Luleå. As the project was successful during the first three years, the work with the ePilot will continue on other parts of the network during 2017-19.

The ePilot focuses on:
- use an industry-wide process-oriented approach
- use an industry-wide service-oriented IT infrastructure that provides decision support based on condition data
- verify that ePilot methods and technology functions as decision support for maintenance contracts in the railway
- increase the number of questions that can be answered by increasing the number of providers of data, which can provide information to the answers
- increase the interest in ePilot practices and technology among entrepreneurs, industry, service providers and academia

The ePilot process for taking care of good ideas
Ideas that are aligned with the ePilot goals can be submitted to the ePilot website. The project idea is evaluated by a feasibility assessment team that consists of possible recipients of the results. The feasibility assessment team gives a recommendation to the project steering committee that decides if the idea is approved. If the idea is approved, the steering committee asks the parties for a complete project specification. The project specification is evaluated by the feasibility assessment team and recommendation to decision is submitted to the steering committee that decides on approval and possible project launch. After a project specification has been approved, the parties will sign a project agreement under the leadership of LTU. At this point, the project can start.

Results
In the ePilot-project, 26 sub-projects have been completed. Some results from the sub-projects are:
- A methodology for analyzing the condition of sections where an ePilot-project will be carried out
- Trend analysis of wheel degradation
- Evaluation of condition-based maintenance based on force measurements
- Evaluation if STEG can be used for a quality assured and integrated picture of the actual capacity utilization of the track
- Assessment if equivalent conicity can indicate the stability of the studied vehicles when it is put into service
- Track Logger as a continuous source of information for condition data
- Camera based surveillance and condition monitoring of switches
- A model for the implementation of infrastructure for data, information and knowledge exchange between railway stakeholders
- A cloud-based infrastructure that implements the model for the development of eMaintenance solutions
- Assessment if satellite measurements can be used for surface surveillance
- Support for monitoring of industry-wide key performance indicators
- Filming of infrastructure from the ordinary train
- Evaluation of speed reduction after wheel damage
- Automated detection of missing fasteners
- Method for assessing the condition of heat transfer functionality from the heater to the switches
- GIS-based risk inventory of railway lines
- Business models related to digital railways
- Implementation model for railway related innovations
Benefit analysis models for the projects
Documentation containing contractual forms and change proposals for governing regulations
Decision support for wheel maintenance

The ePilot aims to further develop the results of previous work focused on implementing a process-oriented approach across organization- and industry boundaries to improve operations. ePilot will among other things contribute to Trafikverket and other industry participants with concrete improvement projects.

**ePilot wins the Strukton Innovation Award**

The ePilot was awarded the Strukton Innovation Award during 2017 for the work on the vision of a punctual rail traffic, with proper maintenance measures at the right time.

– It’s honorable to get this award, it is a recognition from the industry for the effort we have made over the past four years. We have shown that cooperation is needed to succeed in the Swedish rail system. You cannot see tracks, infrastructure or rolling vehicles and equipment as separate devices. You need to get a consensus and an understanding of each other’s challenges - and this is what the project ePilot refers to. We see collaboration as a way to succeed in the rail system, says Ramin Karim, Professor of Operation and Maintenance at Luleå University of Technology.

The jury’s motivation for winning the award was as follows: With the vision of punctual rail traffic, with proper maintenance measures at the right time. JVTC at Luleå University of Technology runs the ePilot, a development and implementation project that fits perfectly in time. The society is moving fast and the ePilot is the experimental box that can give the industry the right tools to keep up. An idea catalyst for fast decision support that is both requested and that gives actual results.

– Within ePilot, we have been the engine in this, but the Swedish Transport Agency has been the fuel. The Swedish Transport Administration has believed in us and helped us throughout the project and this was very important, says Ramin Karim.
To achieve smooth implementation of new research and innovation, the railway stakeholders, e.g., infrastructure manager and railway industry, 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 to disseminate 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. Testbed Railway is powered and hosted by eMaintenance LAB. 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.

Today, the testbed covers two main track-sections (around 5,000 km railway), i.e. Malmbanan and Haparandaban. 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 w/o portable measuring equipment and two laboratories at LTU.

