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Frontpage photo: Thomas Nordmark
2018 was a successful year for JVTC. No less than 34 interesting research projects have been carried out within the railway sector and JVTC has participated in six EU research programmes. Furthermore, the targets the board set for 2018 have, with few exceptions, been achieved. JVTC has been covered by media both locally, nationally and internationally.

JVTC continues to be well positioned with its programs for Dependability, Information logistics, Condition monitoring and Effective maintenance execution. These are all areas where the development is accelerating with commercial development and commercial products being launched at an increasing pace. This requires a research centre like JVTC to be even more on its toes and even more curious about what is coming around the next corner. That is challenging and I think JVTC stands up to that challenge.

For the railway sector a development towards a more automated condition monitoring and more digitalised processes are cornerstones for survival and future success. A successful railway sector is an important piece in the jigsaw puzzle to meet the challenges of the entire society. It all links together and JVTC is and will continue to be an important link in that chain.

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 2019
“Our current focus on application of AI, and advanced data science in our research and innovation projects has yielded positive results for our project portfolio….”

A key challenge for the modern day railway sector is to ensure a safe, reliable, punctual and cost effective mode of transport system for passengers and goods. This necessitates step changes leading to all round transformation in operation and maintenance culture prevalent in the railway sector. To achieve step changes in maintenance process and performance, there is a spoken need for implementation and exploitation of the new transformative technologies and solutions in day to day maintenance activities.

We are excited to be starting a new chapter in our R&D activities with in depth applications of advanced data science, Big Data analytics, machine learning, applications of drone technology, robotics, etc. to facilitate implementation of state of the art maintenance technologies in most of our research and innovation projects. Our current focus on the use of AI, and advanced data science in our research and innovation projects has yielded positive results for our project portfolio. The journey towards this goal seems much easier now with all round effort by the railway sector to adopt digital technologies and solutions for transforming operation and maintenance of railway assets. Our research and innovation platform is fully integrated to meet the challenges of a new generation of railway systems.

Furthermore, as in the past our efforts are also directed towards creating a strong and responsive research 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 Trafikverket (the Swedish Transport Administration) and EU Framework Programme apart from attracting international companies looking for innovative maintenance solutions.

JVTC was established during the year 1998 and we celebrated the 20th anniversary on Sept 6. The celebrations were marked by a workshop on future of railway maintenance. Even though the center 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 members of the Board of JVTC, the management of Luleå University of Technology, my colleagues at the University for their guidance and support to the management team throughout the year.

Finally, I also wish to thank the members of 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 2018.

Professor Uday Kumar, Director
February 06, 2019
R&I at JVTC
Luleå Railway Research Center

Järnvägstekniskt centrum (JVTC) was formally established in 1998 and has during the last 20 years, built up a research and innovation program adopting a distinctive multidisciplinary approach to meet short-term and long-term challenges faced by the operation and maintenance engineers of the railway sector.

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

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

The center has built up world-class competence in the areas of 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 that provide 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 Professor 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
- Norut Teknologi
- Omicold
- Outflight
- 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 together with a number of interested companies in 1998 with support from Lulea Growth Academy, in order to make the area of heavy rail transports in cold climate (Tunga Transporter I Kallt Klimat, T2K2) and mixed traffic more efficient. During the autumn of 2000 the research was focused on 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 iron ore line to 30 tons axle load.

Sustainable bridges

A European research project initiated by Construction Technology was a so-called integrated project, submitted in April 2004. The 4-year project started 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 rail when the train passes. Measurement data are now transferred to the eMaintenance LAB, established 2011. This was the first step in creating a Testbed for Railway.
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.

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

Supportive technologies and solutions are being utilized together with strong domain knowledge, in order to build optimizing technologies and solutions for operation and maintenance. By applying transformative technologies, the aim is to ensure increased availability, capacity, safety and sustainability of the railway system. Areas included in the JVTC R&I Programs has the objective of finding answers to the main research question: How to estimate the remaining useful life of railway components and systems in a specific operating condition?
**Key research and innovation programs:**

<table>
<thead>
<tr>
<th>Condition monitoring and CBM</th>
<th>RAMS⁴</th>
<th>Asset management, Risk and Human Factors</th>
<th>eMaintenance</th>
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<tr>
<td>Context based diagnostics and prognostics</td>
<td>Dependability</td>
<td>Asset maintenance organization and strategy</td>
<td>Big Data analytics</td>
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<td>Threshold limits</td>
<td>LCC</td>
<td>Asset Performance Measurements and management</td>
<td>Cloud-computing and data mining</td>
</tr>
<tr>
<td>Modeling of track geometry</td>
<td>Risk analysis and modeling</td>
<td>LCC and LCP for asset management</td>
<td>Distributed computing</td>
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<td>Wear and friction control</td>
<td>Big Data mining</td>
<td>Maintenance workflow optimization</td>
<td>Crowd-computing</td>
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<tr>
<td>Component improvements</td>
<td>Maintenance optimization and modeling</td>
<td>Maintenance process and procedure analysis</td>
<td>Information logistics</td>
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<td>Grinding optimization</td>
<td>Design for reliability and maintainability</td>
<td>Maintenance contracts</td>
<td>Data integration, fusion and processing</td>
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<td>Condition monitoring techniques and strategies</td>
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<td>Models for evaluating and implementing new knowledge</td>
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<td>Sensor technologies</td>
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<tr>
<td>Demonstrator for testing on rail</td>
<td></td>
<td>Human Factors /Ergonomics for risk management</td>
<td>eMaintenance railway demonstrator</td>
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*Figure. JVTC Research and innovation framework.*
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 and Safety) characteristics for a railway system can be described as the confidence with which it can guarantee the achievement of an agreed volume of traffic with defined quality in a given period. With an increase in performance demands from governments, infrastructure managers and train operators are under pressure, to enhance the RAMS characteristics of their operating systems. As a result, 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 factors in maintenance management for the railway infrastructure is gaining more acceptance. Human errors play a vital role in safety of rail infrastructure. Issues like, man-machine-machine interface coupled with ergonomics is compelling the rail infrastructure managers to look for innovative solutions. Factors like, increased capacity, reliability and availability of the rail infrastructure require knowledge and skill enhancement support. The human factors related projects focus on the increased capacity of the existing railway infrastructure through effective and efficient maintenance processes. The overall purpose of this part of the program is to help the Swedish railway sector to increase their competitiveness by improving maintenance work processes, safety and the reduction of human error/or failure during maintenance activities through the implementation of human factors principles. The fundamental goal of the human factor is that all tools, devices, equipment, machines, and environments should advance, directly or indirectly, the safety, well-being, and performance of humans.
The eMaintenance Research Programme (eMRP) enables Operational Excellence by empowering operation and maintenance with Artificial Intelligence. eMRP focuses on research and innovations that augment the decision-making processes in industrial contexts through enhanced analytics. In eMRP, frameworks, approaches, methodologies, technologies, and tools such as Industrial Artificial Intelligence (IAI), 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 achieve excellence in research and innovation. Our research approach is built upon the understanding of the concept of system-of-systems and considers systems’ whole lifecycle. This to create a holistic system-thinking in our research process, and also enhance the practical implications of our research findings.