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 Service (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. Today, the physical sites of eMaintenance LAB, are located at the University in Luleå and in close collaboration with LKAB (the Swedish mining company) in Kiruna. These sites are designed and developed to facilitate hands-on experiences in eMaintenance research and innovation. The services provided by the lab 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.
eMaintenance LAB services are currently empowering a large number of national and international research projects. This includes industry and research partners from Slovenian, Spain, Italy, Germany, Norway, Finland, and USA.

**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 research projects with context-adapted services.

- Equipment for measuring friction on rail and wear resistance
- Equipment for measuring ultrasound, phased array and SAFT
- Water tank for measuring cracks with ultrasound
- Measurement trolley with winding current technology for detection of rail fasteners
- Level gauge for track position measurements
- Cracking gauge according to the resistance measurement method
- Track profile gauge and surface finometer
- Equipment for wireless transmission of measurement data from the railway

The JVTC Research Station is a measurement station to measure forces exerted by vehicles on the track. The mounting pattern of sensors at measurement point separates the vertical and lateral forces. The measurement station delivers real time data 24 hours a day, identifies trains and wagons, provide a top 10 list of poorly performing axels and internet access to real time data.

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.

eMaintenance 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.

**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.

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 friction modifiers to investigate the effect on eg. friction forces, wear and noise & vibrations.

In the Condition Based Maintenance Lab (CBM LAB) research and training in condition monitoring, experimental tests and product development is conducted. In the laboratory, which has a focus on condition monitoring of railway and mechanical equipment (gears, roller bearings, etc.) there are currently the following test gear and equipment:

- Test rig for condition control of cracks in gears
- Test rig for condition control of different sizes and types of gearboxes loaded with realistic torque and speed
- Test rig for testing rolling bearings where radial force is controlled via computer and where accelerations and temperatures are to be analyzed with smart algorithms

Outside CBMLAB, there is also a complete full-scale track switch mounted. It is 30 meters long and has been donated by the Swedish Transport Administration. The switch will initially be used to study point moter. Furthermore, there is also a 30 m long railroad track for detection of fasteners.
**February**

**ePilot result conference in Luleå, Solna and Borlänge**

The ePilot is a research and implementation project that develops railway maintenance. During 2014-16, the first collaborative project was executed at track section 119 between Boden and Luleå. In February 2017, three result conferences were held in Luleå, Solna and Borlänge with a total of 120 participants, where results from 23 completed sub-projects from 2014-16 were presented. Since the project has been successful within the first three years with relevant and implementable solutions, the work will continue during 2017-19 on other parts of the rail network.

**May and October**

**ePilot workshop Stockholm**

On May 4th, 40 participants from the railway industry met in Stockholm for a workshop within the project ePilot 2.0, to take the next step towards future rail maintenance. This will be done by implementing results that have emerged in the ePilot119 project. Topics discussed included the implementation of solutions for wheel-rail maintenance on Östkustbanan, development potential in regulations, agreements and business models, as well as the results from ePilot119. Participants were divided into groups discussing which areas of improvement should be prioritized, what conditions for successful rollout of digitization of the railway are needed, and which are the main obstacles to implementing new technology and new working methods in the railway industry.

On October 25th, 35 participants from the railway industry met in Stockholm to discuss the future's rail maintenance in ePilot 2.0. Topics discussed, included the implementation of condition-based maintenance of wheels, digital interaction and how this affects the railways and what Trafikverket does to open its operations through the project Reality Lab Digital Railway. The day ended with a discussion on “Future project ideas in collaboration”. Participants were divided into groups that identified improvement areas as well as proposals for projects within these areas.
September

World-leading train manufacturer seeks cooperation with LTU

The world’s leading high-speed train manufacturer CRRC, Beijing, China, has decided to establish a joint research center at LTU. Research at the joint research center at LTU would initially focus on PHM (Prognostics and Health Management) for high-speed rail. The research area PHM involves predicting future maintenance needs and predicting the condition of critical components by implementing solutions developed by the use of new and emerging transformative technologies, such as AI (Artificial Intelligence), ML (Machine Learning) and Big Data etc. By using advanced IT, PHM can contribute to smarter and more efficient operations and maintenance decisions. PHM can also ensure improved reliability and increased capacity throughout the rail system and high-speed rail. CRRC met during September with researchers from LTU.