The overarching objective of the eMaintenance Research Programme (eMRP) is to enable industry to achieve operation excellence. This through a) conduct a multi-disciplinary applied research in maintenance analytics; b) develop and provide an appropriate education platform in eMaintenance; c) establish an innovation process which supports implementation of research outcomes to real-world applications.

eMRP focuses on topics which reflect issues and challenges within industry and academia. Some of these topics are: Industrial Artificial Intelligence (IAI), Machine Learning (ML), Deep Learning (DL), eXplainable AI (XAI), service-oriented and event-oriented approaches, digitalisation, IoT and IIoT, Big Data Analytics, cloud-computing, distributed computing, crowd-computing, information logistics, data integration, data fusion, data processing, data visualisation, and context adaptation.

The programme also aims to design, develop, and provide artefacts based on edge technology to demonstrate proof-of-concept within the aforementioned topics. The main objective of these demonstrators are to validate academic outcome in industrial contexts. To achieve this, EMRP collaborate with eMaintenance LAB.

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

In addition, EMRP has initiated the International Workshop and Congress in eMaintenance, which is the first and only conference in this discipline. EMRP has been hosting the conferences since 2010, in cooperation with the partners from industry and academia. The conferences have been a forum for fruitful knowledge-sharing between industry and academia.
At present, under the JVTC platform, seven H2020 EU-projects within Shift2Rail are running during 2018: IN2RAIL, INFRAALERT, IN2SMART, IN2TRACK, FR8RAIL, SMArT and FR8RAIL II. The descriptions of stated EU projects are given below.

**IN²RAIL**

Sponsors: EU, H2020, SHIFT2RAIL, Trafikverket
Researchers: Matti Rantatalo, Stephen Famureva, Iman Arasteh Khuy, Johan Odelius, Christer Stenström, Aditya Thaduri, Johan Odelius, Lennart Elfgren, Jonny Nilimaa, Björn Tältsten

**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 manage-
### INFRALERT

**Sponsors:** EU, H2020, SHIFT2RAIL, Trafikverket  
**Researchers:** Johan Odelius (PL), Adithya Thaduri, Stephen Famurewa, Amir Garma-baki  
**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 land transport network infrastructure performance and adapt its capacity to meet growing needs by:  

1. ensuring the transport infrastructure operability by optimising network functionality under traffic disruptions  
2. 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  
3. 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 measurements 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](http://infralert.eu/)  

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 eMS performance, a baseline case is defined covering necessary aspects required to evaluate INFRALERT’s goals. External Key Performance Indicator (KPIs) such as asset utilisation, service quality and financial effectiveness will be used for comparison of the baseline condition and the asset condition.  

**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:  

1. 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.  
2. 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.  
3. 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 interventional 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:** 2016-2019
IN2TRACK

Sponsors: EU, H2020, SHIFT2RAIL, Trafikverket
Researchers: Cosmin Popescu, Björn Tålstén, Lennart Elf gren
Objective: The main objective of IN2TRACK project is to set the founda- tions 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

FR8RAIL II

Sponsors: EU, H2020, SHIFT2RAIL
Researchers: Matti Rantatalo (PL)
Objective: Within the challenges highlighted in the IP5 part of the S2R Master Plan, FR8RAIL II further focuses on improving the freight eco system by addressing various challenges: New automatic couplers (1), provided with electrical and data transmission functionalities will massively improve the efficiency of the train composition process, new telematics and electrification (2) will enable Condition Based Maintenance (CBM) by collecting, transmitting and using the necessary information while being supplied with the required energy by means of an advanced energy management system. Improved methods for annual and short-term timetable planning (3) will help traffic operators increasing the overall capacity and raise punctuality and with Real-time network management (4), integrating medium to short-term and operational planning at yards/terminals and in the railway network, inefficiencies will be further reduced or even eliminated. Future freight wagon design (5) is a stream that will contribute in improving reliability of the freight transport while increasing the payload per meter of train. The latter one will be propelled by future main line electric freight locomotives featuring highly flexible freight propulsion (6) systems with reduced operational costs. Furthermore, these new freight trains will be propelled by more than one locomotive running with distributed power (7), thus allowing long freight trains up to 1,500 m. Last but not least, focus is given to driver advisory systems that are connected (C-DAS) to the traffic management systems (8), further enhancing capacity, improving punctuality and optimize energy consumption of the railway system. The objective of the FR8RAIL II project is to further develop technologies relevant for the rail freight sector to reach the goal highlighted in the S2R Master Plan. LTU focuses on WP2 Interoperable Wagon Intelligence.

Duration: 2018-2020
There are about 23 R&I projects in progress within the center related to maintenance and the railway system.

RAMS/LCC for railway track geometry
Sponsor: Trafikverket/JVTC
Researchers: Alireza Ahmadi (PL), Iman Soleimanneigouni
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 goal of railway infrastructure managers is to keep the RAMS parameters of railway system within acceptable limits at lowest possible cost. An efficient an effective way of achieving this goal is to employ applicable and effective maintenance strategy. 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: 2017-2021

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 were 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

Condition monitoring
Researchers: Praneeth Chandran, Matti Rantatalo (PL)
Sponsor: Trafikverket/JVTC
Objective: The goal is to develop a train based system for monitoring track defects and rail track components. With the extension of high-speed railway network, the major challenge lies in reducing these operation and maintenance costs while augmenting the capacity of the rail network. In order to lower maintenance costs, enhance safety and increase track capacity, railroad companies are laying more emphasis on substituting the current manual inspection process with automatic inspection system for more efficient, effective and objective inspections. Machine vision has been gradually adopted by the railway industry as a track inspection technology, however these automated visual inspection techniques are relatively an expensive technique to carry out, especially for long-term projects and long distance measurements. Automated visual inspection becomes a challenge when, the rail and the fasteners is obscured due to dust coverage, surface erosion, rusting or covered under snow or other debris. Further, visual based sensors are found difficult to mount on an in-service train as they are affected by brightness fluctuation and motion blurring during the travel. Therefore, an effective and sophisticated alternative approach for inspection needs to be explored.
Duration: 2017-2021
**Rams Modeling and Simulation at System Level**

**Researchers:** Hamid Khajehei, Alireza Ahmadi (PL), Uday Kumar (PL)

**Sponsor:** Trafikverket/JVTC

**Goal:** The main aim of the project is to provide a railway track maintenance planning framework which assist infrastructure managers in decision making. Project status and results: 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

**Duration:** 2017-2021

![Figure 1. Railway track geometry quality over time](image)

**Predictive Analytics for Degrading Infrastructure**

**Researchers:** Ramin Karim (PL), Ravdeep Kour

**Sponsor:** Trafikverket/JVTC

**Goal:** The objective of this research is to develop a holistic cybersecurity framework for Railway system to ensure data confidentiality, integrity and availability of information. With the adoption of Information and Communications Technologies (ICT) in railway maintenance, vulnerability to cyber threats has increased. It is essential that organizations should 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 evaluate the maturity level of cybersecurity capabilities within different domains of railway organizations and then develop a holistic cybersecurity framework to ensure its security. 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, maintainability, availability, etc. (figure 1).