September

Trainhack

JVTC acted as hosts to 48 system developers who arrived in Luleå with Trainhack - A train with good internet connection adapted for hacking on rails that travel on a 2,000 km long journey, while developing apps, IoT solutions and web services for public transport. JVTC took the opportunity to present its internationally-recognized railway maintenance research at the House of Science in Luleå. Dr Phillip Tretten, Division of Operation and Maintenance Engineering, Dr Peter Söderholm, Trafikverket and Jesper Westerberg, eMaintenance365, presented ongoing projects and future plans.
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.

Universities: Aalto University of Technology, Finland; Birmingham University, UK; Indian Institute of Technology (IIT) Bombay and Kharagpur, India; Kemi Tornio University of Applied Science, Finland; Queensland University of Technology, Brisbane, Australia; Tromsø University, Norway; University of Cincinnati, USA; University of Queensland, Australia; University of Stavanger, Norway; University of Toronto, Canada; VTT, Helsinki, Finland; University of Valencia, Spain; Imperial Collage, UK; University of Twente, NL; Tsinghua University, China; Beihang University, China; China Academy of Railway Sciences (CARS); Shanghai Jiaotong University; Southwest Jiaotong University.

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.

Professor Uday Kumar is a member of the Scientific Advisory Council of RAILENIUM – Technological Research Institute Government of France and French Rail Industries (www.railenium.eu)

JVTC are having close collaboration into the area of reliability engineering, operation and maintenance management with the faculty at IIT Bombay. In relation to this, Prof. A. K. Verma is a Guest Professor at the Division of Operation and Maintenance, Luleå University of Technology.

Professor Pra Murthy from the University of Queensland, Brisbane, Australia is a Guest Professor at the Division of Operation & Maintenance Engineering. He has been actively participating in teaching postgraduate courses and conducting workshops and seminars since the year 2009.

The Division of Operation and Maintenance and JVTC collaborates with NASA in the area of reliability engineering. In relation to this, Dr. Kai Goebel from NASA is a Guest Professor at the Division of Operation and Maintenance, Luleå University of Technology.

Professor Uday Kumar is an Honorary Professor at the Beijing Jiaotong University, which is celebrating its 120 the anniversary is a national key university, which is involved in Research and Innovation work for the railway industry especially for the high-speed trains and is equipped with many key railway laboratories. Prof. Kumar is also distinguished professor at Tsingua University.

JVTC also has a close collaboration and participates in research projects with the Technology Mission for Indian Railways (TMIR).
Doctorate & Licentiate Degree Awardees

Anna Malou Petersson
Title Doctorate Thesis: Collaborative conceptual design methods in the context of the Swedish deregulated railway market: From the perspectives of maintenance, infrastructure management, product provision, and research.
The overall aim of the research for this thesis was to develop an ideation method and a concept selection method specifically for groups acting in the context of the Swedish deregulated railway market, with members from different organizations with different functional knowledge. By means of action design research, the methods were developed within the scope of a research project involving four different actors on the Swedish railway market. The project group tested Method 635, the gallery method and the SIL method. Overall, the gallery method was most popular and the SIL method least popular among the participants. The developed concept selection method combines refined versions of the procedures for topic clarification, goal specification, requirement specification and concept screening developed by Pahl and Beitz with a concept scoring procedure based on the life cycle and societal costs associated with each concept that fulfils the stated requirements. The most important effect of the composition of the group was found to be the wide range of viewpoints on the topic at hand that the representative group of different relevant actors was able to provide.

Liangwei Zhang
Title Doctorate Thesis: Big Data Analytics for Fault Detection and its Application in Maintenance.
This research developed an Angle-based Subspace Anomaly Detection (ABSAD) approach to fault detection in high-dimensional data. The efficacy of the approach is demonstrated in analytical studies and numerical illustrations. Based on the sliding window strategy, the approach is extended to an online mode to detect faults in high-dimensional data streams. Experiments on synthetic datasets show the online extension can adapt to the time-varying behaviour of the monitored system and, hence, is applicable to dynamic fault detection. To deal with highly nonlinear data, the research proposes an Adaptive Kernel Density-based (Adaptive-KD) anomaly detection approach. Numerical illustrations show the approach’s superiority in terms of smoothness, effectiveness and robustness.