**Duration:** 2017-2019

![Figure 1. Cybersecurity challenges and their impact on railway systems](image)

**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

**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

Simulation of railway track geometry and intelligent maintenance planning SIMTRACK

Researchers: Alireza Ahmadi (PL), Arne Nissen (PL Trafikverket), Adithya Thaduri, Iman Soleimanmeigouni, Hamid Khajei
Sponsor: Trafikverket
Goal: To develop decision support methodologies and tools for the optimization 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 realisation 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 6 work packages. WP1 deals with the project management. WP2 presents the industrial scenarios, specifications and requirements that provide inputs to WP3 to WP5 respectively defined as predictive modelling and analytics, track maintenance optimization and decision support system and, absolute track geometry condition evaluation for maintenance intervention. WP6 deals with dissemination and exploitation, is devoted for formulating comprehensive plans for results assimilation by the partners and set the ground for the exploitation. Following the project plan, WP2 is completed and the Industrial scenarios, specifications & requirements of each work package and associated tasks have been analyzed and documented. As part of WP3, a set of degradation model have been developed to assess the probability of isolated defect at line level. In addition, a simulation-based optimization approach has been developed for allocation of an effective maintenance limit for track geometry maintenance.
Duration: 2017-2020

Condition monitoring, prediction and management of railway track assets

Sponsor: Vinnova InfraSweden2030
Researchers: Matti Rantatalo
Objective: In a project financed by InfraSweden2030 issues related to track maintenance in the regional commuter network and subway network in Stockholm is addressed. The aim of the project is to improve the infrastructure manager’s possibility to implement a predictive maintenance strategy. The project has mainly focused on measurement technologies of track properties, mounted on a two-way measurement vehicle. Methods and investigations related to laser scanning of rail profiles and ultrasonic inspection of subsurface cracks has been performed as well as a predictive approach based on data and physical model.
Duration: 2016-2018
Non-destructive Testing of Surface Defect in Railhead

Researchers: Rayendra Anandika, Jan Lundberg (PL), Christer Stenström, Matti Rantatalo

Sponsor: Trafikverket/JVTC

Goal: To develop an accurate condition monitoring tools to be decision support for rail track maintenance actions.

Projects status and results: Phased array ultrasonic testing (PAUT) has been employed to inspect surface cracks in railhead and has been able to measure 2.65 mm depth of real rail surface crack with 17 % accuracy. The measurement was verified by slicing the railhead into thin pieces with a thickness of 0.65 mm. There were surface crack marks at each of these pieces. These sliced rail pieces then were photographed in a way so that the crack marks from all of the pieces can be reconstructed into a 3D image reconstruction of surface crack. This reconstructed image shows a network of surface crack path underneath the rail surface. From the comparison between this image and PAUT, it seems that PAUT is accurate to be used for estimating the crack depth and the crack profile. Furthermore, to increase the accuracy of PAUT, SAFT post-processing method will also be performed.

Duration: 2017-2021

Figure 1. 3D image reconstruction of a surface crack in a railhead (unit in mm).

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

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

Researcher: Christer Stenström (PL)

Sponsor: Trafikverket FUD

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

Figure 1. Illustration of asset management.
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
**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

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**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 have 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. During the course of PipeXrail study, we challenged with poor availability and quality of data for the buried pipeline in an urban area due to the old pipeline network structure and its connected facilities. Hence, there is a need to use new condition monitoring tools in terms of hardware such as sensor-based technologies, software & data management tools. In addition, implementation and utilization of digitalization and artificial intelligence (AI) techniques can convert the current pipeline/infrastructure maintenance engineering to smart infrastructure maintenance.  
**Duration:** 2015-2018

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**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:** The goal of the project is to develop and demonstrate low cost open source IoT data loggers for condition based maintenance of rail infrastructure. In this project, we design data loggers for monitoring railways, which cost one-tenth of conventional measurement systems, with equaler performance, and are smaller in size and based on open hardware and software. The stakeholder group consist of LTU, JVTC, Trafikverket, Infranord, Vossloh, Sweco Rail, eMaintenance365 and Damill. Report ISBN: 978-91-7790-265-2.  
**Duration:** 2016-2018

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**Data processing method based on Genetic Algorithm for assured 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 owns 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
Train Based Differential Eddy Current Sensor System for Rail Fastener Detection

Researchers: Praneeth Chandran, Matti Rantatalo, Johan Odelius, Uday Kumar, Jan Lundberg
Sponsor: Trafikverket/JVTC, INFRASWEDEN, IN2SMART

Objective: In view of mobilisation and transportation of people and commodity, rail transportation plays a significant role. In addition, it forms a major contributing factor in economic and industrial development of a nation. The railway infrastructure has a huge investment and with approximately 15-25 billion per year spent on railway asset maintenance, maintenance managers are striving to cut maintenance costs through effective condition based maintenance. Often railway track issues are responsible for nearly half of all delays to passenger, mainly due to the downtime arising from railway track maintenance and renewal of network. With the extension of high-speed railway network, the major challenge lies in reducing these operation and maintenance costs while augmenting the capacity of the rail network. In order to lower maintenance costs, enhance safety and increase track capacity, railroad companies are laying more emphasis on substituting the current manual inspection process with automatic inspection system for more efficient, effective and objective inspections. Machine vision has been gradually adopted by the railway industry as a track inspection technology, however these automated visual inspection techniques are relatively an expensive technique to carry out. Automated visual inspection becomes a challenge when the rail and the fasteners is obscured due to dust coverage, surface erosion, rusting or covered under snow or other debris. Further, visual based sensors are found difficult to mount and maintain on an in-service trains as they are integrated in the operation and effected by brightness fluctuation and motion blurring during the travel.

Therefore, an effective and sophisticated alternative approach for fastener inspection needs to be explored. This Project will use the concept of Eddy current based inspection method, that can overcome the major challenges mentioned above. The main goal of this project is to develop a train based system for monitoring track defects and rail track components by anomaly detection in the modulated magnetic field, generated and measured by a differential eddy current sensor. The following figure shows the field test pattern carried out to detect missing clamps within a fastener signature. The clamp was removed, from the outer part of the rail at the 20th sleeper, from the inner part at 25th sleeper and from both inner and outer part at the 30th sleeper, after the start of the measurement.

Duration: 2017-2021

Derailment risk assessment

Researchers: Elahe Talebhaoonie, 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 propose a practical framework to predict derailment likelihood based on mechanical simulation and track geometry historical data. The simulation will be performed in real time. Wheel flange climb and gauge widening and rail rollover are the two causes that will be assessed in this project.

Movable cellular automata (MCA) is the selected approach for the mechanical simulation of ballast, rail, sleepers and fasteners. The code of MCA will be developed in GPU to have a faster and more efficient simulation. The MCA is a method in computational solid mechanics based on the discrete concept. It provides advantages both of classical cellular automaton and discrete element methods.

1 km of railway will be simulated. With considering the ballast size as 38 mm and 1000×2×0.5 m as the dimension of the substructure, then 37×10^6 particles in the ballast and around 40×10^6 in total (also considering superstructure elements like rail, sleeper, fastening system, and weld) will be simulated in 1 km of railway. After performing the simulation, the transition rules in the MCA will be calibrated based on the historical data of track geometry.

Duration: 2017-2021
Patent SE 540 066 C2 Wear constant measurement apparatus for computer simulation of rail and wheel wear.

**Researcher:** Jan Lundberg

A completely new compact handheld measuring apparatus which in an unusually simple way, in reality direct on the railroad in the field, can measure both friction and wear values for the railroad is developed. The measurements with the apparatus take into account that there are always grease residues, moisture and other deposits on the railway, which greatly affect the measurement readings. Thus more realistic data for wear, crack and maintenance simulations will be achieved. The apparatus is adjustable for all types of rail dimensions and wear levels and for different axle loads. This leads to new opportunities for significantly better and more realistic input to simulation programs that researchers can use to predict the need for maintenance of rails and wheels, as well as to simulate safety as regards to braking distances, se Figure 1.

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Patent SE 540 419 C2 Transition zone for railway

**Researcher:** Jan Lundberg

This device aims to reduce damages on rail and rail vehicles because of sudden stiffness changes in the ground between ballasted and not ballasted rails. The design should be possible to tamp and will gradually increase the stiffness inside the transition zone, in order to reduced forces due to sudden impacts, se figure below.

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Patent SE 540 652 C2 Transition zone Cross type for railway

**Researcher:** Jan Lundberg

This device also aims to reduce damages on rail and rail vehicles because of sudden stiffness changes in the ground between ballasted and not ballasted rails. Also this design should be possible to tamp and will gradually increase the stiffness inside the transition zone, in order to reduced forces due to sudden impacts, se figure below.
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 continue on other parts of the network during 2017-19.

The ePILOT focuses on:
- using an industry-wide process-oriented approach
- using an industry-wide service-oriented IT infrastructure that provides decision support based on condition data
- verifying that ePILOT methods and technology functions as decision support for maintenance contracts in the railway
- increasing the number of questions that can be answered by increasing the number of providers of data, which can provide information to the answers
- increasing 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, 29 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
- Governance of railway data
- A national strategy for “Mesuring station Sweden”

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 collaboration partners

![List of collaboration partners images]
ePilot wins the Strukton Innovation Award

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.

**The ePilot support team at LTU:** Veronica Jägare, Project Leader, Ramin Karim, Responsible Information Logistics; Ulla Juntti, Process Manager; Cecilia Glover, Project Controller and Alexandra Lund Cipolla, Project Administrator.

At the award ceremony: Veronica Jägare, Ulla Juntti and Ramin Karim.
Currently, the railway system needs to embrace and get the best out of new technologies, innovations, and implementation of research results in a day-to-day management. However, it is highly important to address and study the implementation of new technologies and new innovative solutions at the outset, results in lower than expected benefit or lot of expenses for little benefit to the stakeholders in terms of capacity and reliability.

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 wayside and 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 Services (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). The integrated services can smoothly be adapted to the context of different stakeholders, applications, and industries.

Today, the eMaintenance LAB offers artefacts based on technologies, methodologies, and approaches such as Artificial Intelligence, Machine Learning, Big Data, Cloud computing, Edge computing, and cyber security. The lab supports research and innovation (R&I) projects in aviation, mining, railway, energy, and process industry. To support a wide range of R&I projects and initiatives, the lab provides a combination of physical and virtual sites.

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. Devices for detecting missing railway fasteners, laser-based rail profile measurement equipment, devices for measurement of vibrations, temperature, vertical position of rail, railway roughness, friction coefficients on rail, wear constants in railway applications etc.

Condition Based Maintenance Lab (CBM Lab)

CBM Lab is our new and rapidly expanding facility for supporting researchers, PhD students and basic education students regarding condition monitoring, experimental tests and product development. The main focus is railway related research but also other types of projects are supported. On-going research and development projects that are supported are for instance:

- Life time of rolling bearings with initial defects, using neural network
- Point machinery for railway switches
- Machine component failure predictions
- Ultrasonic measurements of near surface cracks on rails
- Top of rail lubrication
- Detecting missing railway fasteners

CBM Lab have access to advanced measurement devices such as ultrasonic equipment, devices for detecting missing railway fasteners, laser-based rail profile measurement equipment, devices for measurement of vibrations, temperature, vertical position of rail, railway roughness, friction coefficients on rail, wear constants in railway applications etc.

CBM Lab have during 2018 achieved a top modern Bombardier point machine, ready for digitalization and smart algorithm adaption to the future 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, provides a top 10 list of poorly performing axles 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.

At LTU, 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 motor. Furthermore, there is also a 30 m long railroad track for detection of fasteners.
International Railway Research Collaboration & Network

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

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

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

We have started a collaboration with GE Global Research and Dr. Abhinav Saxena, managing data scientist, GE, is adjunct professor at LTU. The division and JVTC collaborates with NASA in the area of reliability engineering. In relation to this, Dr. Kai Goebel became an Adjunct Professor at the Division of Operation and Maintenance, Luleå University of Technology.

Furthermore, JVTC collaborates in the maintenance area with The Center for Intelligent Maintenance Systems (IMS) at University of Cincinnati, USA, where Professor Uday Kumar is a guest professor. Professor Jay Lee, Director of IMS is a guest professor at LTU.

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

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

Juhamatti Saari
Title Doctorate Thesis: Machinery diagnostic techniques for maintenance optimization

This doctoral thesis addresses the need to prepare for the internet of things by developing diagnostic tools where manual work is minimized by using smart algorithms. Framework presented in this study addresses issues on how to tune diagnostic techniques by selecting the appropriate criticality of the system together with considering the operation context by separating the data into individual operating classes. Machinery diagnostic and prognostic techniques for data driven approach

This research studied how a one-class SVM can be optimized by tuning the algorithm to function properly by taking the criticality of the system into consideration. Another topic dealt with was how a one-class SVM can be used for identifying the location of faults by carefully selecting proper input features. Furthermore, a method was tested where a variational Bayesian for Gaussian mixture algorithm was used for preprocessing and separating the condition monitoring data into operation mode classes. Later these classes can be used for improving the time for acquiring the condition monitoring data or to give more information as to how prognostic algorithms should be selected. In addition, a method was tested which involved the use of a Random Forest for feature selection and for the creation of indifference to load or other similar external factors by comparing separate classes with each other. Overall, the idea is that all of these techniques can be combined and merged in order to improve machinery diagnostic tools and prepare for the coming era of digitalization.