Conference Papers


Keynote


Bachelor Thesis


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<th>Project</th>
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</table>
| Maintenance decision support models for railway infrastructure using RAMS | Dr Alireza Ahmadi +46 920 3047  
PhD candidate  
Iman Soleimanmeigouni +46 920 493258 | Trafikverket/JVTC                | Active                         |
| Reduction of damages in wheel/rail interaction - Top of rail (ToR)      | Prof Jan Lundberg, +46 920-491748  
Dr Christer Stenström +46 920-491476  
Dr Matti Rantatalo +46 920-492124  
PhD candidate:  
Saad Ahmed Khan +46 920-491402 | Trafikverket/JVTC                | Active                         |
| Predictive analytics for degrading infrastructure                       | Prof Ramin Karim, +46 920-492344  
PhD candidate:  
Ravdeep Khour, +46 920-49 2898 | Trafikverket/JVTC                | Active                         |
| Anomaly detection and system diagnostics                               | Dr Matti Rantatalo +46 920-492124  
PhD candidate:  
Praneeth Chandran | Trafikverket/JVTC                | Active                         |
| Derailment risk assessment                                             | Prof Uday Kumar, +46 920-491826  
PhD candidate:  
Elahe Talebihaohoe | Trafikverket/JVTC                | Active                         |
| RAMS modeling and simulation at system level                           | Dr Alireza Ahmadi +46 920 3047  
PhD candidate:  
Hamid Khajehei | Trafikverket/JVTC                | Active                         |
| Optimal rail grinding                                                  | Prof Jan Lundberg, +46 920-491748  
PhD candidate:  
Rayendra Anandika | Trafikverket/JVTC                | Active                         |
| Methods for effective implementation of maintenance related railway innovations | Prof Jan Lundberg, +46 920-491748  
PhD candidate:  
Veronica Jägare, +46 920-491629 | Trafikverket/JVTC                | Active                         |
| MaintTrain                                                             | Prof Jan Lundberg, +46 920-491748  
PhD candidate:  
Thomas Nordmark, +46-920-493476 | LXAB                           | Active                         |
| Bayesian reliability modeling for railway infrastructure                | Dr Janet Lin, +46 920-49 1564     | Trafikverket/JVTC              | Active                         |
| Life length estimation of rolling stock                                | Dr Behzad Ghodrati, +46 920-491456 | Trafikverket/JVTC              | Active                         |
| Statistically based maintenance planning for railway                   | Prof Bjarno Bergquist +46-920-49 2137 | Trafikverket/JVTC              | Active                         |
| ePilot 2.0                                                             | Prof Ramin Karim, +46 920-492344  
Veronica Jägare, +46 920-491629 | Trafikverket/JVTC              | Active                         |
| Testbed Railway                                                        | Veronica Jägare, +46 920-491629   | Trafikverket/JVTC              | Active                         |
| ReRail the environmentally friendly rail – ultrasonic testing          | Dr Christer Stenström, +46 920-49 1476 | Trafikverket                  | Active                         |
| Harmonisation of asset management definitions and data quality assurance in rail transport | Dr Christer Stenström, +46 920-49 1476 | Trafikverket/JVTC              | Active                         |
| Analysis of rail wear for maintenance evaluation and improvement       | Dr Stephen Famurewa, +46 920-49 2375 | Trafikverket                  | Active                         |
| Prognostic for railway S&C geometry degradation                        | Dr Matti Rantatalo +46 920-492124  
PhD candidate:  
Madhav Mishra +46 920-49 2325 | SKF-UTC                       | Active                         |
<p>| Improve availability and reduced life cycle cost of track switches      | Prof Jan Lundberg, +46 920-491748 | Trafikverket                  | Active                         |
| Underground pipelines and railway infrastructure - Failure consequences and restrictions | Dr Amir Garabaki +46 920-49 | Vinnova InfraSweden 2030 | Active                         |
| Condition based maintenance of rail infrastructure using Internet if Things loggers | Dr Christer Stenström +46 920-491476 | Vinnova InfraSweden 2030 | Active                         |</p>
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<td>Automatic detection of railway fasteners and track defects</td>
<td>Dr Matti Rantatalo +46 920-492124</td>
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<td>Condition monitoring, prediction and management of railway track assets</td>
<td>Dr Matti Rantatalo +46 920-492124</td>
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<td>In2Rail</td>
<td>Prof Uday Kumar, +46 920-491826 Dr Matti Rantatalo +46 920-492124</td>
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<td>Prof Diego Galar +46 920-2437</td>
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<td>Optirail</td>
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<td>SAFT Inspect</td>
<td>Dr Matti Rantatalo +46 920-492124</td>
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<td>Increased railway infrastructure capacity through improved maintenance practices</td>
<td>Prof Uday Kumar, +46 920-491826 Dr Matti Rantatalo +46 920-492124 Stephen Famurewa +46 920-492375 2015 – Doctoral thesis Matthias Asplund +46 920-491062 2016 – Doctoral thesis</td>
<td>Trafikverket/JVTC</td>
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<td>ePilot119</td>
<td>Prof Ramin Karim, +46 920-492344 Veronica Jägare, +46 920-491629</td>
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<td>Big data analytics for fault detection and its application in maintenance</td>
<td>Prof Ramin Karim, +46 920-492344 Dr Janet Lin, +46 920-49 1564 PhD candidate: Liangwei Zhang, +46 920-491382</td>
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<td>Link and effect model application through life cycle cost and return of investment analysis</td>
<td>Dr Christer Stenström +46 920-491476</td>
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<td>Maintenance Thresholds</td>
<td>Prof Uday Kumar, +46 920-491826 Dr P-O Larsson-Kråk, +46 10-231884 Dr Iman Arastehkhoy +46 920-2071</td>
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<td>OptKrea - Optimala metoder för innovative produktutveckling och beslutsstöd</td>
<td>Prof Jan Lundberg, +46 920-491748 Anna Matou Petersson +46 920-491734 2017 – Doctoral thesis</td>
<td>Trafikverket/JVTC/ VosslohInfranord</td>
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<td>Solstormars påverkan på transportsystemet</td>
<td>Prof Uday Kumar +46 920-2437</td>