Madhav Mishra
Title Doctorate Thesis: Prognostics and Health Management of Engineering Systems for Operation and Maintenance Optimisation.

This PhD thesis focuses especially on Prognostics and Health Management of Engineering Systems for Operation and Maintenance Optimisation. Prognostics and health management (PHM) is an engineering discipline that aims to maintain system behaviour and function and ensure mission success, safety and effectiveness. Prognostics is defined as the estimation of remaining useful life. It is the most critical part of this process and is a key feature of maintenance strategies since the estimation of the remaining useful life (RUL) is essential to avoiding unscheduled maintenance.

Prognostics is relatively immature compared to diagnostics, and a challenging task facing the research community is to overcome some of the major barriers to the application of PHM technologies to real-world industrial systems. This thesis presents research into methods for addressing these challenges for industrial applications. The thesis work focuses on prognostic approaches for three different engineering systems with different characteristics in terms of the prognostics of operation and maintenance aspects. The aim of this thesis is to facilitate better operation and maintenance decision making. The main benefits of prognostics are in anticipating future failures to increase uptime, implementing dynamic maintenance planning toward decreasing total costs and decreasing energy consumption. Therefore, there is a need for methods that can be used in these cases to classify the health states and predict the remaining useful life of assets. The studied engineered systems in this thesis are railway tracks, batteries and rolling element bearings.
Publications

Journals Papers


Technical reports

4. ePilot:
   a. eP20-201-2017-Projektrapport - Modeller för samverkan, innovation, implementering, avtal och affärsmodeller (SIIAA)
   c. eP20-204-Projektrapport - Nuågesanalys

Bachelor Thesis

Keynote/Invited speech

Kumar, U. Transformative Technologies and Solutions for the future Mining Systems 2030, International seminar on “Minerals and Metals outlook” on 9th-10th October 2018, New Delhi, India.

Kumar, U. New Technologies Empowered Industrial Asset Management: Research Priorities and Future Directions, 9th International Conference on Quality, Reliability, Infocom Technology and Business Operations (ICQRTBO) 2018 during Dec. 27th-29th, 2018 at Conference Centre, University of Delhi, India.

Kumar, U. Transformative maintenance solutions for railway assets, International Seminar on Industrial Revolution 4.0, “An unprecedented range of technology on offer”, 28th May to 1st June at the Bilbao Exhibition Centre, Spain.

Jägare V., Junnti U. Intelligent Rail Summit. Reliable railways through collaboration and intelligent innovations. 28th-29th November 2018, Malmö, Sweden.


Rantatalo, M. “Diagnostic and prognostic for industrial applications”, Diamond Jubilee National Convention of IIE & International Conference on “Role of Industrial Engineering in Industry 4.0 Paradigm (ICIEIN 2018)”, IIE Odisha Chapter, in collaboration with Siksha ‘O’ Anusandhan (Deemed to be University), 27th to 30th September 2018, Bhubaneswar, India.


Galar, D. DMIN 2018. “Data Science in Industry Transport: The black Swan effect and the swan song desire”. The 14th International Conference on Data Mining, 30th July to 02nd August 2018, Las Vegas, Nevada, USA.


Galar, D. “Virtual assets and Virtual commissioning: Digitization in Industry 4.0.” IEEE International Workshop on. Metrology for Industry 4.0 & IoT. 16th-18th April, Brescia, Italy.


Galar, D. IPCEM 18 Congress Peruano Ingeniería de Mantenimiento. 26th-27th October, Lima, Perú.


Conference Papers


Book Chapters


Newly Published Academic Literatures

   This comprehensive textbook links theory with practice using real illustrative cases involving plants, infrastructure and other engineering products and components and exposes the students to the evolutionary trends in maintenance engineering and management. The book has been written by authors with extensive experiences in teaching and research apart from working with different industrial sectors.

   The handbook explores and presents the key aspects of effective and efficient maintenance management using performance measurement as foundation. The book is equally useful for students and engineers and will serve as a valuable resource for those in the field.

   Containing selected papers from the ICRESH-ARMS 2015 conference in Lulea, Sweden, collected by editors with years of experiences in Reliability and maintenance modeling, risk assessment, and asset management, this work maximizes reader insights into the current trends in Reliability, Availability, Maintainability and Safety (RAMS) and Risk Management. Featuring a comprehensive analysis of the significance of the role of RAMS and Risk Management in the decision making process during the various phases of design, operation, maintenance, asset management and productivity in Industrial domains, these proceedings discuss key issues and challenges in the operation, maintenance and risk management of complex engineering systems and will serve as a valuable resource for those in the field.

   Artificial Intelligence is a methodology and a programming approach, developed, and still under improvement, for effective maintenance management through its use in condition monitoring. Artificial intelligence is used in all kind of maintenance for industry machines. Because of the success in Condition monitoring, this book compiles and structures all AI tools used in CM in a reference handbook.

5. eMaintenance Essentials electronic tools for efficiency
   Authors: Galar, D. and Kumar, U.. Publisher: Academic Press
   The book eMaintenance: Essential Electronic Tools for Efficiency enables the reader to improve efficiency of operations, maintenance staff, infrastructure managers, and system integrators, by accessing a real-time computerized system from data to decision. The book provides an introduction to collecting and processing data from machinery, which explains the methods of overcoming the challenges of data collection and processing and presents tools for data-driven condition monitoring and decision-making. This is a handbook for those interested in the possibilities of running a plant as a smart asset. It shows how to use sensor-based tools to improve decision-making and enhance operational efficiency in the industrial plant environment.

6. Maintenance Cost and Life Cycle Cost Analysis
   Authors: Galar, D., Sandborn, P., Kumar, U.. Publisher: CRC Press,
   The book “Maintenance Cost and Life Cycle Cost Analysis” contributes towards a better understanding of maintenance cost and that this enhanced knowledge will be used to improve the maintenance process. It is motivated by the persistent pattern of failure of maintenance engineers to explain the basics of maintenance cost and associated risks and benefits to senior managers in their organizations. This motivation was reinforced by the recent success of several publications putting this type of research into the spotlight, especially the new ISO 55000. The book is intended for managers, engineers, researchers, and practitioners directly or indirectly involved in the area of maintenance.

7. Quality, IT and Business Operations Modeling and Optimization
   Editors: Kapur, P.K., Kumar, U., Verma, A.K.. Publisher: Springer
   The book “Quality, IT and Business Operations Modeling and Optimization” discusses action-oriented, concise and easy-to-communicate goals and challenges related to quality, reliability, info comm technology and business operations. It brings together research works in the area of software reliability, e-maintenance and big data analytics, highlighting the importance of maintaining the current growth in information technology (IT) adoption in businesses, while at the same time proposing process innovations to ensure sustainable development in the immediate future. In its thirty-five chapters, it covers various areas of e-maintenance solutions, software architectures, patching problems in software reliability, preventive maintenance, industrial big data and reliability applications in electric power systems.
Newly Published Academic Literatures

Amparo Morant, Trafikverket, presents the ERTMS project.

Peter Söderholm, Trafikverket, welcomes the participants to the ePilot result conference in Borlänge.

Håkan Jarl, Tågkompaniet, presents results from a Pilot sub-project

Bengt Jonsson, eMaintenance365, talk about maintenance analytics.

Director General Lena Erixon, Trafikverket, initiates the seminar.

2018 - News and highlights

JANUARY
Transport forum

VTI arranged Transport forum on the 10-11 of January in Linköping. The theme of the introduction was accessibility and transport in rural areas with an opening speech by Tomas Svensson, Director General of VTI and an opening speech by Tomas Eneroth, Minister of Infrastructure. Maria Öberg from Luleå University of Technology presented “Better management, governance and collaboration to take advantage of the European Transport Corridors (TEN-T CNC)”.

FEBRUARY

ePilot result conference in Luleå, Solna and Borlänge

The ePilot is a research and implementation project that develops railway maintenance. In March 2018, three result conferences took place in Luleå, Solna and Borlänge with a total of 140 participants, where results from ongoing sub-projects were presented.

Trafikverket’s trainee group visits JVTC

On February 6, Trafikverket’s trainee group visits JVTC to learn more about research and innovation at Luleå University of Technology.

Research activities in collaboration with CRRC

CRRC Corporation Limited (known as CRRC) is a Chinese publicly traded rolling stock manufacturer, which is the largest rolling stock manufacturer in the world. From September 2017, CRRC set up a CRRC-LTU PHM Research Center at LTU, which will highly promote the PHM research level of railway system in the world. The first project started in February 2018, titled “Prognostic and Health Management for Rail Transportation Equipment – Application studies on maintenance strategies of EMU axle bearing and collaborative maintenance management technologies”. The axle bearing is one of the critical components of high-speed train equipment. This project aims to extend the service life of EMU axle bearing, and achieve the optimization of the maintenance strategy from a lifecycle point of view through considering information from the train, test rigs, physics models, and operation context under the framework of Prescriptive Maintenance.

MAY
Trafikverket’s Research and Innovation day

Researchers from JVTC took part in Trafikverket’s Research and Innovation day in Stockholm on May 16. This year’s theme was Development for a modern, efficient and sustainable transport system. Director General Lena Erixon initiated the seminar and in her speech mentioned the ePilot as a good example of collaboration and how to test new solutions in real-life environments. During the day, the participants learned more about the Trafikverket’s new plan for research and innovation and which needs are prioritised.
2018 - News and highlights

MAY
JVTC hosts Royal Swedish Academy of Engineering Sciences (IVA)
The Division of Architectural and Civil Engineering of the Royal Swedish Academy of Engineering Sciences visited JVTC on May 17. JVTC research initiatives were presented followed by a tour of the CME labs.

IVA visits JVTC and eMaintenanceLAB.

MAY
The Ruwanda Transport delegation visits JVTC
A delegation from Ruwanda Transport visited JVTC on May 21 to discuss research and development topics for railway.

The delegation from Ruwanda Transport together with professor Uday Kumar, vice chancellor Birgitta Bergvall-Kåreborn samt professor Lennart Elfgren.

MAY
Energy-efficient rail vehicle competes at Delsbo Electric
For the fourth consecutive year, students from Luleå University of Technology participated in the Delsbo Electric competition. The aim of the competition is to drive a rail vehicle as energy-efficient as possible on a stretch of 3.36 km. The students stood for a strong achievement when they beat last year’s world record and finished second.

LTU:s Energy-efficient rail vehicle

MAY
The Ruwanda Transport delegation visits JVTC
A delegation from Ruwanda Transport visited JVTC on May 21 to discuss research and development topics for railway.

The delegation from Ruwanda Transport together with professor Uday Kumar, vice chancellor Birgitta Bergvall-Kåreborn samt professor Lennart Elfgren.

JUNE
20th Nordic Seminar on Railway Technology
Researchers from JVTC participated in the 20th Nordic Seminar on Railway Technology. The seminar took place on 12-13 June at Chalmers University of Technology in Gothenburg. The theme of the seminar was Research and innovations for a sustainable railway. The objective of the seminar was to gather colleagues especially from the Nordic countries who are active in the railway field. This includes staff from universities, institutes, authorities, manufacturers, operators, maintenance companies and consultancies. Topics presented and discussed comprise of infrastructure, vehicle and system issues, and all the phases of design, operation and maintenance.
JUNE

JVTC 20th Anniversary

Luleå Railway Research Center (JVTC) at Luleå University of Technology celebrated its 20th anniversary on September 6, 2018 at Quality Hotel in Luleå. During the day, 80 people from academia, companies and authorities participated. Awards were given to Jan Hertting, former regional manager at Banverket and chairman of JVTC, as well as Lennart Elfgren, professor emeritus in construction technology at Luleå University of Technology, for their contribution to the success of JVTC.

JVTC conducts applied research and development with a focus on streamlining operations and maintenance of the entire railway system. Thanks to the proximity to both the main line through upper Norrland and the Iron Ore Line enables unique research that is currently in worldwide demand. JVTC offers a platform for effective crosscutting collaboration between universities, companies and authorities.

- JVTC is good at understanding the needs of problem-based solutions that the railway industry has. The researchers also help to evaluate which problems is most important to solve in maintenance in order for us to get a solution that works in reality, says P-Ö Larsson-Kråik, the Swedish Transport Administration.

- I am a supporter of fast trains and believe that Sweden would benefit from such an infrastructure, however a major challenge right now is to secure the operation and maintenance of existing infrastructure. We can monitor and maintain by utilising technologies such as Artificial Intelligence, Big data and integrate sensors in our rail system, says Uday Kumar, professor in operation and maintenance technology at Luleå University of Technology and director at Luleå Railway Research Center.

JVTC has a number of successful research projects after 20 years in the industry and one example is the ePilot-project where the goal is to improve punctuality and minimize interference within rail traffic by designing decision support for maintenance operations by testing new solutions together with research results.

- One effect of this project has been that we built up a strong expertise in how to implement railway innovations, says Veronica Jägare, manager at JVTC.

JUNE

Award winner Jan Hertting

Award winner Lennart Elfgren

The opening speech at Intelligent Rail Summit 2018.