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<td>Winter preparation switches – failure consequences and restrictions</td>
<td>Per Norrbin +46 70-630 5248</td>
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<td>Railway infrastructure robustness, attributes, evaluation, assurance, and improvement</td>
<td>Dr Aditya Parida, +46 920-491437 PhD candidate: Per Norrbin +46 70-630 5248 2016 – Licentiate thesis</td>
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<td>DeCoTrack, Track degradation modelling and analysis related to change in railway traffic</td>
<td>Prof Uday Kumar, +46 920-491826 PhD candidate: Dan Larsson (Damll AB) 2004 - Licentiate Thesis</td>
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<td>Maintenance human factors ergonomics</td>
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<td>Investigation of end-user needs for eMaintenance on railway</td>
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<td>RAMS in signalling</td>
<td>Prof Uday Kumar, +46 920-491826 PhD candidate: Amparo Morant +46 920 2518 2015 – Doctoral Thesis</td>
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<td>ReRail</td>
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<td>Automain</td>
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<td>Bothnian Logistics Green Corridor, BGLC</td>
<td>Dr Ulla Juntti +46 920-491991</td>
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<td>NoRRTeC establish a Swedish-Norwegian research platform</td>
<td>Veronica Jägare, +46 920-491629 Dr Matti Rantatalo +46 920-492124</td>
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<td>Integrated reliability analysis for maintenance optimization</td>
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<td>Condition based maintenance for Vehicles</td>
<td>Prof Uday Kumar, +46 920-491826 Dr P-O Larsson-Krålåk +46 10 231884 PhD candidate: Mikael Palo, +46 920-492009 2012 – Licentiate Thesis 2014 – Doctoral Thesis</td>
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<td>From measurement to maintenance decision</td>
<td>Dr Häkan Schunnessson, +46 920-491696 PhD candidates: Mikael Palo, +46 920-492009 Iman Arastehkhouy, +46 920-492071</td>
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<td>Ergonomic analysis for railway vehicle maintenance and workshop facilities</td>
<td>Dr Rupesh Kumar, +46 920-491685</td>
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<td>Dynamic maintenance programme</td>
<td>Dr Ramin Karim, +46 920-492344</td>
<td>Trafikverket/JVTC</td>
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<td>Reliability analysis of switches and crossings</td>
<td>Dr Behzad Ghodrati, +46 920-491456</td>
<td>ALSTOM / Trafikverket</td>
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<tr>
<td>Development of a demonstrator for eMaintenance on railway</td>
<td>Dr Ramin Karim, +46 920-492344</td>
<td>Trafikverket/JVTC</td>
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<tr>
<td>Developing a method for the specification and selection criteria for technical systems and equipment</td>
<td>Prof Jan Lundberg, +46 920-491748</td>
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<td>RAMS and LCC in the planning phase</td>
<td>Dr Ulla Juntti +46 920-491991</td>
<td>Trafikverket/JVTC</td>
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<tr>
<td>Support vector machine (Demonstrator)</td>
<td>Dr Yuan Fuqing +46 920-49 1682</td>
<td>Trafikverket/JVTC</td>
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<tr>
<td>Detection of internal flaws in railway manganese crossings by using Synthetic Aperture Focus Technology (SAFT)</td>
<td>Dr Jan Lundberg, +46 920-491748</td>
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<tr>
<td>LCC and RAMS for railway vehicles</td>
<td>Prof Uday Kumar, +46 920-491826 PhD candidate: Ambika Patra 2007 - Licentiate Thesis</td>
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<tr>
<td>Maintenance decision support models for railway infrastructure using RAMS &amp;LCC Analyses</td>
<td>Prof Uday Kumar, +46 920-491826 PhD candidate: Ambika Patra 2009 - Doctoral Thesis</td>
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<tr>
<td>Risk based inspection intervals</td>
<td>Prof Uday Kumar, +46 920-491826 Dr Alineza Ahmadi, +46 920-493047</td>
<td>Trafikverket/LTU</td>
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<tr>
<td>Support Vector Machine (data mining) and demonstrator</td>
<td>Prof Uday Kumar, +46 920-491826 PhD candidate: Yuan Fuqing +46 920-49 1682 2011 - Doctoral Thesis</td>
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<td>Wear in crossings</td>
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<td>Technical specifications for crossings</td>
<td>Prof Jan Lundberg, +46 920-491748</td>
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<td>Ultrasonic measurements of internal cracks in manganese crossings</td>
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<td>Infrastructure winter ability analysis</td>
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<td>Maintenance performance indicators (MPis) for Swedish Rail Administration</td>
<td>Prof Uday Kumar, +46 920-491826 Dr Astiya Parida, +46 920-491437Thomas Åhren 2008 – Doctoral Thesis</td>
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<td>Design for/out maintenance</td>
<td>Prof Uday Kumar, +46 920-491826 Dr Håkan Schunnesson, +46 920-491696Stefan Nicka 2008 – Doctoral Thesis</td>
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<td>LCC analysis of railway switches and crossings (S&amp;C)</td>
<td>Prof Uday Kumar, +46 920-491826Arne Nissen 2009 – Doctoral Thesis</td>
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<td>Maintenance strategy for railway infrastructure</td>
<td>Prof Uday Kumar, +46 920-491826PhD candidate: Ulla Espling (Juntti) 2007 – Doctoral Thesis</td>
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<td>Condition based maintenance strategy for railway systems</td>
<td>Prof Uday Kumar, +46 920-491826PhD candidate: Robert Lagnebäck</td>
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<tr>
<td>Reliability analysis and cost modelling of degrading systems</td>
<td>Prof Uday Kumar, +46 920-491826PhD candidate: Saurabh Kumar 2008 – Doctoral Thesis</td>
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<td>Improved train punctuality through improvement in engineering systems</td>
<td>Prof Uday Kumar, +46 920-491826PhD candidate: Rikard Granstöm 2008 – Doctoral Thesis</td>
<td>Trafikverket, EU-structural funds</td>
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<tr>
<td>Improved punctuality through effective maintenance management</td>
<td>Prof Uday Kumar, +46 920-491826Per-Anders AkerstenPhD candidate: Birre Nystöm, 2008 – Doctoral Thesis</td>
<td>Trafikverket, EU-structural funds</td>
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**Department of Civil, Environmental and Natural resources engineering / Division of Structural and Fire Engineering**