A project with Tsinghua University, China

Tsinghua University (Beijing, China) is at the top of the list of Best Global Universities for Engineering published by the US News. In 2018, researchers from JVTC were involved in one project of Tsinghua University (Department of Industrial Engineering) titled “Big data driven high availability studies on high speed railway” as an external consultant. This project was financed by the National Natural Science Foundation of China.
<table>
<thead>
<tr>
<th>Project</th>
<th>Project members</th>
<th>Sponsor</th>
<th>Status</th>
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</table>
| Maintenance decision support models for railway infrastructure using RAMS | Dr Alireza Ahmadi +46 920 3047  
PhD candidate: Iman Soleimanimeigouni +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: Raydeep 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 |
| Framework Railway asset maintenance management and info logistics       | Prof Uday Kumar, +46 920-491826  
PhD candidate: Elahe Talebianhoie | Trafikverket/JVTC               | Active |
| RAMS modeling and simulation at system level                           | Dr Alireza Ahmadi +46 920 3047  
PhD candidate: Hamid Khajehei | Trafikverket/JVTC               | Active |
| Rail grinding decision support                                         | 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 |
| Effects on increased axle load for heavy freight trains                 | Prof Jan Lundberg, +46 920-491748  
PhD candidate: Thomas Nordmark, +46 920-493476 | LKAB | Active |
<p>| 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 |
| Statistikst baserad underhållsplanering inom järnväg                  | Prof Bjarte Berghquist +46-920-49 2137 | Trafikverket/JVTC               | Active |
| ePilot 2.0                                                             | Veronica Jägare, +46 920-491629Prof Ramin Karim, +46 920-492344 | Trafikverket/JVTC               | Active |
| Testbed Railway                                                        | Veronica Jägare, +46 920-491629 | Trafikverket/JVTC               | Active |
| ReRail den miljövänliga rälsen - test                                  | 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 |
| Simtrack                                                               | Prof Alireza Ahmadi, +46 920-49 3047 | BVFF                           | 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 |
| Automatic detection of railway fasteners and track defects             | Dr Matti Rantatalo +46 920-492124 | Vinnova InfraSweden 2030 | Active |
| Condition monitoring, prediction and management of railway track assets | Dr Matti Rantatalo +46 920-492124 | Vinnova InfraSweden 2030 | Active |</p>
<table>
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<td>Prof Uday Kumar, +46 920-491826 Dr Matti Rantatalo +46 920-492124</td>
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<td>Fr8Rail</td>
<td>Prof Lennart Elfgren, +46 920-491360</td>
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<td>SMAFTE</td>
<td>Prof Alireza Ahmadi, +46 920-49 3047</td>
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<td>Improve availability and reduced life cycle cost of track switches</td>
<td>Prof Jan Lundberg, +46 920-491748</td>
<td>Trafikverket</td>
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<td>Prognostic for railway S&amp;C geometry degradation</td>
<td>Dr Matti Rantatalo +46 920-492124 PhD candidate: Madhav Mishra +46 920-49 2325</td>
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<td>TREND</td>
<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>
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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>OptiKrea - Optimala metoder för innovative produktutveckling och beslutsstöd</td>
<td>Prof Jan Lundberg, +46 920-491748 Anna Malou Petersson +46 920-491734 2017 –Doctoral thesis</td>
<td>Trafikverket/JVTC/Vosloh/Infranord</td>
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<td>Solstornars 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 (Damill AB) 2004 - Licentiate Thesis</td>
<td>Trafikverket</td>
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<td>Dr Rupesh Kumar, +46 920-492812</td>
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<td>Investigation of end-user needs for eMaintenance on railway</td>
<td>Dr Ramin Karim, +46 920-492344</td>
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<td>RAMS in signalling</td>
<td>Prof Uday Kumar, +46 920-491826</td>
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<td>Amparo Morant +46 920 2518</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</td>
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<td>Link and effect models of railway infrastructure</td>
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<td>Christer Stenström +46 920-491476</td>
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<td>Integrated reliability analysis for maintenance optimization</td>
<td>Dr Janet Lin, +46 920-491564</td>
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<td>Condition based maintenance for Vehicles</td>
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<td>Reliability analysis of switches and crossings</td>
<td>Dr P-O Larsson-Krak +46 10 231884</td>
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<td>Mikael Palo, +46 920-492009</td>
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<td>Optimization of track geometry inspection interval (Maintenance limits)</td>
<td>Prof Uday Kumar, +46 920-491826</td>
<td>Trafikverket/JVTC</td>
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<td></td>
<td>Dr P-O Larsson-Krak +46 10 231884</td>
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<tr>
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<td>Iman Arastehkhouy +46 920-2071</td>
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<tr>
<td>From measurement to maintenance decision</td>
<td>Dr Håkan Schunnesson, +46 920-491696</td>
<td>LTU, LKAB</td>
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<tr>
<td></td>
<td>Mikael Palo, +46 920-492009</td>
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<td>Iman Arastehkhouy, +46 920-492071</td>
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<td>Dynamic maintenance programme</td>
<td>Dr Ramin Karim, +46 920-492344</td>
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<tr>
<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</td>
<td>Prof Jan Lundberg, +46 920-491748</td>
<td>Trafikverket</td>
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<td>technical systems and equipment</td>
<td>Dr Ramin Karim, +46 920-492344</td>
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<tr>
<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>
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<td>Detection of internal flaws in railway manganese crossings by using</td>
<td>Dr Jan Lundberg, +46 920-491748</td>
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<tr>
<td>Synthetic Aperture Focus Technology (SAFT)</td>
<td>Dr Yuan Fuqing +46 920-49 1682</td>
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<tr>
<td>LCC and RAMS for railway vehicles</td>
<td>Prof Uday Kumar, +46 920-491826</td>
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<td></td>
<td>Ambika Patra</td>
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</table>
| Maintenance decision support models for railway infrastructure using RAMS & LCC Analyses | Prof Uday Kumar, +46 920-491826  
PhD candidate: Ambika Patra  
2009 - Doctoral Thesis | Trafikverket/ALSTOM Transport         | Completed |
| Risk based inspection intervals                                       | Prof Uday Kumar, +46 920-491826  
Dr Alireza Ahmadi, +46 920-493047 | Trafikverket/LTU                   | Completed |
| Support Vector Machine (data mining) and demonstrator                 | Prof Uday Kumar, +46 920-491826  
PhD candidate: Yuan Fuqing +46 920-49 1682  
2011 - Doctoral Thesis  | Trafikverket/JVTC                  | Completed |
| Wear in crossings                                                     | Prof Jan Lundberg, +46 920-491748                                              | Trafikverket                     | Completed |
| Technical specifications for crossings                                 | Prof Jan Lundberg, +46 920-491748                                              | Trafikverket                     | Completed |
| Ultrasonic measurements of internal cracks in manganese crossings      | Prof Jan Lundberg, +46 920-491748                                              | Trafikverket                     | Completed |
| Infrastructure winter ability analysis                                | Dr Ulla Juntti, +46 920-491991                                                 | UIC                              | Completed |
| Maintenance performance indicators (MPIs) for Swedish Rail Administration | Prof Uday Kumar, +46 920-491826  
Dr Aditya Parida, +46 920-491437  
PhD candidate: Thomas Ähren  
2008 – Doctoral Thesis | Trafikverket                      | Completed |
| Design for/out maintenance                                            | Prof Uday Kumar, +46 920-491826  
Dr Håkan Schunnesson, +46 920-491696  
PhD candidate: Stefan Niska  
2008 – Doctoral Thesis | Trafikverket                      | Completed |
| LCC analysis of railway switches and crossings (S&C.)                  | Prof Uday Kumar, +46 920-491826  
PhD candidate: Arne Nissen  
2009 – Doctoral Thesis | Trafikverket                      | Completed |
| Maintenance strategy for railway infrastructure                        | Prof Uday Kumar, +46 920-491826  
PhD candidate: Ulla Espling (Juntti)  
2007 – Doctoral Thesis | Trafikverket                      | Completed |
| Condition based maintenance strategy for railway systems               | Prof Uday Kumar, +46 920-491826  
PhD candidate: Robert Lagnebäck | Trafikverket, LKAB                | Completed |
| Reliability analysis and cost modelling of degrading systems           | Prof Uday Kumar, +46 920-491826  
PhD candidate: Saurabh Kumar  
2008 – Doctoral Thesis | Trafikverket/JVTC                  | Completed |
| Improved train punctuality through improvement in engineering systems  | Prof Uday Kumar, +46 920-491826  
PhD candidate: Rikard Granström  
2008 – Doctoral Thesis | Trafikverket, EU-structural funds       | Completed |
| Improved punctuality through effective maintenance management          | Prof Uday Kumar, +46 920-491826  
Per-Anders Akersten  
PhD candidate: Birre Nystrom,  
2008 – Doctoral Thesis | Trafikverket, EU-structural funds       | Completed |
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<th>Project</th>
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<td>In2Rail/In2Track</td>
<td>Cosmin Popescu/Jonny Nilimaa/Björn Täljsten/Thomas Blanksvärd/Lennart Elfgren</td>
<td>Shift2Rail/Horizon 2020</td>
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<td>In2Track2</td>
<td>Thomas Blanksvärd</td>
<td>EU/Trafikverket</td>
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<td>Increased axle loads on railway bridges</td>
<td>Dr Thomas Blanksvärd, +46 920-491642</td>
<td>LKAB/HLRC</td>
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<td>Design performance</td>
<td>Dr Björn Täljsten, +46 920-493360</td>
<td>Formas</td>
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<td>Sustainable Bridges</td>
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<td>Assessment of bridge condition</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 Långforsen bridge</td>
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<td>Assessment of Byulsälven bridge</td>
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<td>Sustainable renovation</td>
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<td>Formas/Trafikverket</td>
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<td>Kiruna mine bridge</td>
<td>Mats Emborg, +46 920-491348</td>
<td>LKAB</td>
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<td>Rock mechanics consequences of fire in tunnels</td>
<td>Prof Erling Nordlund, +46 920-491335</td>
<td>Trafikverket</td>
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<td>Structural sound</td>
<td>Prof Erling Nordlund, +46 920-491335</td>
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<td>Deformation and failure of hard rock</td>
<td>Prof Erling Nordlund, +46 920-491335</td>
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<tr>
<td>A pre-study on wheel/rail interface friction management</td>
<td>Dr Braham Prakash, +46 920-493055</td>
<td>Trafikverket/JVT/JVTC/LKAB</td>
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<tr>
<td>Surface roughness and rail grinding</td>
<td>Dr Jens Hardell, +46 920-491 000</td>
<td>Trafikverket</td>
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<td>Improved condition assessment through statistical analysis</td>
<td>Prof Bjarne Bergquist, +46 920-492137</td>
<td>Trafikverket/JVT/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/JVT</td>
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</table>
Results

JVTC has successfully been expanding during the last 20 years. The financial turnover for 2018 was 37 MSEK.

<table>
<thead>
<tr>
<th>JVTC Management and Administration 2018</th>
<th>SEK</th>
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<tr>
<td>Membership fees</td>
<td>925 000</td>
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<td>Funding from JVTC framework</td>
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<td>TOTAL INCOME</td>
<td>1 275 000</td>
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<td>Salaries personnel</td>
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<td>Other personnel costs</td>
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<td>Facilities</td>
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<td>IT/Computers</td>
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<td>Materials</td>
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<td>Travel</td>
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<td>Consultants</td>
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<td>Other operating costs</td>
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<td>OH</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>SUMMA</td>
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JVTC Contribution 2018

- Membership 2%
- LKAB, 3%
- In Kind, 10%
- Swedish transport Administration, 55%
- LTU, 5%
- EU, 23%
- Companies, 2%

Turnover JVTC Year 2013-2018

- 2010: 5 000 000
- 2011: 10 000 000
- 2012: 15 000 000
- 2013: 20 000 000
- 2014: 25 000 000
- 2015: 30 000 000
- 2016: 35 000 000
- 2017: 40 000 000

- 2018: 41
JVTC Members and Board of Directors

Back row from the left: Per-Olof Larsson-Kräik, Trafikverket; Johan Svanberg, Bane NOR, JVTC Board; Veronica Jägare, LTU; Sven Ödeen, Trafikverket, chairman of the JVTC board; Annika Jahnke, Vossloh; Jan Lundberg, LTU; Mikael Åstrand, Infranord, JVTC board.

Middle row from the left: Birgitta Olofsson, Tyréns, JVTC Board; Ulla Juntti, Omicold; Dan Larsson, Damill; Mats Jonsson, Bombardier.

Front row from the left: Anders Ahlquist, Vossloh, JVTC Board; Bengt Jonsson, eMaintenance365; Jonas Lindkvist, Trafikverket; Helena Sjaunja, Sweco; Uday Kumar, LTU, JVTC director; Anna-Karin Ylvainio, LKAB, JVTC Board; Susanne Rymell, SJ, JVTC Board.

Missing in the picture from the JVTC board: Thomas Blanksvärd, LTU; Elisabet Kassfeldt, LTU.

Contact:
Veronica Jägare
JVTC manager of operations
veronica.jagare@ltu.se
0920-491629
PARTNERS & SPONSORS

Alstom

LKAB

Duroc Rail

Sustainable engineering and design

Sweco

Norut

Bombardier

Outflight

Trafikverket

Bane Nor

Damill AB

Infranord

Vossloh Cogifer

Omicold

Tyréns

Kolarctic

BVFF

Horizon 2020

Interreg Nord

Vinnova

European Regional Development Fund

European Union