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<th>Project</th>
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<td>Sustainable Bridges</td>
<td>Prof Lennart Elf gren, +46 920-491360</td>
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<td>Mainline</td>
<td>Prof Lennart Elf gren, +46 920-491360</td>
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<td>In2Rail/In2Track</td>
<td>Cosmin Popescu/Jonny Nilimaa/Björn Täljsten/Thomas Blamqvist/Lennart Elf gren</td>
<td>Shift2Rail/Horizon 2020</td>
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<td>Increased axle loads on railway bridges</td>
<td>Dr Thomas Blamqvist, +46 920-491642</td>
<td>LKAB/HLRC</td>
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<tr>
<td>Design performance</td>
<td>Dr Björn Täljsten, +46 920-493360</td>
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<tr>
<td>Assessment of bridge condition</td>
<td>Prof Lennart Elf gren, +46 920-491360 Ulf Ohlsson/Natalie Sabouroua +46 920-491853</td>
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<td>Assessment of Vindelälven bridge</td>
<td>Martin Nilsson, +46 920-492533</td>
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<td>Assessment of Längforsen bridge</td>
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<td>Sustainable renovation</td>
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<td>Kiruna mine bridge</td>
<td>Mats Emborg, +46 920-491348</td>
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<td>Rock mechanics consequences of fire in tunnels</td>
<td>Prof Erling Nordlund, +46 920-491335 PhD candidate: Kristina Larsson, + 46 920-492913</td>
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<tr>
<td>Structural sound</td>
<td>Prof Erling Nordlund, +46 920-491335 PhD candidate: Andreas Etzenberger + 46 920-492267</td>
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<tr>
<td>Deformation and failure of hard rock</td>
<td>Prof Erling Nordlund, +46 920-491335 PhD candidates: David Saiang, + 46 920-491053 Perez, Kelvis 2013 - Doctoral thesis</td>
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<tr>
<td>A pre-study on wheel/rail interface friction management</td>
<td>Dr Braham Prakash, +46 920-493055 Dr Jens Hardell, +46 920-491774</td>
<td>Trafikverket/JVTC/ LKAB</td>
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<tr>
<td>Surface roughness and rail grinding</td>
<td>Dr Jens Hardell +46 920-491 000</td>
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<td>Improved condition assessment through statistical analysis</td>
<td>Prof Bjarne Bergquist, +46 920-492137</td>
<td>Trafikverket/JVTC/ LKAB/Infranord</td>
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<td>Statistically based maintenance planning for railway</td>
<td>Prof Bjarne Bergquist, +46 920-492137</td>
<td>Trafikverket/JVTC</td>
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<tr>
<td>Teknikhistoria elektrifiering av Malmbanan</td>
<td>Roine Wiklund</td>
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Results

JVTC has successfully been expanding during the last 19 years. The financial turnover for 2017 was 35 MSEK.

<table>
<thead>
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<th>JVTC Management and Administration 2017</th>
<th>SEK</th>
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<tr>
<td>Membership fees</td>
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<td>Funding from JVTC framework</td>
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<td>TOTAL INCOME</td>
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<td>Salaries personnel</td>
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<td>RESULTS JVTC</td>
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<td>Total Turnover JVTC area of interest 2017</td>
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<td>JVTC projects LTU</td>
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<td>SUMMA</td>
<td>35 141 743</td>
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</table>

JVTC Contribution 2017

- Membership fees, 3%
- LKAB, 4%
- In Kind, 71%
- LTU, 5%
- Swedish transport Administration, 51%
- EU, 24%
- Companies, 2%

Turnover JVTC Year 2013-2017
JVTC
Board of Directors

Standing back row from left: Uday Kumar, LTU, JVTC director; Dan Larsson, Damill, JVTC member; Mikael Åstrand, Infranord, JVTC board; Knut Karlsen, BaneNor, JVTC Board; Dan Bergman, Duroc Rail, JVTC member; Anders Dalstål, eMaintenance365, JVTC member; Anna-Karin Ylivainio, LKAB, JVTC Board; Björn Svanberg, Sweco, JVTC Board;

Standing front row from left: Ulla Juntti, Omicold, JVTC member; Björn Lundwall, Vossloh, JVTC Board; Sven Ödeen, Trafikverket, chairman of the JVTC board; Lennart Elfgren, LTU, JVTC Board; PerOlof Olofsson, WSP, JVTC member.

Missing in the picture: Birgitta Olofsson, Tyréns, JVTC Board; Elisabet Kassfelt, LTU, JVTC Board; Susanne Rymell, SJ, JVTC Board.

Contact:
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